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The implementation of building-integrated photovoltaics in Singapore: drivers versus barriers

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ABSTRACT

As a highly urbanised city-state with limited rooftop space but large façade areas of skyscrapers, Singapore is particularly suitable for the implementation of building-integrated photovoltaics (BIPV). This study aims to identify relevant barriers that still hinder the greater adoption of BIPV perceived by stakeholders in Singapore, as well as the drivers for BIPV that would lead building sector to adopt BIPV technologies. The study involved five important groups of stakeholders i.e. governmental authorities, building developers, architects, engineers, and PV/BIPV manufacturers to participate in a questionnaire survey. The results identified that on-site generation of clean energy bundled with economic benefits, Green Mark certification, and avoidance of CO_2 emissions are the most influential drivers, while long-term payback period, high upfront cost, and low energy conversion efficiency are the three most substantial barriers to BIPV. Furthermore, one-way analysis of variance (ANOVA) was conducted to examine whether the various stakeholder groups perceive the drivers and barriers differently. It was discovered that various stakeholder groups perceive the drivers similarly, but the significantly different opinions have been perceived on several barriers. This study provides suggestions to overcome barriers to BIPV not only in Singapore, but also other countries that aim to promote BIPV technologies.

1. Introduction

Building Integrated Photovoltaic (BIPV) is an innovative solar module designed to be integrated into buildings skin as a function of skylight roofs, windows, claddings, or balconies by replacing the traditional construction materials [1,2]. It provides multi-functionalities of building skin, i.e. structural norms, weather and noise protection, heat insulation and aesthetics. BIPV systems used on building surfaces that intercepts the sun utilize an abundant solar energy resource to generate on-site clean energy [3], without the need for burning fossil fuels for energy, and thus significantly reduce CO_2 emissions [4]. In addition, BIPV could also enable transition towards decarbonisation and the aspirations for low carbon cities and zero-energy buildings.

Singapore, as a small city-state, does not have many natural resources and has been depending on imports of oil and natural gas to meet the country's energy demands [5]. With the depletion of natural resources, the increasing share of renewable energy in energy supply is on a high political agenda for Singapore's transition towards sustainable development. As a highly urbanised city with large façade areas of numerous skyscrapers, Singapore is particularly suitable for accelerated implementation of BIPV. Despite a wide range of BIPV technologies with different colours, designs, and applications available on the PV market, penetration of BIPV technologies has not occurred rapidly. Various aspects need to be considered in BIPV implementation, such as the optimal placement of BIPV onto the building facade, economic viability, and the coordination between BIPV system installation with the building structure [6]. For instance, many studies indicated that the most prominent obstacle to the accelerated adoption of BIPV system was attributed to the high cost. The initial cost of BIPV system includes the cost of components such as inverters, electrical storage or grid-metered connections, fault protection, cabling and wiring, as well as the cost of design and installation [7]. The economic viability of

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BIPV systems is determined by the initial cost involved and benefits obtained by on-site energy generation. Many factors could cause the power loss of BIPV systems such as pollution particles in the air, shading, and inappropriate orientation of the BIPV modules. According to Azadian and Radzi [4], partial shading caused 5%–10% of power losses in BIPV systems, and this could potentially damage the PV cells. This was further supported by an experiment conducted by Borg and Jansen [8], which indicates shading causes loss of available radiation, resulting in less energy produced than the optimally situated system. The barriers could be not only economic and technical, but also social and cultural. Implementation of BIPV systems into buildings is an innovative trend, which requires architects or designers to have sufficient knowledge about BIPV technologies and to possess the appropriate design tool to include BIPV in the building in the pre-design phase [9]. Yang [10] highlighted that some architects might not want to consider BIPV systems in their design due to their inadequacy of knowledge and expertise in BIPV systems.

