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Barriers and policy enablers for solar photovoltaics (PV) in cities: Perspectives of potential adopters in Hong Kong

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ABSTRACT

The rapid decline of solar PV costs and the urgency to develop effective post-Fukushima climate/energy plans in recent years have led to an upsurge of policy interest in deploying solar in international megacities including New York, Tokyo and Singapore. Nonetheless, overcoming barriers to large-scale uptake of urban solar PV remains under-explored. This study conducted 57 face-to-face interviews with potential solar PV adopters from the residential, institutional, and commercial sectors in Hong Kong, to understand perceived barriers and policy preferences. We found that firstly, most interviewees perceived high upfront costs and long payback period as primary barriers. Secondly, a reduced payback period is effective in improving their attitude towards installing solar. A majority of the residential interviewees shifted away from the "low level of interest" group to higher levels of interest if payback periods could be reduced from 35 years (business-as-usual scenario) to 8 years. Thirdly, potential PV adopters had different policy preferences. While residential interviewees indicated a strong preference for subsidies, institutional interviewees leaned towards regulatory measures, and commercial interviewees preferred feed-in-tariffs. Our findings suggest that the Hong Kong government needs to adopt the enabling framework developed in this study to effectively steer, nurture, and regulate PV deployment.

1. Introduction

Once a prohibitively expensive technology, solar electricity generation via photovoltaics (PV) has experienced major growth as costs of modules and systems declined rapidly over the past 20 years [1]. From 2008 to 2012, PV system prices dropped by around 60% in mature markets such as Italy. The levelised cost of energy from PV systems is below retail electricity prices in some countries [1]. Global solar PV capacity increased more than 50-fold from 3.7 GW in 2004 to 277 GW in 2016 [2,3]. However, while the International Energy Agency sees PV's share of global electricity capacity reaching 16% (4600 GW) by 2050, PV's current share of total global installed capacity is only 2.9% [1,3].

The deployment of solar also demonstrates considerable disparities across countries and regions, and the geographical pattern is changing rapidly. In Italy and Germany, countries which have committed to solar power, the share has reached 7% and 5% respectively. However, solar (PV and concentrated solar power (CSP)) only accounts for 2.4% of the European Union's electricity supply [4]. Global growth is focused in Asia, particularly China and Japan, whereas mature markets, most notably Europe, the US, and Australia, have shrunk in recent years as financial incentives have been reduced [4,5]. Since 2013, China has led the global PV market, followed by Japan, and the US [1].

It is in this global context that megacities and large urban centres have become increasingly proactive in exploring solar PV as part of their climate change and/or post-Fukushima energy plans [6,7]. New York's Sun Initiative [8], London's Bring Me Sunshine! [9], Seoul's Solar Power Generation Citizens' Fund, and Tokyo's Rooftop Solar Register initiative [10] are examples of such city initiatives. However, many cities, including Hong Kong, have yet to experience significant growth in PV electricity generation. Just how cities can overcome barriers to enable major penetration of solar PV in conventional energy systems has remained under-explored.

This study investigates how potential PV adopters in the residential, commercial, and institutional sectors in Hong Kong perceive barriers

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and possible policy changes to rooftop PV deployment, as well as the potential magnitude of their attitudinal change under three proposed payback period scenarios. We also aim at developing a framework of enabling factors which can be used as guidance for solar policy developments in Hong Kong.

Hong Kong merits study for several reasons. It is atypical and differs from other cities in important ways in terms of its socio-economic and political context as well as the particular characteristics of its energy portfolio and electricity market [11–14]. Hong Kong, nonetheless, shares with New York, London, Sydney, and other high-income, developed cities certain challenges in solar PV deployment. These include a cityscape featuring high-rise buildings with major space constraints for solar exposure (e.g. limited rooftop space) [9], and a society with a low acceptance of the tariff and regulatory changes that are often regarded as pre-requisites for a major uptake for PV [15]. However, Hong Kong also shares with some other large cities opportunities for PV adoption, such as rooftop PV in semi-rural built up areas. The experience of Brixton in suburban London where households participated and invested in community PV projects sheds light on the opportunities that PV may offer to Hong Kong's bottom-up initiatives on sustainable energy transitions [9]. Hong Kong's experience in solar PV deployment therefore has a relevance that extends beyond its own boundaries and may contribute to our understanding of how large cities respond to the opportunities offered by this energy option in their search for more sustainable energy futures.

This study focuses on the deployment of rooftop PV as an energy option for power generation in Hong Kong. While solar thermal has traditionally been the main solar application in rural and urban areas around the world, solar PV has become increasingly popular in urban settings. While utility-scale solar farms in rural or semi-rural areas constitute the majority of PV installations worldwide, decentralised, small-scale rooftop projects, alongside community-scale solar building-integrated PV (BIPV), have been growing in number and policy significance. The mechanisms through which to capitalise on underutilised rooftops to generate solar electricity in cities are, however, under-studied, except for the work by, for example, [8,16,17]. This study aims to contribute to our understanding of the barriers to and enabling policies for rooftop solar from the perspectives of potential solar PV adopters in Hong Kong in the residential, commercial, and institutional sectors.

The paper is organised into five sections. Following the introduction is a section that outlines the global trends of solar PV deployment, a theoretical discussion, and the Hong Kong context. That is followed by an outline of our methods. We then provide a detailed discussion of our findings. This paper concludes by discussing the policy implications of the findings.

2. The deployment of solar PV in cities: global trends, a theoretical discussion, and the Hong Kong context

2.1. Global trends and major developments in solar PV

High costs and space constraints have traditionally made solar PV a prohibitively expensive option for cities. Although solar PV has been a neglected energy option for cities for some time, the rapid decline in the cost of solar PV systems, especially over the past five years, has led to an upsurge of interest in deploying solar electricity in many megacities, including New York City, London, Tokyo, Seoul, and Singapore [7]. The rapid decline in PV costs worldwide has been largely driven by policy support as well as economies of scale achieved by China's PV industry which has led to a flooding of the global market of cheap panels [18,19].

Cities have made progress in deploying solar technologies using various approaches. New York City, one of the Solar America Cities recipients (in 2008) [20], aims to increase its domestic solar PV capacity by a factor of eight in the coming decade [9]. London has made significant progress in promoting community-based solar projects through effective solar policies and by developing new business models. A solar project at a social housing estate in Brixton, suburban London, is an example of such community initiatives. In Asia, Tokyo, Seoul and Singapore are the frontrunners. Tokyo's Solar Loans for Roof Power and the Tokyo Rooftop Solar Register are notable initiatives. Singapore published a national solar PV roadmap in 2014 [21] and is planning to raise the adoption of solar power from the current 19 MW to 350 MW by 2020. This would constitute about 5% of the projected peak electricity demand [22]. Empirical data also suggest that residential PV can play more than a niche role in the energy mix. A recent study has found that about 9% of new homes built by the top 10 builders in the top five metropolitan areas in California in the first quarter of 2016 had solar PV systems installed [23]. A review of major solar initiatives in selected cities is provided in Table 1.

2.2. Solar PV in cities: a theoretical discussion

Cities, which broadly include all urban areas, from megacities to smaller scale urban settlements [65], have increasingly become the focal point for solar PV deployment. It has been increasingly recognised that cities can contribute to climate action by implementing national policies as well as initiating city-led bottom-up activities [12,66]. Many cities have framed their solar plans as part of national schemes focused on climate change or economic structuring (e.g. Korea's National Strategy for Green growth) [7]. In some cases, these solar city concepts have been regarded as a key component of post-Fukushima energy policies [44].

Research on solar PV diffusion first started to emerge in the 1980s, and has grown rapidly over the past decade. Empirical studies have shed light on the rapid development trends of this technology, in terms of different types of PV applications (e.g. rooftop solar, building-integrated, utility-scale, community projects, floating PV systems) [67] and geographical distribution e.g. solar diffusion in high-income mature markets as well as emerging low-income economies in urban and rural settings [7,16], as well as in different sectors (e.g. in institutional, commercial, and residential) [20,68].

A stream of solar literature suggests that factors that affect PV deployment are multi-dimensional, which include technical suitability (such as availability of solar resources), economic viability, and social acceptance [21,61,62]. However, despite the potential of solar as an energy option, there are many cities, including Hong Kong, which have not been proactive in developing PV electricity generation. An extensive range of literature in the broader field of renewable energy has identified five main types of barriers that limit site suitability, economic viability, and social acceptance of large-scale deployment of the solar option (see for example [21,69]). These include technical barriers (such as space constraints, intermittency, and grid connection limitations) [1], economic considerations (e.g. long payback period, high costs) [1], market factors (e.g. misplaced incentives, unpriced costs, insufficient information, difficulty in accessing reliable information, access to finance) [1,70], as well as institutional, regulatory (e.g. the existence of vested interests against new energy options, difficulties in dealing with permission requirements) [6,71], and social barriers (e.g. lack of public acceptance of new energy technologies, low perceived usefulness of a new energy technology) [71].

While many of these barriers are relevant to most renewable sources, some of them are more context-specific, depending on the local climatic situation and the physical features of the prevalent building stock of a particular city [6]. In addition, some are more relevant to solar PV. High upfront costs, long payback periods, and space constraints have been consistently found to be key barriers to installing PV systems in urban settings [6]

The rapid decline of PV costs worldwide has given rise to a growing body of literature studying PV payback periods [1]. A comparison of PV payback periods in different countries, local states, and cities is provided in Table 2. While payback periods vary remarkably across countries, ranging from 3 to 72.5 years according to these selected studies, payback periods have already been reduced to below 10 years in a number of countries (e.g. US, Australia, Italy, and Japan) and cities (e.g. New York City and Seoul).