Despite the above previous studies, there are gaps of knowledge in the promotion of BIPV. Different stakeholders may have divergent opinions on BIPV systems. To effectively promote BIPV systems, the government needs to clearly understand the factors driving and prohibiting BIPV development perceived by different stakeholder groups, thereby issuing targeted policies to strengthen the drivers and weaken the barriers. However, there is a lack of studies holistically investigating both the drivers and barriers to BIPV perceived by different stakeholders. Little is known in terms of whether different groups of stakeholders perceive the drivers and barriers impacting BIPV development differently. There are also few studies examining factors impacting BIPV in southeast Asian countries, such as Singapore. This study aims to identify the influential factors to form targeted policies to strengthen the drivers and weaken the barriers towards BIPV. This study aims to answer the following important questions: 1) what are the drivers that facilitate the adoption of BIPV in Singapore; 2) what are the barriers that hinder the accelerated adoption of BIPV in Singapore; and 3) whether different stakeholders perceive these drivers and barriers differently.

2. Drivers and barriers impacting the development of BIPV

Previous studies have identified various merits of BIPV systems, which drive the implementation of BIPV. Firstly, BIPV can be aesthetically appealing, functional and yet flexible, giving the positive impact on buildings with many opportunities for innovative architectural design. For instance, it has been argued that when BIPV systems are architecturally integrated into the building design, it could convey the coolness of its appearance [6]. Buildings with BIPV systems could be more iconic as compared to normal buildings [11].

Furthermore, from an economic perspective, the electricity generated by BIPV systems creates savings that reduce the operating budget [12]. There could be substantial incentives for consumers and companies to adopt BIPV by enabling them to sell excess power to the grid at a high price [13]. Song et al. [14] discovered that the five leading countries with large solar installations namely Germany, Japan, Italy, China, and the USA have a similarity in the incentive policies of PV technology. In Singapore, incentives such as Solar Capability Scheme (SCS), and Green Mark Scheme (GMS) are provided, but in Singapore, the rate of the adoption of BIPV is still moderate.

Environmentally, by analyzing a 5-year Malaysia BIPV project, Hashim and Ho [15] showed that greenhouse gas emissions of the project were obviously lower than conventional buildings with similar function and scale. Since BIPV systems can generate electricity in a greener way, they could nurture occupants' environmental consciousness. For instance, Bollinger and Gillingham [16] found substantial neighbor effects exist in PV system adoption. This was consistent with Schiller [17], which indicates that one BIPV installation within households would increase the chances of the second installation in their neighbours by half. This chain effect of environmental efforts and behaviour within communities could facilitate the spread of BIPV systems. Technically, BIPV systems can either be interfaced with the utility grid or designed as stand-alone, off-grid systems [3,18]. Developments in R&D could also be strong drivers for BIPV development. For instance, the R&D in this field is strongly supported by the EU government. Because of the strong R&D, BIPV has been developing rapidly in European countries, and there are successful demonstration projects of BIPV systems, most of which are high-profile buildings.

Apart from the drivers mentioned above, the development of BIPV systems may face various barriers as well. BIPV modules as building components must fulfill the mandatory requirement of different government agencies. However, up to the present stage, there are no specific standards in Singapore for BIPV installation. As the planning and construction process of a building could be complicated by the use of BIPV, a distinct and separate set of standards is needed to guide and standardize the installation and execution process [19].

Moreover, in comparison to other countries, the cost of BIPV in Singapore is significantly higher due to the small market size, and inexperienced and limited BIPV manufacturers and suppliers [20]. The length of time required to recoup the initial cost of capital is known as the payback period [21]. Azadian and Radzi [4] elaborated that BIPV is a long-term investment and from an economic perspective, it only produces the best result 20 years later after the installation. Hammond et al. [22] showed the payback period for BIPV system is 15 years with the support of feed-in tariff, but if such support was removed, the payback period could be as long as 53 years. By contrast, Jelle [23] indicated that the maximum payback period for BIPV systems is estimated to be 10 years with government support and subsidies. It seems that the long-term payback period could be a significant barrier to the development of BIPV systems.

Technically, the installation of BIPV systems requires proper electrical planning, and the electrical component of BIPV systems has to be designed by specialists due to its complexity [19]. BIPV will be accepted by builders, architects, and end-users only if the quality of the BIPV system is assured [6]. Similarly, Peng et al. [24] indicated that the lack of knowledge in installation and maintenance is an essential barrier leading to the slow growth of BIPV. Contractors and installers must have a clear understanding of BIPV systems to integrate them in buildings in a satisfactory way [25].

To summarise, previous studies indicate that there are various drivers and barriers impacting the diffusion of BIPV systems in the building sector. However, there is a serious lack of studies to holistically investigate different stakeholder groups' perceptions on both the drivers and barriers impacting BIPV.

3. Methodology

To investigate the drivers and barriers to BIPV in Singapore, a questionnaire survey was employed in this study. Firstly, a literature review was conducted to identify the potential drivers and barriers to BIPV, and 12 drivers and 21 barriers were identified from the literature. Then, six experts of BIPV from the Solar Energy Research Institute of Singapore were invited to attend a focus group discussion of the identified factors. Experts provide a critical analysis of the factors one by one, to evaluate whether they could be further grouped together and whether there are significant factors not mentioned in previous studies. After the focus group discussion, there are 12 drivers and 18 barriers listed as the final factors impacting BIPV development in Singapore, as shown in Table 1 and Table 2 respectively.

Then, an online questionnaire was created using Google form to investigate the stakeholders' perceptions of the identified drivers and barriers. Respondents of the questionnaire survey were carefully selected. The respondents need to play a substantial role in the decision-making process of green building development, preferably with the experience of using PV in their projects. To capture the perspectives from different stakeholders, in this study five major groups of stakeholders were considered, including 1) architects/designers, 2) building developers, 3) façade/construction engineers, 4) local authorities, and 5) PV/BIPV manufacturers. The approach of snowball sampling was adopted, due to the impracticability to draw accurate probability sample since the entire population is unknown [26]. The sample group from snowball sampling is mostly based on referrals from initial subjects to generate additional subjects via chain referral [27]. The questionnaires were disseminated to relevant firms in Singapore through emails and LinkedIn messages over a period of five months from March to July 2017.

Invitations to participate in the survey were distributed to 487 industry professionals working in Singapore and there were 99 valid responses received, with the response rate being 20.3%. Among the 99 respondents, 82.8% of the respondents have involved in projects with PV systems and 63.6% of the respondents have worked for projects with BIPV systems. Especially, 17 respondents have more than 5 years of working experience specifically for BIPV projects. The respondents are all based in Singapore and working for companies in Singapore, such as Surbana Jurong, City Developments Limited, Eigen Energy, Façade Global Master, or governmental agencies for Singapore such as Housing & Development Board and National Environmental Agency.

Statistical Package for Social Sciences (SPSS) software was used to conduct the data analysis process. In the questionnaire survey, respondents were asked to evaluate the degree of importance for each of the drivers and barriers based on a 5-point Likert scale, with 1 indicating “Not at all important”; 2 indicating “Slightly important”; 3 indicating “Moderately important”; 4 indicating “Very

Table 1
Drivers for BIPV.

Code	List of Drivers	Sources														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
D1	Positive impact on the property value	✓	✓	✓	✓		✓									
D2	Enhance green image for better marketing	✓			✓	✓										
D3	Generation of renewable energy which brings economic benefits		✓				✓		✓			✓		✓		
D4	Improve the performance of the building envelope							✓	✓							
D5	Obtain governmental incentive									✓	✓			✓		
D6	Achieve Green Mark certification						✓					✓			✓	
D7	Reduce CO_2 emission	✓		✓			✓					✓	✓		✓	
D8	Reduce dependency on fossil fuels	✓		✓			✓						✓		✓	
D9	Demonstrate green image and sustainable development to public	✓			✓	✓										
D10	Encourage the occupants to adopt pro-environmental behaviour				✓	✓										✓
D11	To be partially independent of the grid	✓						✓						✓		
D12	Grow industrial R&D capacities for technology			✓	✓					✓	✓					

Sources: 1 = Deo Prasad [6]; 2 = Pacheco-Torgal et al. [28]; 3 = Petter Jelle et al. [29]; 4 = Heinstein et al. [11]; 5 = Cholakkal [30]; 6 = Debbarma et al. [1]; 7 = Eiffert and Kiss [31]; 8 = Scognamiglio [2]; 9 = Pagliaro et al. [13]; 10 = Song et al. [14]; 11 = Harris and Roach [32]; 12 = Casini [33]; 13 = Biyik et al. [34]; 14 = Hashim and Ho [15]; 15 = Steg and Vlek [35].