How, then, can barriers to PV deployment be overcome? While an

Table 1
A review of major solar initiatives in selected cities.
Sources: Authors; data of **New York City** from [7,8,26–34], **London** from [8,9,35–41], **Seoul** from [7,42–44], **Tokyo** from [10,45–53], **Singapore** from [21,22,24,25,54–60], and **Foshan** *(in Guangdong, China)* from [61–64].

	New York City (NYC)	London	Seoul	Tokyo	Singapore	Foshan, China
Major Solar/ Solar-related Energy Plans	– NYC One City: Built to Last Plan (2014) – NYC Solar Partnership – NYC Solarize – NY Solar Initiative	– RE: NEW – Bring me Sunshine! How London's homes could generate more solar energy (2015) – London Plan (2015) – Scenarios to 2050: London Energy Plan	– Seoul's Master Plan for Green Growth (2007) – One Less Nuclear Power Plant Policy (OLNPPP)	– Tokyo Renewable Energy Strategy (2006) – Tokyo Climate Change Strategy (2007) – Tokyo Environment Outlook (2015) – Tokyo Environmental Master Plan (2016)	– National Solar Repository (since 2010) – Solar Photovoltaic (PV) Roadmap for Singapore – SolarNova (2014)	– National solar FiT (since 2014) – Guangdong Solar Photovoltaic Power Generational Development Plan (2014–2020)
Estimates of (Rooftop) Solar PV Potential	– 57 million m^2 of available rooftop area are suitable for PV, and could install 5.8 GW PV systems, equivalent to 40% of NYC's peak demand	– 50% of London's roofs are suitable for solar PV, and could install 2.1–9.2 GW PV system, equivalent to 4.4–19.2% of London's electricity demand in 2008	– Solar PV's technical potential equivalent to 30% of the city's annual electricity consumption can be supplied by widespread deployment of rooftop-based distributed PV systems	– Solar PV on rooftops in Tokyo could help meet peak requirements and power equivalent to 26.5% of Tokyo's nuclear generation capacity	– Solar PV could contribute 6–30% of Singapore's electricity by 2050	– Full load hours of solar PV: 1,000 to 1,200 h per year
Urban Solar Applications	– 30 MW PV installed capacity (2014): 0.7 (2.3%) MW was on City-owned rooftops; others: municipal facilities (e.g. sewage facilities, hospitals), residential and commercial buildings	– 57 MW PV installed capacity (2015): across roughly 15,000 homes and 210 schools – Major city landmarks and infrastructure rooftops (e.g. solar bridge at Blackfriars rail station, St Mary's Church, carpark roof at Olympic Park) produce 0.36 MW – Residential sector: mainly installed in low-rise buildings in inner city London; also several community solar energy schemes and housing associations (e.g. Brixton)	– 50 MW PV installed capacity (2014): including 23 MW at 38 locations installed in municipal facilities and also in public buildings (e.g. sewage plants, schools), private buildings (e.g. apartments), and infrastructure (e.g. bus shelters)	– 260 MW PV installed capacity (FY2012) – Residential, commercial and industrial sectors, and other applications include solar carports	– 71.3 MW PV installed capacity (Q1 2016): 71.3–66.9 MW non-residential and 4.4 MW residential – Other applications include 1 MW solar PV system at Choa Chu Kang Water Works [24,25] – Other applications include solar vans, Marina Barrage Solar Park and floating PV systems such as the pilot project on Tengeh reservoir	– Distributed Solar PV (end 2016): 270 MW; 0.3% of Foshan's total electricity consumption; a total of 826 projects: 763 residential projects and 62 non-residential projects
Major Solar Policies/ Initiatives	– Subsidies e.g. NY Sun Initiative – Net Metering – Renewable Portfolio Standards – Technical Support e.g. NYC Solar Map and NYC Solarize – Renewable energy certificates – Rooftop leasing (e.g. SolarCity)	– Renewable feed-in tariff (REFiT) (national) – Regulatory Measures e.g. London Plan – Technical Support e.g. RE: NEW and London Energy Plan – Renewable energy certificates – Green bonds e.g. GBP London Green Fund	– Subsidies - One Less Nuclear Power Plant Policy (OLNPPP) – REFiT (municipal) – Regulatory Measures e.g. solar PV penetration in OLNPPP, Renewable Portfolio Standards – Technical Support e.g. Seoul Solar Map – Renewable energy certificates – Green bonds e.g. Solar Power Generation Citizens' Fund	– Solar Subsidies; Solar Loans - "Roof Power" – REFiT (national) – renewable and solar energy targets – Technical Support e.g. Tokyo Rooftop Solar Register – Renewable energy certificates – Rooftop leasing	– Subsidies/REFiT e.g. Central Intermediary Scheme (since April 2015) – Regulatory Measures e.g. Enhancements to the Regulatory Framework for Intermittent Generation Sources in the National Electricity Market in Singapore: Final Determination Paper and Clarification Paper – Technical Support e.g. National Solar Repository – Rooftop leasing e.g. SolarNova	– Solar PV target of 1.5 GW total installed capacity by 2020 – A Foshan REFiT of RMB0.12/ kWh for 3 years (introduced in 2014)

Table 2
Comparison of payback periods of solar PV in different countries and states/cities, including Hong Kong.

Location	Projected payback period (year)	Remarks	Reference
Countries			
Australia	3–6	– With FiT	Burtt and Dargusch [80]
France	14–25+	– With FiT	Campoccia et al. [81]
Germany	13–25+	– With FiT	
Greece	13–15	– With FiT	
Italy	9–20	– Net-metering or FiT	
Japan	40.8 (with net-metering)	– Assumptions of 4 kW (7.7 years) solar PV system on a residential building and of 100 kW (8.05 years) solar PV system on non-residential building	Muhammad-Sukki et al. [82]
	7.7 (with FiT)	– Under the new FiT since 2012	
United Kingdom	67	– Assuming 75% of electricity generated is used onsite; if a gross FiT of 37.8p/kWh is assumed, payback period drops to 16 years	O'Flaherty et al. [83]
	16–25+	With FiT	Campoccia et al. [81]
	13.2	Using the revised FiT scheme	Muhammad-Sukki et al. [84]
States/Cities			
California, US	6–9*	– Applied for the state, and is the average payback period for a residential solar PV system depending on the cost of the system and utility bill savings	CEC [23]
New York, US	8*	– State average based on 45,000 estimates by real U.S. homeowners in 2011	CPR [85]
New York City, US	19.45 (projected estimate under Finance scenario)	– Assumes that solar PV installed on 30% of the city's commercial and public buildings (ie. solar city vision)	Byrne et al. [8]
	9.67 (projected estimate under Policy scenario, consistent with Finance scenario)	– Assumes that all electricity generated is available for self-consumption – Calculated 2 payback periods based on certain policy conditions and current policy with the issuance of bonds	
Hawaii, US	5*	– State average based on 45,000 estimates by real U.S. homeowners in 2011	CPR [85]
Wisconsin, US	17*		
Seoul, South Korea	8*	– Assumed Seoul-Type FiT of 100KRW/kWh (rate as of 2015) – Payback period for non-residential building rooftops such as water treatment plants, subway train depots	Ming Pao [86]
Tianjin, China	11.7	– Assuming 75% of electricity generated is used onsite, assuming a net FiT of CNY 0.0678/kWh	Zhao et al. [68]
Chengdu, China	13.5		
Hefei, China	5.9		
Hong Kong, China	72.5	– Electricity price assumed to be constant; if a carbon price of HK$0.23/kg is imposed, payback period drops to 61.4 years	Li et al. [87]
	15	– Total initial costs for case study solar PV project is HK$40,000 – Assuming electricity tariff to be HK$1.0/kWh (HEC), and excluding maintenance and repair costs	Zhang et al. [88]

Note: All are estimated payback periods, except those marked with *.

extensive body of literature on awareness-action gaps highlights the importance of education and information in rousing motivation for pro-environmental behaviour, another body of literature on energy policy sheds light on the roles of governments in city-led energy initiatives [12,72]. Studies that review and assess a variety of solar policies and programmes suggest that government interventions may address many of those barriers [73,74]. These policy levers can be classified into five major categories: (1) provision of subsidies, (2) regulatory measures e.g. a renewable portfolio standard that mandates a certain share of a utility's power plant capacity or generation to come from renewable energy sources, (3) renewable feed-in tariffs [73], (4) net metering, and (5) provision of technical support [1,73]. Many of them are often used in combination with other policies, and their acceptance and effectiveness vary in different contexts [1].

It is also important to note that, while policy support continues to be critical to PV deployment, there has been a rapid emergence of market-oriented business models that contribute to making PV one of the least-cost options for power generation from renewable energy sources [75]. In addition, the literature also sheds light on the changing roles of government in an increasingly market-based society. Studies by Lee et al. [76] and Hammer [77] emphasise the role of local leadership (particularly from city mayors) on climate and energy initiatives. Work by Keiner and Kim [78,79] examines how local governments have moved away from traditional implementation of national policies and have assumed a proactive role in establishing new market rules and conditions that are conducive to sustainable energy transitions, as well as in developing networks and partnerships with market and civil society.

2.3. The Hong Kong context

Hong Kong, a world city of 7.3 million people, has been reliant on a combination of fossil fuels and nuclear power for its electricity supply. Coal, imported nuclear (from neighbouring Guangdong Province), and natural gas amounted to 53%, 23%, and 22% of the city's electricity fuel mix, with a total generation capacity of 12,645 MW (2012) [89]. Hong Kong has, however, become increasingly proactive in developing major climate and energy plans including a Climate Change Strategy and Action Agenda and an energy saving plan [90,91]. The government very recently set a renewable energy target of 3–4% by 2030 in its Hong Kong Climate Action Plan 2030+, which was published in early 2017 [92]. A renewable energy feed-in tariff is also going to be introduced starting October 2018.

It is in this climate and energy context that Hong Kong has made some initial attempts to deploy solar PV. There were about 165 solar PV projects in Hong Kong in 2014 [93,94]. A 1 MW solar PV system on Lamma Island, a rooftop solar facility at the headquarters of the government's Electrical and Mechanical Services Department in Kowloon Bay, and the building-integrated PV systems in Wanchai Tower are some of the major solar projects underway.

However, despite the recent growth in PV deployment globally and in mainland China, Hong Kong has not experienced major growth in PV electricity generation. Solar PV generated only approximately 10.55 million kWh, with an installed capacity of less than 5 MW, contributing 0.1% of total electricity consumption in Hong Kong [92,95]. Most of the local PV systems are deployed in institutional settings (such as government buildings and schools), with some in commercial buildings (e.g. BIPV at Peking Road No. 1). Installed PV in residential buildings

Table 3
Recent studies estimating Hong Kong's solar PV output potential to the total electricity consumption by its respective year.

Authors	Estimated solar PV potential output (%) of total electricity Consumption (Year)	Methodology/remarks
You and Yang [103]	35% (1995)	– Includes BIPV (residential, commercial, institutional) such as rooftops and outer walls oriented south, east, and west, but excludes shadow facades of high-rise buildings
EMSD [104]	17% (1999)	– Includes BIPV (residential, commercial, institutional) and non-BIPV such as open space, roads and railways, airport and non-built areas such as grasslands and country parks; however, this estimate did not factor in cloud cover or shading
Peng and Lu [105]	14.2% (2011)	– Includes rooftop PV – Takes into account of partial shading
Lu [106]	10.7% (2014)	– Includes rooftop PV – Do not take into account of shading
Wong [107]	5.9% (2012)	– This potential is specific to rooftop solar PV; this study also addresses solar PV deployment on all open space areas and Government, Institution and Community facilities, which could contribute to 6.4% and 1.1% respectively of Hong Kong's total electricity consumption in 2012. – Done with remote sensing, included cloud cover

has been minimal, except in some public building blocks built by the Housing Authority. Of the 165 PV projects in Hong Kong, 112 were undertaken by the government with the remaining 53 installed by non-government bodies such as schools, universities, and NGOs [93,94].

Although solar resources contribute a very small portion of the fuel mix in Hong Kong, local studies have estimated Hong Kong's solar PV output potential to range from 5.9% to 35%, depending on methodologies and assumptions (Table 3). It is also important to note that several contextual features of Hong Kong have created opportunities for a domestic market for PV. First, due to its atypical conservation and Small House policies, its cityscape accommodates a considerable number of house-type dwellings extending throughout the rural and semi-rural built-up areas in the New Territories, which make up approximately 86% of Hong Kong's territory [96,97]. Conservation policies have designated approximately 40% of Hong Kong's total area of 1,108 square kilometres as country and marine parks and special areas, and have therefore worked to contain urban sprawl in the city. The Small House Policy, introduced in the 1970s to address the housing needs of indigenous villagers in the New Territories, grants male indigenous villagers rights to build a small house with a maximum height of three storeys and roofed area of 700 square feet [97–99]. This policy has incentivised the spread of a large number of 3-storey house dwellings, and many of these houses are owned by middle to high-income earners. A local study has found that over 25% of the households under the Small House Policy earn more than HK$50,000 or above per month [97]. These two policies have therefore created a favourable market environment for PV where there are a substantial number of potential rooftop PV adopters who are owner-occupiers and who can afford to install solar PV systems.

Another contextual feature that creates opportunities for Hong Kong to deploy rooftop solar PV is that the peak or near-peak energy usage in Hong Kong typically occurs in the afternoon (Fig. 1) and this coincides with the periods when solar electricity generation can be maximised [100–102]. The potential to cut electricity bills, and thus bring economic benefits to consumers, could be a motivating factor for Hong Kong to explore this energy option.

Despite this potential, solar PV electricity generation has, as noted, remained very limited in Hong Kong. A number of local studies have identified multiple barriers that impede PV deployment. These include long payback periods, high initial costs, space constraints, inadequate service infrastructure, difficulties in ensuring grid access by third-party renewable producers, lack of community and stakeholder participation, and lack of incentives provided by legislation and regulations [68,100,108]. Two privately-owned, vertically-integrated utilities, China Light and Power (CLP) and Hongkong Electric (HKE), operate as geographical monopolies which are governed by a regulatory framework known as the Scheme of Control Agreements (SCAs). As the energy literature in Hong Kong argues, the SCAs, which link the rates of return of the two power companies to their fixed asset investment, have not created sufficient incentives to decentralise power generation [11–13,109].

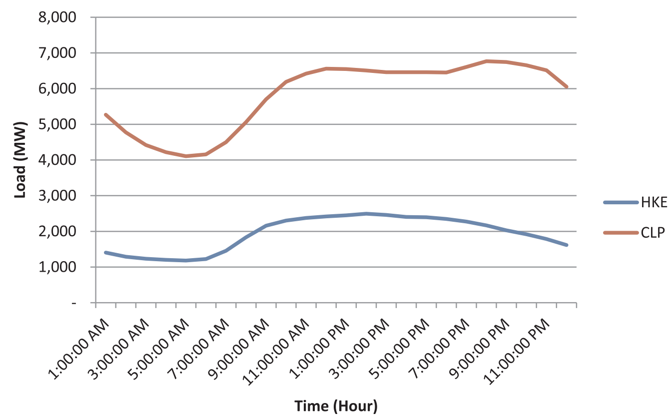

Fig. 1. Peak day load curve in Hong Kong (2012).
(Source: authors; Data from (HK Government, 2013))

The literature has been useful in shedding light on the factors affecting PV deployment in cities. There are, however, important knowledge gaps. While local studies on various types of solar applications have been relatively extensive (from grid-connected systems [102] and stand-alone systems [101], to rooftop solar [110], BIPV applications [102], and to hybrid systems [111]), studies that examine policies that may motivate and incentivise potential solar adopters to install solar systems have remained sparse. Since a long payback period is one of the primary barriers identified, it is particularly important to gain a better understanding of the occurrence and magnitude of attitudinal changes if PV payback periods can be reduced through policy levers.

3. Methodology

Our findings are mainly drawn from desktop studies and 57 semi-structured interviews. Those interviews include 40 with residential respondents and 12 and 5 with institutional and commercial respondents, respectively. Clearly, this is a small sample size and our findings cannot claim to have statistical significance or to represent all potential PV adopters in Hong Kong. Nonetheless, the richness of the data from our in-depth interviews provides us with a variety of important insights and does, we suggest, enhance the credibility of our observations and the arguments derived from our analysis.

This study adopts the snowballing method to identify prospective interviewees in the three sectors. Of the 40 residential interviewees, 33 are village house residents, 6 interviewees live in apartment buildings, and 1 resides in a tenement building. These residential interviewees represent the diverse geographical distribution and socio-economic background of potential solar householders in Hong Kong (Appendix A and B). These samples also represent owner-occupiers and tenants who

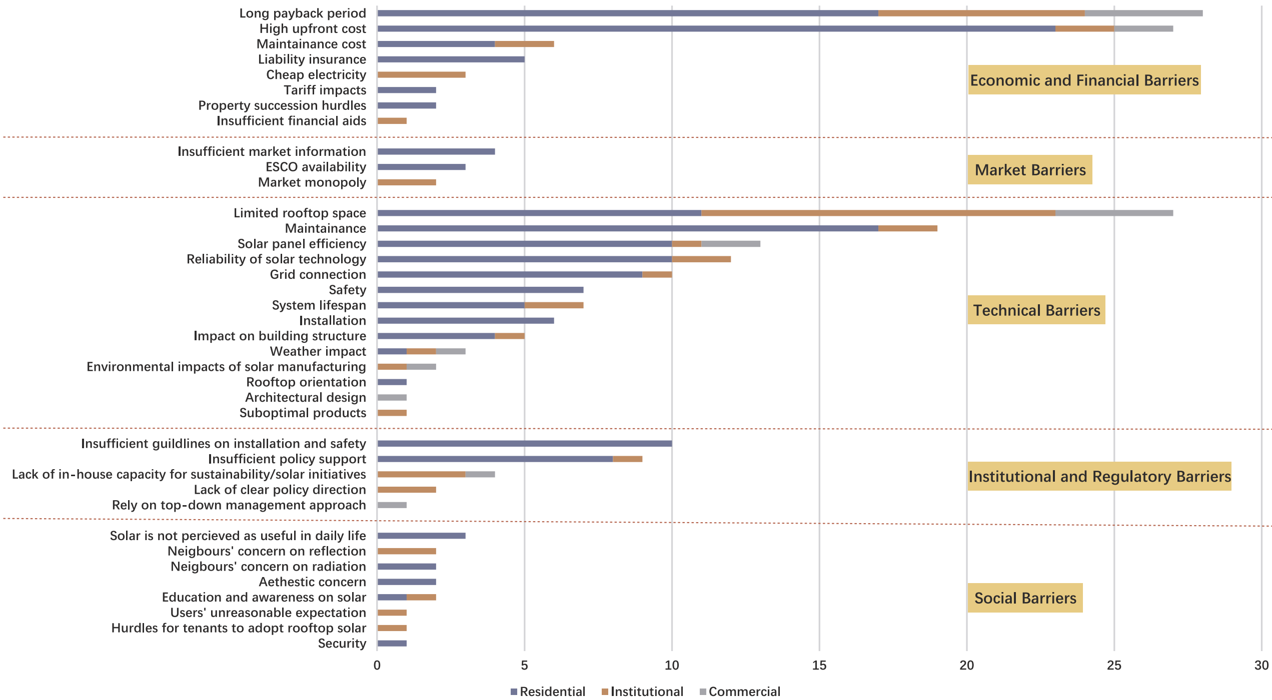

Fig. 2. Perceived barriers of residential interviewees to PV deployment (by barrier types and by interviewee's sectors).

have access to rooftops in various types of houses in Hong Kong. The sampled house dwellings include typical 3-storey dwellings with a roofed area of 700 square feet, old dwellings, modern houses, a tenement building, and apartment buildings; some are in rural villages while some are in urban villages (or what are referred to as "metropolitan village" in Connell's model of suburbanization process [96]) and some occupy purpose-built high status suburbs. While the literature suggests that householders living in low-rise owner-occupied houses with more roof space may have higher levels of interest to invest in renewable energy [9], PV adoption is also emerging in multi-tenanted buildings in some cities such as San Francisco [112]. The samples from the tenement and apartment buildings are, therefore, also useful for our analysis. Appendix C shows rooftop images of some of our sampled residential dwellings.