Table 2
Barriers to BIPV.

Code	List of Barriers	Sources														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
B1	Difficulties in obtaining governmental approvals (e.g. from different agencies)	✓														
B2	Lack of BIPV specific design standards and codes	✓		✓									✓	✓	✓	
B3	Uncertainties in BIPV policies (e.g. the source and stability of subsidy funds)	✓	✓			✓	✓	✓	✓	✓		✓		✓	✓	
B4	Lack of R&D support covering the entire industry chain of BIPV		✓			✓			✓					✓		
B5	Projects awarded to lower price tendering															✓
B6	Few choices for BIPV products									✓	✓					
B7	High upfront capital costs of BIPV		✓		✓	✓	✓	✓			✓			✓	✓	
B8	The long-term payback period of BIPV							✓	✓		✓					
B9	Low electricity tariff from conventional sources (i.e. natural gas)					✓										
B10	The low energy conversion efficiency of BIPV systems			✓		✓			✓							
B11	Difficulty in integrating BIPV into the grid			✓						✓		✓		✓	✓	
B12	Fluctuating energy generation due to weather			✓					✓							
B13	Unclear maintenance procedures (e.g. replacement of BIPV modules)			✓								✓				
B14	Few numbers of competent contractors and installers					✓		✓	✓							
B15	Lack of successful BIPV demonstration							✓		✓						
B16	Lack of BIPV knowledge for professionals					✓		✓	✓	✓						
B17	Additional time and efforts to collaborate with stakeholders (e.g. communications between engineers and designers)			✓												
B18	Lack of public awareness of BIPV				✓	✓	✓	✓			✓					

Sources: 1 = Ferrara et al. [19]; 2 = Song et al. [14]; 3 = Shukla and Sharma [36]; 4 = Sozer and Elnimeiri [7]; 5 = Yang and Zou [37]; 6 = Rahman et al. [20]; 7 = Goh et al. [38]; 8 = Azadian and Radzi [4]; 9 = Biyik et al. [34]; 10 = Jelle [23]; 11 = Mousa [39]; 12 = IEA [40]; 13 = Huo and Zhang [41]; 14 = Shen and Luo [42]; 15 = Lim [43].

important and 5 indicating “Extremely important”.

Regarding the data analysis process, firstly Cronbach's alpha was calculated to examine the internal reliability of ratings for the drivers and barriers respectively. As suggested by most social science research, a reliability coefficient of more than 0.70 is deemed acceptable [44]. Then, descriptive statistics of the mean was employed to describe the central tendency of the responses. Subsequently, to identify if there is any divergence in responses between different groups of stakeholders, One-way ANOVA was employed [45]. For this statistical analysis, 95% level of confidence was used. Specifically, if the p-value for ANOVA is less than 0.05, the means of the six groups are significantly different from each other. However, the significance value of ANOVA alone does not provide information about which pair of stakeholders has differing opinions. To identify the exact pair of stakeholders with significantly different opinions, this study subsequently employed the Tukey post-hoc analysis, which compares each pair of stakeholder groups in the rating of each factor. In the post-hoc analysis, if the significance value of certain pairs of groups for a factor was less than 0.05, the compared pairs have significantly different ratings for the factor.

4. Results

The Cronbach's alpha values for drivers and barriers were 0.860 and 0.872 respectively, indicating a high internal consistency. The respondents had an average of 1.8 PV projects involvement, and 1.29 years of experience in BIPV projects. Around 31.3% of the respondent's companies have 11 to 100 employees, and 25.3% of the respondents are in the companies that have at least 1000 employees.