It is important to note that, among these residential interviewees, 8 were identified as solar "first-movers" as they were subscribers to a free solar energy assessment service provided by a local power company. Since they made self-motivated decisions, and took action to subscribe to the service, the identification of this group of potential PV adopters is instructive to contribute to the emerging body of literature that divides adopters into categories: innovators, early adopters, early majority, and laggards [113].

We also conducted 12 interviews with senior/mid-level managers from the institutional sector, including a government agency, a statutory body in the aviation sector, a not-for-profit private institute which operates an amusement park, 5 universities, and a secondary school. In addition, we interviewed 5 representatives from the commercial sector: from a manufacturing company, the IT sector, an airline company, and the property sector. Details on the background of all interviewees in these two sectors are presented in Appendix D.

All interviews were conducted between October 2015 and June 2016. All but 5 were face-to-face interviews, the 9 others being phone interviews. Based on our literature review, we developed an interview guide. This consisted of three main themes: their interests in installing PV systems in three payback scenarios, their perceived barriers, and their perceived effectiveness of five possible solar policies, i.e. subsidies, regulatory measures, feed-in tariff, net metering, and technical support. Each interview lasted between 30 and 90 minutes. We conducted site observations in all but 10 of the sampled residential premises as site observations were not possible in these other 10 cases.

Most interviews were audio-recorded (except 11 for which meeting notes were taken instead as audio-recording was not possible). Responses of all interviews were coded according to the main themes and sub-themes of the interview guide, and subsequently input into an Excel file in order to facilitate a systematic analysis of emerging themes, and to allow us to identify similarities and differences of views across the three adopter groups. Selected sections of some interviews were fully transcribed when needed. 3 supplementary telephone interviews with a solar installation contractor and a senior executive of a utility were conducted in September 2017 to gain energy practitioners' views and experiences.

4. Major findings and discussions: perceptions and attitudes of potential solar adopters in Hong Kong

4.1. Perceived barriers

All interviewees from the three selected sectors were asked to identify key barriers to rooftop solar PV adoption from their own individual perspectives. Fig. 2 presents an overview of perceived barriers. It is important to note that potential solar adopters across the three sectors presented many convergent and divergent perspectives on barriers to rooftop solar. Three main observations are important:

(a) **Economic factors (upfront costs and payback period) were perceived to be the key barriers**

High upfront costs and long payback period were perceived by the interviewees as major barriers to solar PV deployment. Over half of the residential interviewees (23 out of 40, 57.5%) considered high upfront costs as a major barrier, and 2 out of 5 commercial interviewees reported this as their main perceived barrier. In terms of the payback period, of our 40 residential interviewees, 17 (42.5%) stated that a long payback period was their primary concern. 4 out of 5 commercial interviewees stated that long payback was their main concern.

It is important to note that these two economic barriers are closely related, but have subtle differences. High upfront costs relate to capital

(a) Rooftop space occupied by steel-frame laundry rack

(b) Rooftop space occupied by steel-frame sunshade

(c) Rooftop space occupied by household stuff

Fig. 3. Selected examples of occupied rooftop space.

investment costs which can be a problem for various reasons, and could be effectively overcome by subsidies that aim at reducing upfront investment [75]. Payback period is the duration that an investment takes to break even or recover its cost [114]. Cost reductions, alongside other measures such as loans with low interest rates could shorten payback periods and help to overcome this economic barrier. It is in this context that three observations should be noted:

First, the commercial sector is highly sensitive to the payback period while showing less concern for upfront costs. Our interview with a senior manager (Interviewee #14 in Appendix D) of a data centre revealed that the payback period is of utmost importance for the commercial sector in Hong Kong. Interviewee #14 reported that his company, which is located in an 18-storey industrial building in the southwest of the New Territories, is a large electricity consumer with a monthly electricity bill amounting to HK$400,000 (approximately US $51,280). Since his company has the right to use a spacious balcony adjoining their rented office, the company was interested in exploring the possibilities of installing solar PV on this balcony, and conducted a solar feasibility study several years ago. Their study found that a set of 20 m × 5 m solar panels (about 100 m^2) can be installed on the balcony. But this project was estimated to require an initial investment of HK$400,000 which would be recovered in 10 years. Since three years is generally regarded as a reasonable payback duration for the company's investments, the company did not pursue this solar idea, and it was not even submitted to senior management for consideration.

Second, the responses from the residential interviewees need to be interpreted with caution. Although about 40% of them did not state costs as their perceived barriers, a substantial number of these interviewees noted that since they did not even have space for PV installations, they simply see costs as a non-issue and thus did not perceive this as a barrier.

Third, the institutional sector was less sensitive to these two economic barriers. Only a few institutional interviewees (2 out of 12, 16.7%) reported high upfront costs as their perceived barrier. While over half of interviewees from this sector (7 out of 12, 58.3%) indicated that payback period is still a concern, it is not a major one. These participants were mainly from the fully-funded public tertiary institutions where the costs of installing solar panels could be financed through government grants.

(b) **In addition to costs and payback period, the adoption of PV is affected by a variety of non-economic barriers that include technical, market, regulatory, and social concerns**

As shown in Fig. 2, technical barriers (in particular, limited rooftop space, maintenance), market barriers (such as the lack of availability of energy services company (ESCO) services, insufficient market information, and the existence of market monopoly), institutional and regulatory barriers (including insufficient guidelines on installation, and insufficient policy support), and social barriers (e.g. solar is not perceived as useful in daily life, neighbours' concerns about reflection caused by PV panels) are perceived by our interviewees across the three sectors as important factors affecting their level of interest in installing rooftop PV systems.

In this regard, it is important to highlight one interesting finding that relates to the barrier of space constraints. Given the compacted urban setting and vertical building structures in Hong Kong, it is, perhaps, not surprising that limited rooftop space was identified as a major barrier by our interviewees. But our study can shed light on the nature of this problem. As reported in the methodology section, we site visited most sampled residential premises. We found that it was a common phenomenon that a substantial rooftop area of these rooftops was occupied, and was therefore not available for PV installation. These rooftops were occupied by a variety of uses – some were used to store household items while some were occupied by rooftop mounted building maintenance units (BMUs), water tanks, and even illegal structures such as steel-frame sunshades (Fig. 3). The space constraint is also perceived as an important barrier by institutional and commercial interviewees but for different reasons. Interviewees from a governmental agency pointed out that existing regulations require high-rise public housing blocks to reserve not less than 50% of the rooftop area as a refuge for occupants in case of fire. Interviewees also noted that owners of commercial buildings may give priority to other rooftop uses such as installing BMUs and roof gardens.

(c) **Perceptions of barriers differ across adopters' sectors**

Our findings suggest that some barriers seem to be more sector-specific. An example of the sectoral differences of responses is that the institutional sector seems to be more sensitive to the issues of cheap electricity and market monopoly. It is the only sector that has stated their concerns over these economic and market barriers. Some of our interviewees from the institutional sector were of the view that the local power companies would not be supportive of distributed energy generation. They noted that there would be major challenges in dealing with the power companies in relation to grid connection issues. In contrast, none of the residential or commercial interviewees cited these as perceived barriers. While several residential interviewees did note the existence of a monopolised market in Hong Kong's electricity sector, they did not consider it as a barrier to solar adoption.

4.2. Shortening of the payback period is effective in changing attitudes among potential residential PV adopters

Our second finding provides a better understanding of the

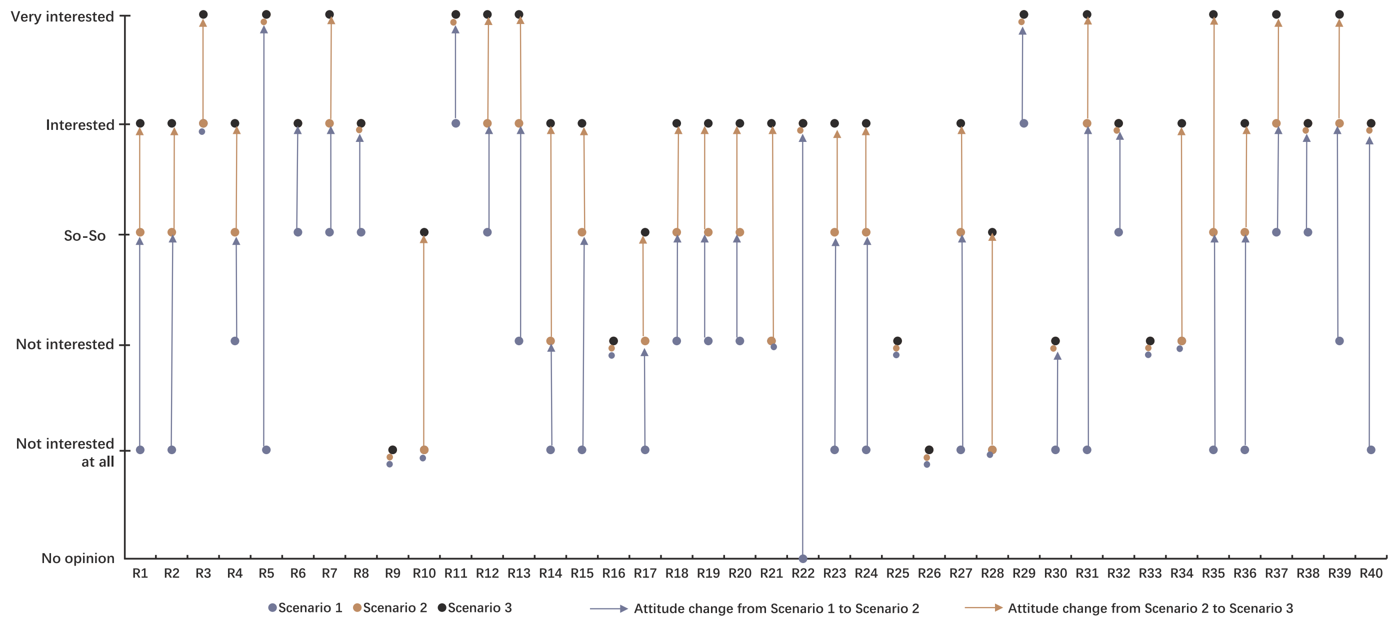

Fig. 4. Changes of attitude in response to different payback period scenarios: individual residential interviewees' responses.

magnitude of potential attitudinal changes if the payback period is reduced. We asked our 40 residential interviewees to indicate their levels of interest in adopting rooftop solar PV under different scenarios (Appendix E). Scenario 1 is the business-as-usual scenario – in which the upfront cost of installation is HK$55,000 and the payback period is 35 years. Scenario 1 is developed based on the market information provided by informants from the power/solar industries in Hong Kong.[1] Scenario 2 is a moderate-cost option in which the upfront cost is reduced to HK$24,000 and the payback period is shortened to 15 years. Scenario 3 is a more radical reduced-cost option in which the upfront cost is further reduced to HK$13,000 and the payback period is shortened to 8 years. This study did not invite commercial and institutional interviewees to evaluate these scenarios in view of the fact that the physical settings such as the roof space availability, BMU requirements, as well as decision-making on payback period may be highly diverse among these two sectors and this may make it difficult to generate useful cross-sectoral comparisons. More details about the three scenarios can be found in Appendix E.

Our findings are summarised and presented in Fig. 4. Five important points should be noted:

- Most residential interviewees (72.5%, 29 out of 40) express a low level of interest in installing rooftop PV under the business-as-usual scenario (with a payback period of 35 years).
- The shortening of the payback period is effective in raising residents' interest in adopting rooftop solar PVs. As scenario changes from a payback period of 35 years (business-as-usual) to 15 years (moderate-cost scenario) and further to 8 years (radical reduced-cost scenario), 87.5% (35 out of 40) of the residential interviewees shifted away from the "low level of interest" group to having higher levels of interest.
- If the payback period is reduced to 8 years (an indicative payback period that has already been achieved in Seoul, some states in the US, and a number of other places worldwide as shown in Table 2), 31 out of 40 interviewees (77.5%) would be interested or very interested in installing PV.
- Potential PV adopters in the residential sector in Hong Kong can be stratified and differentiated into three groups, *highly-responsive*, *laggard*, and *indifferent* groups. *Highly-responsive* householders are those 30 interviewees (75%) who stated that they would shift from the "low level of interest" group to the "high level of interest" group even though there was only a moderate change in the payback period (i.e. reduced from 35 to 15 years); out of these 30 highly-responsive householders, 20 interviewees reported a further increase in interest when the payback period is reduced to 8 years, while the remaining 10 did not state a further attitudinal change. *Laggard* householders are those 5 (12.5%) interviewees who remained unmoved when the payback period changed from that of Scenarios 1–2; but they reported an increase in interest levels when the payback period was further reduced to 8 years under Scenario 3. This indicates that they needed a more substantial shortening of the payback period for their attitude change. *Non-responsive* householders are those 5 (12.5%) interviewees who were *consistently* not interested in solar projects. They were indifferent to scenario changes. They are either senior citizens or young professionals who have a high education level and a high income. Those "*indifferent*" senior citizens stated that they were concerned about the long payback period as they are in their later years. Those "*indifferent*" young professionals stated that they lacked confidence in solar technologies and were disappointed with the lack of effective solar policies.
- This study attempted to quantify the impacts of the shortening of the payback period on attitudinal changes in our three scenarios. The methodology developed to do this is outlined in detail in Appendix F. The overall magnitude of attitudinal changes (when the payback period is shortened from 35 years to 8 years) is 1.93 units (Fig. 5*a*). It is important to note that the most noticeable attitudinal changes were recorded when the payback period is shorted from 35 years to 15 years (from Scenario 1 to Scenario 2), with an average unit of attitudinal change recorded at 1.15 units (Fig. 5*b*). Attitudinal changes become moderate when the payback period is further reduced (from Scenario 2 to Scenario 3), with an average unit of attitudinal change recorded at 0.78 units (Fig. 5*c*). This observation has policy relevance because it may indicate that the Hong Kong government needs to pay attention to the possible diminishing increase in adopter's interest as it strengthens its solar policies.

[1] On the rooftop of a typical 700 square feet village house, it is estimated that 6 solar PV panels with a total installed capacity of 1.56 kW could be installed. The average size of a solar panel is 1.65 m^2. In line with current market prices, the total electrical equipment cost is estimated as HK$55,000. The actual total electricity output would be 1,560 kWh (about 4.27 kWh per day), and the actual annual electricity saving could be HK$1,560 (assuming the tariff is HK$1 per kWh). Thus, the payback period would be about 35 years.

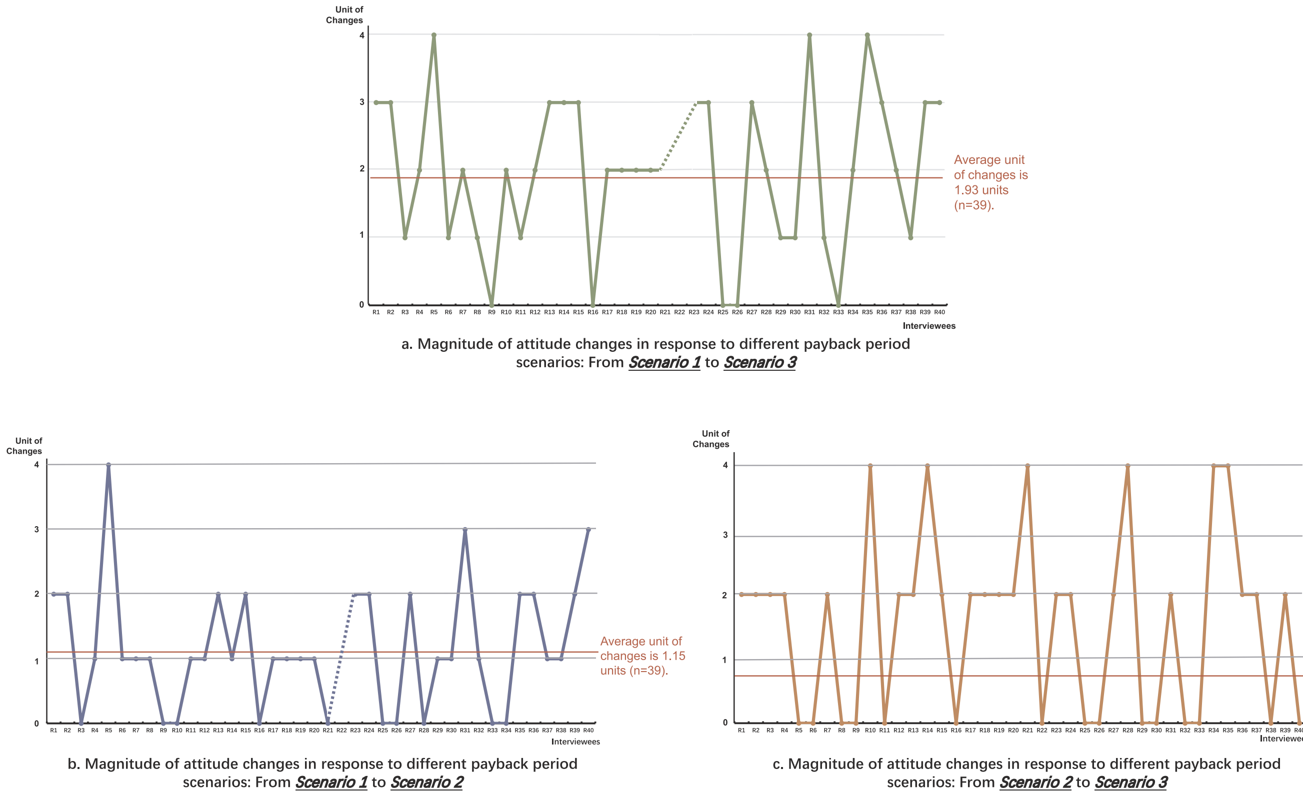

Fig. 5. a Magnitude of attitude changes in response to different payback period scenarios: From *Scenario 1 to Scenario 3*. b Magnitude of attitude changes in response to different payback period scenarios: From *Scenario 1 to Scenario 2*. Fig. 5cMagnitude of attitude changes in response to different payback period scenarios: From Scenario 2 to Scenario 3. Note: Data of Respondent No. 22 (R22) is not applicable to the analysis of Figs. 5*a and* 5b: she stated "no opinion" as her initiate point of attitude level in Scenario 1 and that cannot be assigned with a value. R22's data is therefore excluded in these two analyses (i.e. n = 39).