4.1. Drivers for BIPV in Singapore

The ANOVA tests indicate that the significance values for all drivers are higher than 0.05, which suggests that there is no significant difference between the ratings provided by the five categories of stakeholders. Hence, the different groups of stakeholders share similar opinions in the ranking of the drivers for BIPV in Singapore. Specifically, as shown in Fig. 1, the driver ranked as the most significant is the generation of renewable energy which brings economic benefits. Monetary benefits in the form of cost savings or higher returns is a vital incentive driving the implementation of BIPV [46]. There is an association between the adoption of BIPV and the higher premium of the project compared to using the conventional rooftop PV panels and traditional construction materials [13]. BIPV can bring about enhanced value to the building system such as improved marketing opportunities and equity value of the property [30,47]. To recoup the cost of installing and implementing BIPV systems, the monetary benefits brought by BIPV systems becomes critical to stimulating the widespread use of BIPV [37]. This is in accordance with Biyik et al. [34], Goh et al. [38] and Sozer and Elnimeiri [7], who indicated that economic factors play a significant role in the decision making relevant to BIPV systems.

Achieving Green Mark Certification was ranked as the second most significant driver. Green building certifications are associated with proper standards and environmental benefits [48]. Having the ability to obtain green building certificate such as Green Mark in Singapore serves as a form of recognition, strengthening the public image of a building [49]. Heinstein et al. [11] and Schuetze [50] indicated with the inclusion of evaluating BIPV in green building certification, BIPV could receive broad acceptance in the industry [51]. Other highly ranked drivers include reducing CO_2 emissions and the demonstration of the green image to the public. With the

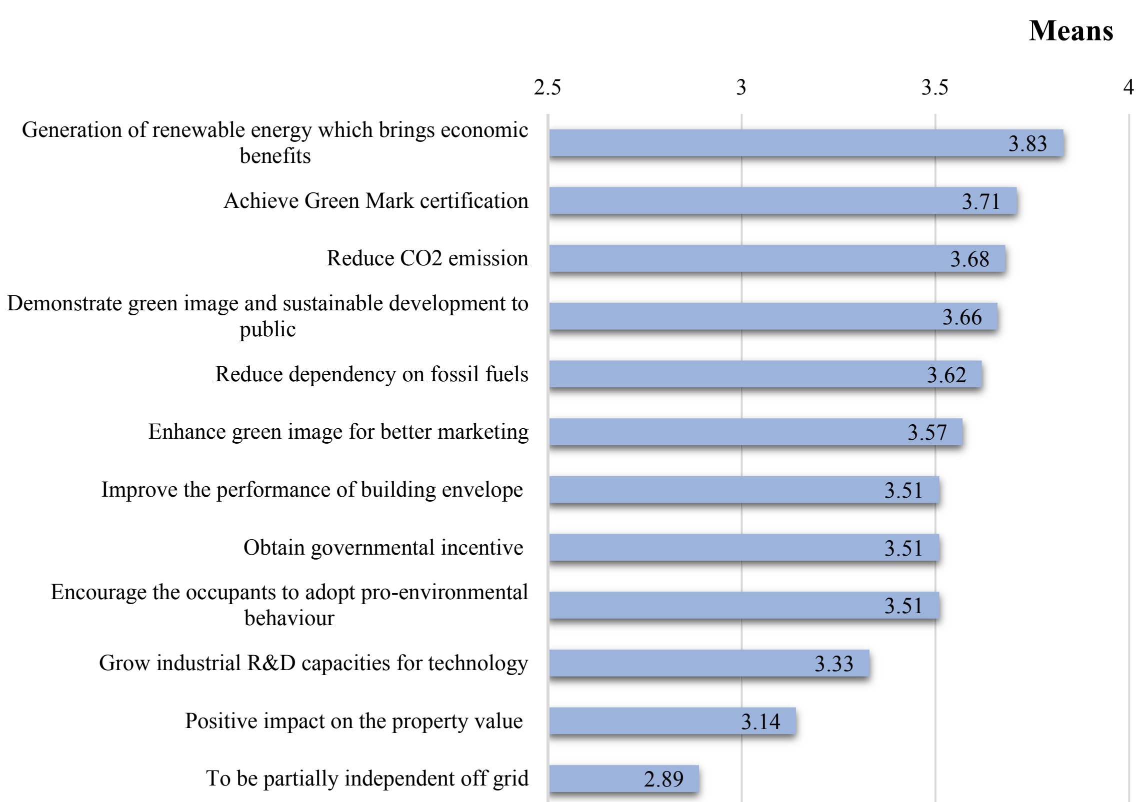

Fig. 1. Ranking of drivers for BIPV in Singapore.

increasing recognition of climate change in both politics and business, the reduction of CO_2 emission act as an important driver for BIPV since the renewable energy produced by BIPV could result in carbon offset [37]. Similarly, by displaying a green and sustainable image to the public, the adoption of BIPV systems could demonstrate the corporate social responsibility of mitigating adverse environmental impacts and saving energy, enhancing the profile of a sustainable corporate image.