4.3. Perception of prospective policy enablers

Interviewees in the three sectors were asked to prioritise the five major possible policies for solar PV in terms of their perceived effectiveness. The policies are renewable feed-in tariff (REFiT), net metering, governmental subsidies, regulatory measures, and technical support. Most of interviewees perceived regulatory measures and governmental subsidies as the two most effective policy levers, while other policy schemes, such as REFiT and net metering, were also seen as effective.

An interesting finding of our study is that various groups of stakeholders perceived the most effective policy options differently as shown in Fig. 6. For residential interviewees, the highest ranked policy is subsidies. Over half of residential interviewees commented that substantial subsidies from government could directly address their concerns about the high upfront costs, which could subsequently shorten the payback period, and thus enhance the economic viability of PV systems. Some of them held the view that any investment has to be cost-effective as this is a social norm recognised in Hong Kong and other capitalist economies.

For institutional interviewees, the highest ranked policy is regulatory measures (such as a renewable portfolio standard), while one quarter of them regarded REFiT as also being an effective option to promote rooftop solar deployment. Although institutions also considered long payback period as one of the barriers to solar adoption, they are not as constrained by financial factors. Most of them, like universities, may obtain certain governmental subsidies to support renewable/solar projects.

For the commercial interviewees, both REFiT and net metering are ranked as the most effective policies. This group seemed to pay more attention to the role of the market in promoting rooftop PV deployment in Hong Kong. They recognised the advantages for the commercial sector in deploying innovative business models to make PV installations economically viable. Some of them suggested that a more competitive electricity market in which more private companies participate in PV development could provide a conducive environment for rooftop solar. Regarding subsidies and other direct government support, they commented that, while they would welcome governmental support, they would not rely on it too much.

4.4. The development of an enabling framework for rooftop solar PV deployment in Hong Kong to guide policy developments

Based on the interview data and desktop studies, we developed an enabling framework for rooftop solar PV deployment in Hong Kong (Fig. 7). This enabling framework consists of two integral levels. The first level emphasises that there are three yardsticks for sustainable PV deployment: technical suitability, economic variability, and social acceptance. The importance of these three yardsticks has been highlighted in the literature [21,115,116]. The second level specifies how government interventions in the form of solar policies can create five types of enablers in order to achieve these three normative yardsticks. These five policy enablers are technical enablers, economic and financial enablers, market enablers, regulatory and institutional enablers, and social enablers. Our framework has important policy implications. It suggests that the government needs to assume a more proactive and dynamic role as follows:

First, the government needs to adopt a systemic view of governing the developments of PV. Economic enablers to cut upfront costs are important. But our framework suggests that there exists a wide range of non-cost issues associated with, for example, social and institutional barriers. It is particularly important to note that the government needs to leverage the synergy among these enablers. Our framework suggests that some enablers are highly related and reinforcing. For example, institutional enablers that facilitate new market entrants and address the problems associated with a market monopoly may also promote innovation in business models (market enablers).

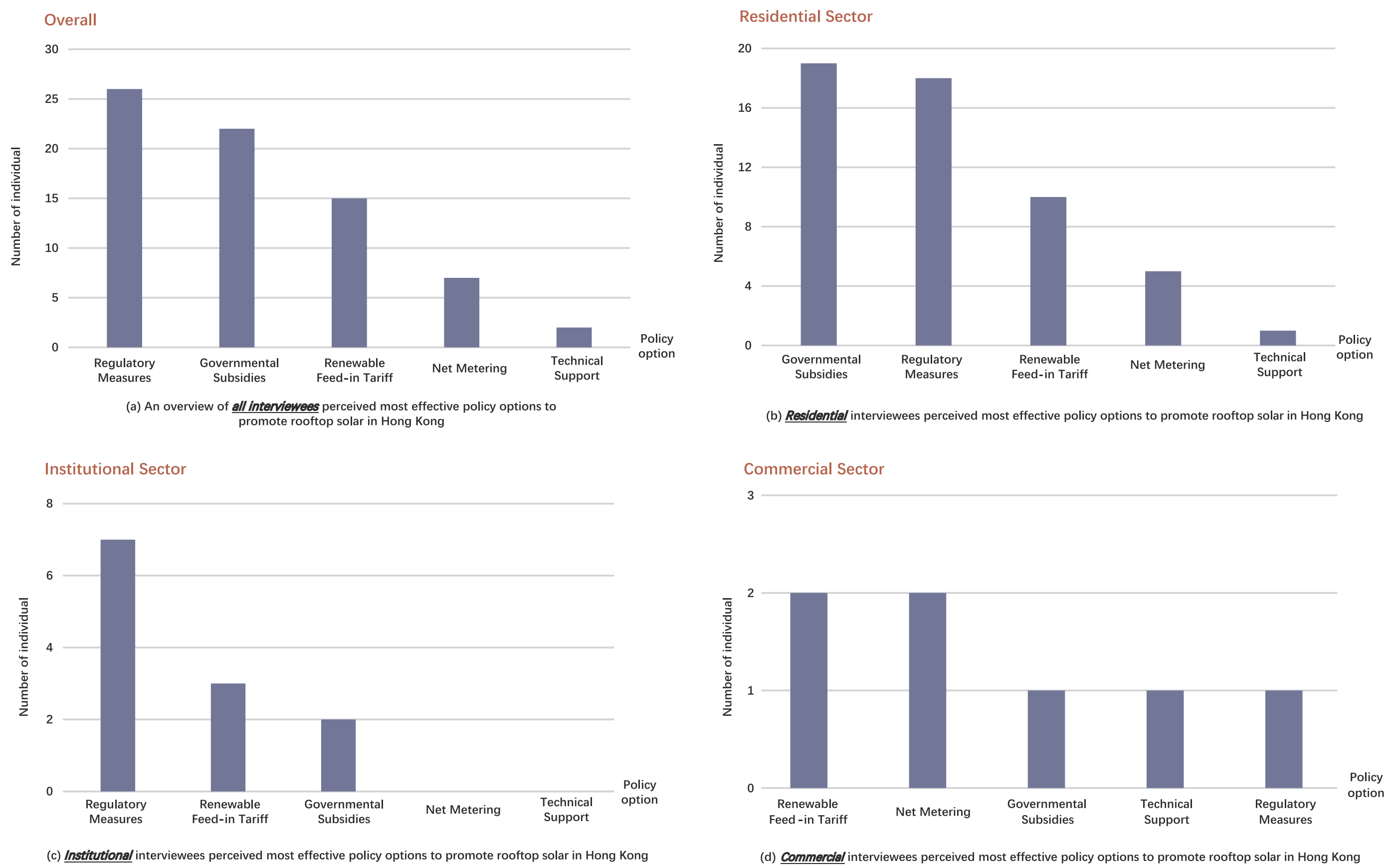

Fig. 6. Perceived effectiveness of policy options (by potential adopters' sectors).

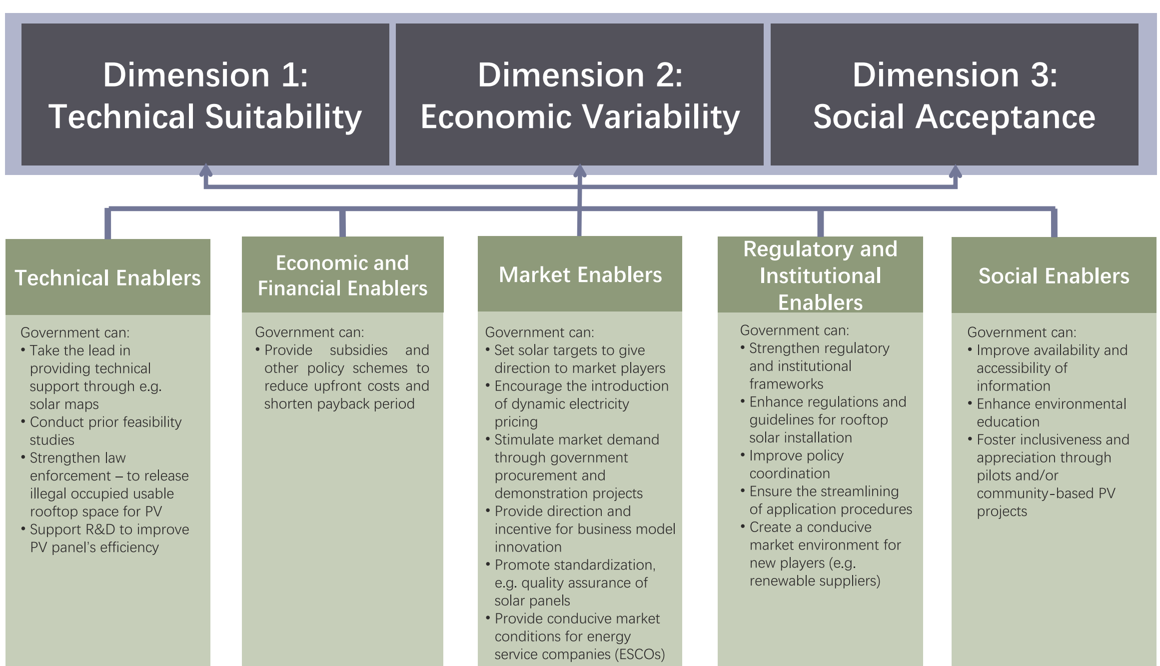

Fig. 7. An enabling framework for rooftop solar PV deployment in Hong Kong.

Second, the government needs to assume a proactive role in creating market conditions that are conducive to PV development. Our findings suggest that business model innovation may be key to reducing the high upfront costs of solar PV. According to local market information accessed during this research, a unit cost of a 1.5 kW solar system in a single purchase order would be approximately HK$10/W, whilst the unit costs could be reduced to approximately HK$6/W in bulk orders.[2] However, due to the small scale of solar development in Hong Kong, the

[2] HK$10 is approximately US$1.3.

opportunities of collective purchase have been limited (Interview with Solar Installer A, 2017).

Elsewhere in, for example, Portland, business model innovations appear to be a potential measure to reduce initial costs. The Portland model is a community collective purchasing programme. Energy Trust (an NGO) in Southeast Portland, in collaboration with other NGOs and neighbourhood volunteers, facilitated collective purchasing. Energy Trust played a central role in coordinating tendering processes for prospective solar household adopters. It solicited and obtained contractor bids. A single contractor would then be selected to serve all project enrollees with a single price [117]. Reducing transaction costs and increasing the transparency of market information appeared to be key in the Portland model. The Hong Kong government may introduce explicit and effective renewable energy policies and funding programmes that provide clear market signals and incentives for business model innovations and business-community partnerships.

Thirdly, in order to effectively address the issue of grid connection, the government needs to leverage its roles as a regulator and market-builder. Grid access has been identified by our interviewees as a major barrier. Some of our respondents expressed concern regarding hurdles in fulfilling technical requirements of grid connection and a lack of energy service companies in the local market. These views are consistent with the observations of two interviewed solar installers (Interviews with Solar Installer A and Solar Installer B (in 2017)). However, utility companies seemed to hold different views, emphasising that technical standards for RE-grid connections are already in place [118] (Interview with an anonymous senior executive at a local utility company, 2017). These mixed views from these key stakeholders suggest that local electric technicians may lack competences in providing professional solar installation services. Our framework suggests that while introducing clear market rules to ensure grid connection is an important regulatory enabler, the government also needs to create favourable market conditions for the scaling up of a competent solar industry in Hong Kong.

5. Conclusion and policy implications

This study has reviewed the recent trends in urban initiatives toward solar PV, and has collected data by conducting 57 interviews with potential rooftop solar PV adopters from the residential, institutional, and commercial sectors in Hong Kong to assess the perceived barriers and effectiveness of possible government policies. We make two important contributions in the field of urban energy policy. First, we have partially filled the gap in the current research on renewables in urban settlements by introducing a local governance perspective. Our findings suggest that city governments have an important role to play in steering PV deployment. While Hong Kong potential adopters stated a low level of interest in installing PV, they demonstrated a considerable magnitude of attitudinal change with the reduction of payback period. They also raised concerns about non-economic barriers, ranging from technical, regulatory, to social ones. The enabling framework that we develop suggests that the Hong Kong government should assume a proactive role in formulating PV policies, and can steer, nurture, and regulate PV deployment by creating technical, economic and financing, market, regulatory and institutional, and social enablers.

Second, our findings contribute to the literature on stakeholder perspectives of PV deployment [119]. A growing body of solar energy literature has emerged to examine how PV adopters, existing power companies, and entrepreneurs respond to new opportunities to deploy PV technologies. Noll et al. [20] examined how early adopters of solar installations responded to positive peer effects. Tongsopit et al. [17] examined how existing business and new entrepreneurs formed partnerships and generated value-added solutions by developing new business models for the rooftop solar market. Our findings contribute to this theme by shedding light on the sectoral differences of potential adopters' perspectives on PV deployment. Our findings are particularly useful in providing a better understanding of the residential sector. By investigating residents' responses to payback period scenario changes, this study contributes to the literature by specifying three distinctive types of residential adopters: highly-responsive, laggard, and indifferent potential adopters. We also found that the existence of opportunity costs as a key factor affecting households' decisions regarding renewable energy adoption. Some of our surveyed rooftops were used for storage of household items, resulting in opportunities costs that have to be borne by prospective solar households.

Our findings have the following policy implications. Firstly, we found that potential adopter's interest in PV is hampered by multiple barriers. Some of the key issues that require policy attention include: (1) how to formulate subsidy strategies and other policy levers so that upfront costs and payback period could be reduced to a *sufficient* extent that potential PV adopters could be motivated to install PV, (2) how to incentivise potential adopters to free up rooftop spaces for PV rather than to use it for other purposes such as household storage, and (3) how to ensure sufficient technical support is provided to those considering PV installations.

Secondly, the enabling framework that we have developed can provide guidance on solar policy development in Hong Kong. While our framework highlights the important roles of city governments, the Hong Kong government can draw on the practical experiences of other large cities (summarised in Table 1) to develop the required economic, market, regulatory, technical, and social enablers. An important trend in policy development in other large cities is that regulatory changes, market formation, as well as the provision of extensive technical support have increasingly become the policy focus, especially for those that envisage a major uptake of PV in the near future. Governments in New York, Singapore, and Tokyo, for example, have shown their leadership and political commitment by raising renewable targets [10]. London and Singapore have been proactive in strengthening their institutional and regulatory frameworks in order to accommodate PV and other intermittent energy sources. The Central Intermediary Scheme introduced in Singapore in 2015 to streamline market registration and settlement procedures is one of these initiatives. Governments in New York City and some other states in the US have nurtured the emergence and development of solar third-party ownership firms and a great variety of business models to support rooftop solar [120]. Many governments have also assumed important roles in creating enablers by introducing not only technical assistance programmes, but also online solar maps. The New York City, Seoul and Tokyo governments have either provided or funded research institutes to establish online solar maps to calculate the amount of electricity generated from building rooftops. All these government functions seem to be critical to stimulating and assisting the attitudinal changes, and hopefully behavioural changes, of potential PV adopters.

Third, our findings help to identify the policy preference of prospective PV adopters in Hong Kong. Policymakers should focus on formulating a policy framework that can effectively address identified barriers through a strategic combination of policy levers. Policymakers need to pay particular attention to the stratification of policy target groups. Our findings identify that the institutional sector, which was not sensitive to the payback period, and some specific large local electricity consumers, such as data centres, could be the first movers in the major uptake of PV in Hong Kong. This observation is consistent with global trends in which a majority of PV systems in cities are installed in institutional buildings. Worldwide, data centres have also attracted growing attention as they are massive energy users with significant scope for reducing energy consumption and costs [121].

Policy target groups can also be differentiated by their policy preferences and responses to the shortening of payback period. Our findings suggest that residential interviewees welcome subsidies while institutional interviewees prefer regulatory measures and the commercial sector prefers feed-in tariffs. Our study also differentiated between highly-responsive, laggard, and indifferent potential adopters in the residential sector. Residential respondents reported a more noticeable increase in interest when the payback period is reduced to 15 years, and a less marked increase when the payback is further reduced to 8 years. Our findings suggest that such policy levers may need to be designed in ways that address the perceived needs of specific target groups of potential adopters and that they need to be introduced in phases.

This paper is mainly based on in-depth interviews conducted with potential PV adopters in Hong Kong. As noted earlier, Hong Kong is atypical in many important respects and this sets it apart from many other major cities. But our findings can be generalised, at least to a certain extent, to other cities in high-income economies in the West (such as New York City and London) and in Asia (such as Tokyo, Seoul and Singapore) which share with Hong Kong similar challenges and opportunities for deployment of PV in urban settings.

This exploratory study has a number of limitations. Firstly, because the sample size is small, the findings are indicative rather than conclusive. Secondly, this study adopted the perspectives of potential PV adopters to enrich our understanding of the factors affecting PV deployment. However, the literature suggests that the scale and pathway of PV deployment is often underpinned by a highly dynamic stakeholder landscape that involves incumbent utilities, new market players such as ESCOs, manufacturers, and policymakers. Further studies may generate useful data by enlarging the sample size, and by extending this study to other key stakeholder groups, and other large cities.

Acknowledgements

We acknowledge the funding support from the Research Committee of Hong Kong Baptist University, and CLP.

Appendix A

See Fig. A1.