4.2. Barriers to BIPV in Singapore

This study identifies that the top two most critical barriers were both related to economic aspects, namely the long-term payback period and high upfront capital cost, as shown in Fig. 2. Developers prefer to invest in projects with a high rate of returns ideally over a short time and with low initial investment [52]. Taleb and Pitts [53], Azadian and Radzi [4], and Yang and Zou [37] identified economic barriers as the most prominent barriers hindering the growth of BIPV and concluded that BIPV is currently not financially beneficial. The projects with extended payback period tend to have high risks of capital recovery [54]. It takes time to receive substantial returns from investments on BIPV systems, as the payback period of BIPV systems can be as long as 53 years [22]. Due to the lack of knowledge on the payback period of BIPV systems, industry practitioners could be hesitant to adopt BIPV [53]. Stakeholders may not be interested in spending resources to take up expensive BIPV systems if conventional construction materials generate a higher profit margin.

However, Eiffert and Thompson [12] indicated that considerable savings in the overall lifecycle cost could be achieved. The total prices of BIPV systems could be lower than a separate PV system that requires dedicated and mounted system [3]. Furthermore, the high initial cost of BIPV can be partially offset by the reduced standard construction costs, since BIPV modules replace some building materials. When compared to traditional construction materials such as glass, steel or conventional cladding material, the BIPV only adds up to a marginal extra cost of 2%–5% of the overall construction costs with additional benefits of energy cost savings [1,29]. Thus, there is controversy regarding the economic feasibility of BIPV systems in the literature, and to support the decision making of industry practitioners, lifecycle cost-benefit analysis of BIPV systems in different projects in various country backgrounds are urgently needed.

The low energy conversion efficiency of BIPV systems was ranked as the third most significant barrier. The low energy conversion efficiency of BIPV was regarded as one of the widely mentioned risks and restrictions affecting the growth of the BIPV market [37,55,56]. Agrawal and Tiwari [57] indicated the energy

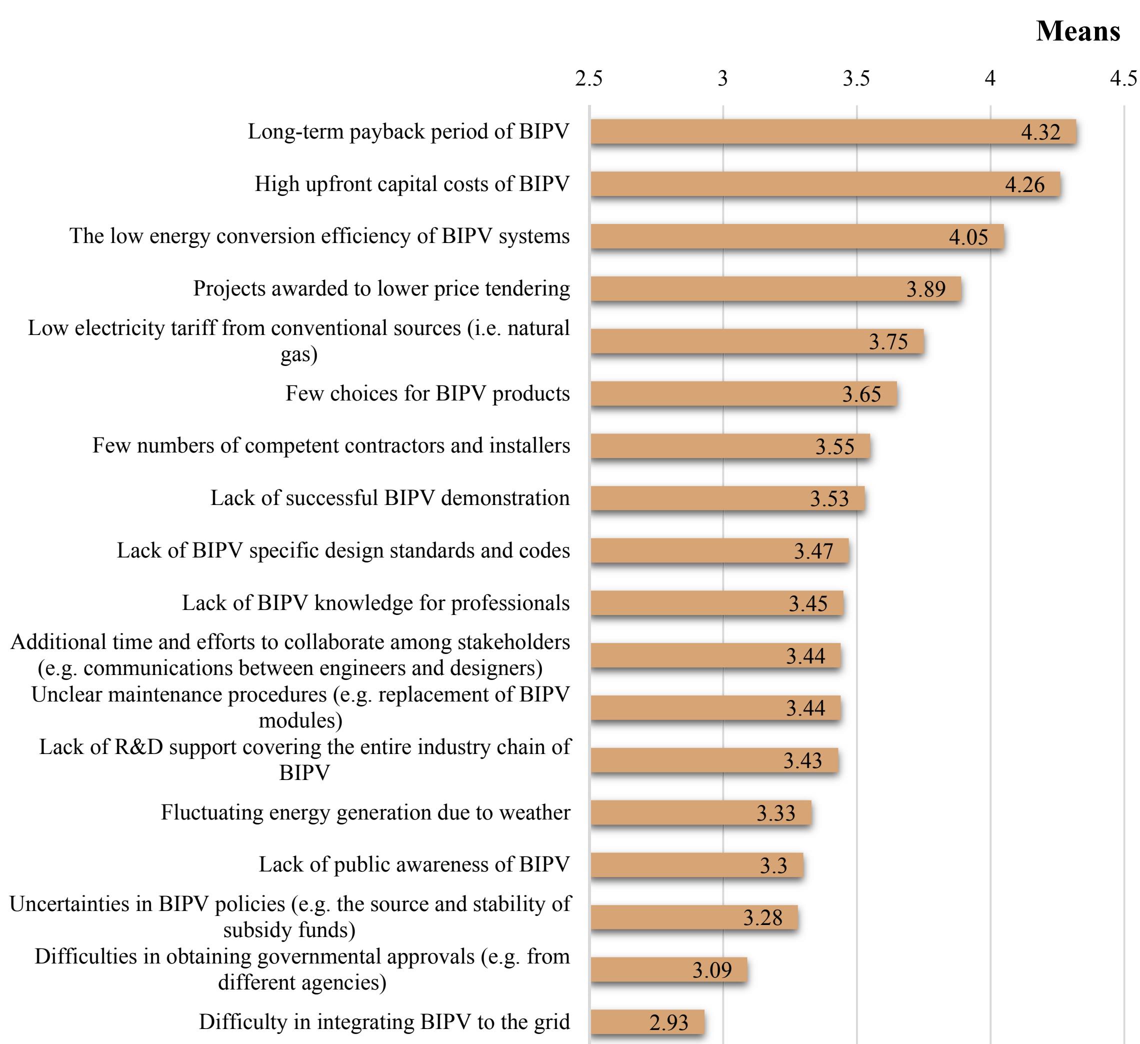

Fig. 2. Ranking of barriers to BIPV in Singapore.

efficiency of PV systems is generally less than 20%. An architect who lacks understanding of PV systems tends to design BIPV systems to meet architectural criteria rather than technical criteria, thus further limiting the system performance of BIPV [58]. Similarly, the barrier of few choices for BIPV products was also highly ranked. For instance, transparent PV modules have enormous potentials for aesthetical reasons and the ability to allow sunlight to pass through, reducing the energy consumption of indoor lighting. However, the efficiency of entirely transparent PV modules is lower than that of opaque and semi-transparent PV modules [59]. Generally speaking, the more transparent the solar PV module is, the lower the energy efficiency [60]. The products of transparent PV modules with high energy conversion efficiency need to be further developed to provide more options for the industry.

An interesting finding of this study is the identified high importance of the barriers "projects awarded to lower price tendering" and "low electricity tariff from conventional sources", which have not been highlighted by previous studies. This finding suggests the barriers to BIPV come from not only the various aspects of BIPV itself, but also the competing energy sources and deep-rooted culture of conservatism in the industry.

The ANOVA tests reveal that four barriers received significantly different ratings from diverse groups of stakeholders. Post-hoc analysis was conducted to determine which pairs of groups differ from each other. The results are shown in Table 3, where stakeholders in category A and B are significantly different in perceiving the barriers. For instance, regarding the barrier of long-term payback period of BIPV, there are four pairs of stakeholders with significantly different perceptions, namely designers and manufacturers, developers and manufacturers, engineers and manufacturers, and local authorities and manufacturers. Fig. 3 demonstrates the stakeholder groups' ratings on the identified four barriers.