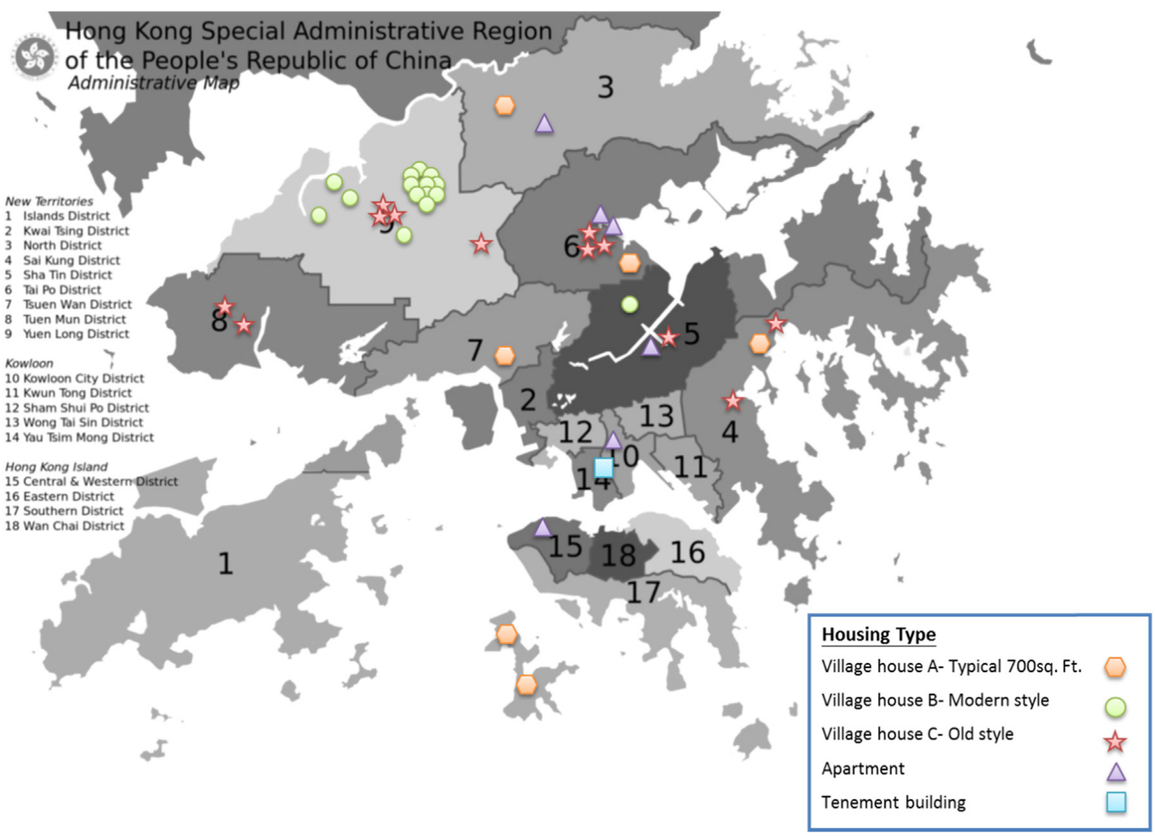

Fig. A1. Geographical distribution of 40 residential interviewees.

Appendix B

See Table B1.

Table B1
Socio-economic and demographic features of residential interviewees.

Age	Number	Percentage	Household Monthly Income	Number	Percentage	Education attainment	Number	Percentage
18–25	4	10.0%	Below 5000	2	5%	Primary school or below	3	7.5%
26–35	6	15.0%	5000–10, 000	0	0.0%	Secondary School	16	40.0%
36–45	10	25.0%	10,001–20,000	5	12.5%	Matriculated	2	5.0%
46–55	6	15.0%	20,001–30,000	2	5.0%	Non-degree tertiary	3	7.5%
56–65	10	25.0%	30,001–40,000	5	12.5%	University	12	30.0%
Above 55	4	10.0%	40,001–50,000	6	15.0%	Postgraduate or above	4	10.0%
			Above 50,000	16	40.0%			
			Refused	4	10.0%			

Note: The total number of residential interviewees is 40 (23 males and 17 females).

Appendix C

See Fig. C1.

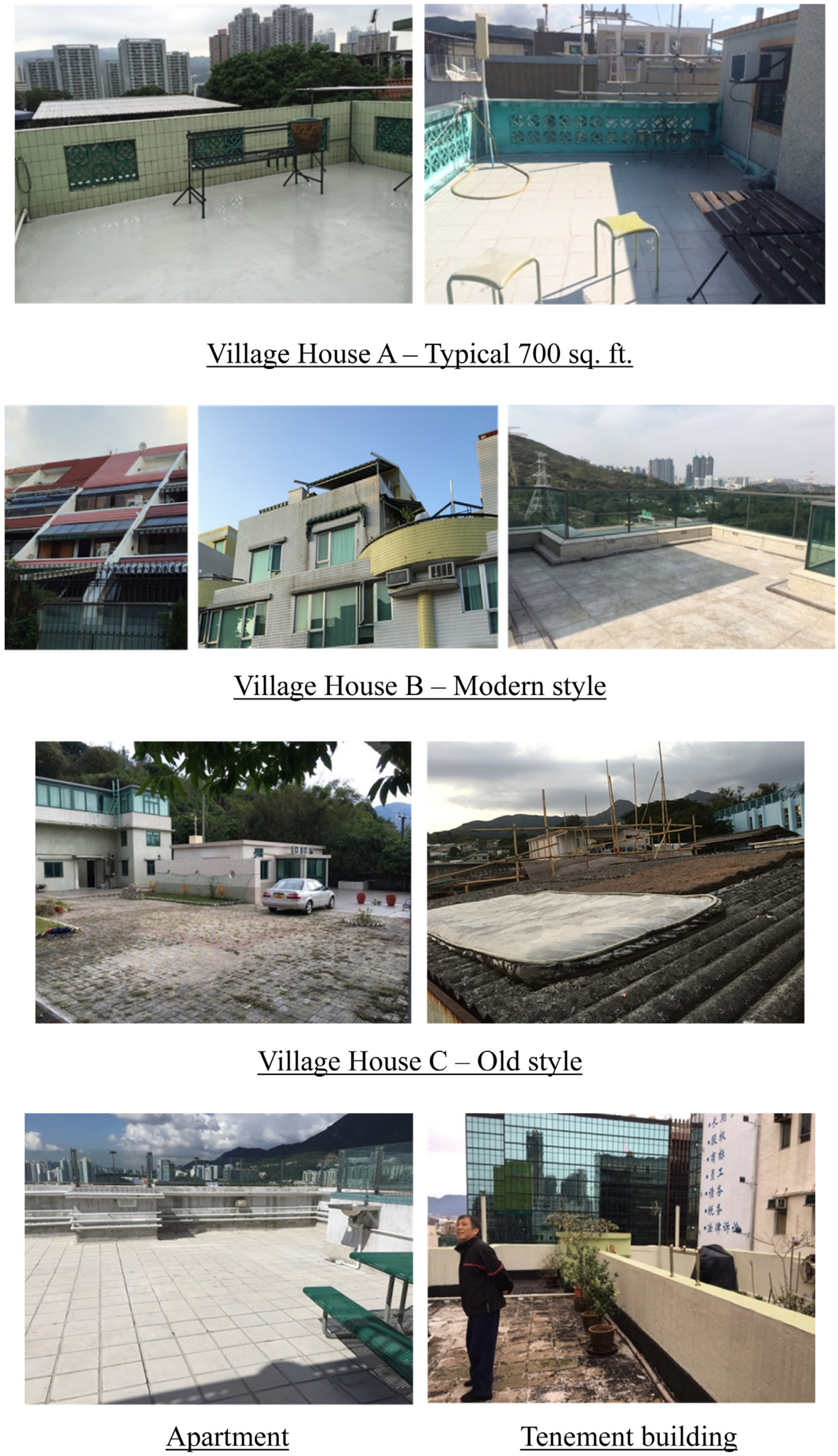

Fig. C1. Rooftop images of some of our sampled house dwellings.

Appendix D

See Table D1.

Table D1
List of interviewees from the institutional and commercial sectors.

Code	Institutional sector			Commercial sector		Background
	Not-for-profit private institute	University/ School	(Quasi-) Government department	Industry	Business/ Developer	
#1	√					A facility manager, engineer by training, from a non-for-profit private institute which is registered as charity
#2	√					A facility manager, engineer by training, from a non-for-profit private institute which operates an amusement park in Hong Kong
#3		√				The director of a sustainability office at University A
#4		√				A retired engineer and facility manager, also was former Director of Facility Management Department at University B
#5		√				A facility manager of University B, who is specializing in mechanical engineering
#6		√				A facility manager of University C
#7		√				A facility manager of University D
#8		√				A facility manager of University E
#9		√				A principal of a secondary school which was honoured as one of "Greenest School on Earth"
#10			√			A senior manager from a statutory body in the aviation sector
#11			√			A senior building services engineer from an actor in the institutional sector
#12			√			A senior building services engineer from a governmental agency
#13				√		A senior manager of a local manufacturing company
#14					√	A senior manager of a data centre
#15					√	A senior manager of a real estate developer
#16					√	A senior manager of a real estate developer
#17					√	A senior facility manager from an airline company

Appendix E

See Tables E1.

Table E1
Three proposed scenarios for rooftop solar PV adoption.

Scenarios	Cost and Payback period	Very interested	Interested	So-so	Not interested	Not interested at all	No opinion
Scenario 1	Upfront cost: HK$55,000 Payback period: 35 years						
Scenario 2	Upfront cost: HK$24,000 Payback period: 15 years						
Scenario 3	Upfront cost: HK$13,000 Payback period: 8 years						

Appendix F. Detailed methodology of quantifying the impacts of the shortening of payback period on attitudinal changes in our three solar PV scenarios

This study attempted to quantify the impacts of the shortening of payback period on attitudinal changes in three proposed scenarios. The following steps were taken:

1. We first assigned different levels of attitude to payback period with different values. Interviewees who are very interested were assigned a value of 5, those who are interested were assigned a value of 4, those who have a neutral attitude (So-So) were assigned a value of 3, those who are not interested were assigned a value of 2, and those who are not interested at all were assigned a value of 1. Interviewees who do not have an opinion cannot be assigned with a value.
2. We then calculate the "units of changes", which is used to quantify the magnitude of attitudinal changes. For example, in a case where an interviewee first stated that he or she was "interested" in Scenario 1 (assigned a value of 4) but then became "very interested" (assigned a value of 5) in Scenario 2, his or her level of attitudinal change (from value 4 to value 5) was quantified as 1 unit of change.

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