Regarding the high upfront cost, PV/BIPV manufacturers provide significantly lower ratings on this barrier than local authorities. Similarly, PV/BIPV manufacturers also believed the payback period of BIPV systems is not a serious issue, as the mean value of "long-term payback period" is only 3 rated by manufacturers, while the other stakeholder groups, including local authorities, designers, engineers and developers all rated this barrier very high, around 4.5. This indicates that unlike other stakeholder groups, manufacturers do not seem to reckon economic issues as significant barriers to the adoption of BIPV. A possible explanation is PV/BIPV manufacturers understand the tangible and intangible benefits of BIPV, believing that cost can be justified in the long run. PV/BIPV manufacturers "are the main investors in production, R&D of PV/BIPV technology to meet market demands for technical, liability and economic aspects" [61]. Thus, they are generally more optimistic about the BIPV market than other industry players as they are the initial driving force [62].

The post-hoc tests also reveal that engineers and designers have significantly different opinions on two technical barriers, namely the difficulty in integrating BIPV to the grid and fluctuating energy generation due to weather. Designers rated these two barriers significantly higher than engineers. This could be explained by the fact that constructors/engineers are more involved in the technical aspects of BIPV whereas architects/designers are in charge of designs. Thus, engineers may have a better understanding of the technical details of BIPV and are more optimistic about the system performance of BIPV. The divergence of the stakeholder opinions on these barriers to BIPV reflects the existence of information asymmetry in the industry. Various stakeholders have different knowledge backgrounds which impact their perceptions of BIPV.

Table 3
Results of post-hoc analysis.

Dependent Variable	Stakeholder category A	Stakeholder category B	Mean Difference (A-B)	Std. Error	Sig.
High upfront capital costs of BIPV	Local Authorities	PV/BIPV manufacturer	1.067*	0.349	0.034
Long-term payback period of BIPV	Architects/Designers	PV/BIPV manufacturer	1.223*	0.274	0.000
	Building Developer	PV/BIPV manufacturer	1.600*	0.337	0.000
	Constructors/Engineers	PV/BIPV manufacturer	1.248*	0.285	0.000
	Local Authorities	PV/BIPV manufacturer	1.567*	0.346	0.000
Difficulty in integrating BIPV to the grid	Architects/Designers	Constructors/Engineers	1.407*	0.298	0.000
Fluctuating energy generation due to weather	Architects/Designers	Constructors/Engineers	1.143*	0.333	0.011

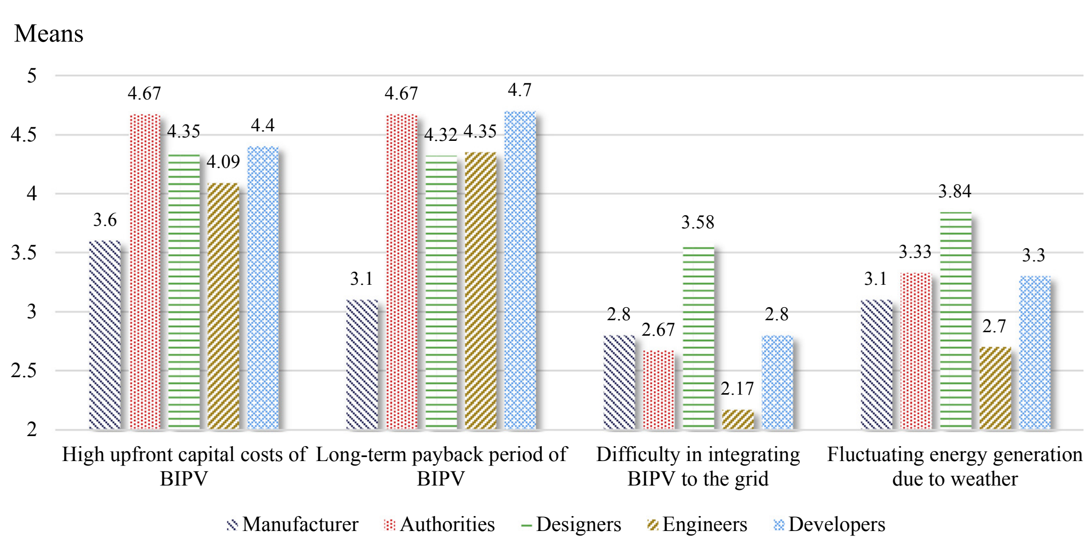

Fig. 3. Comparison of stakeholder groups' perspectives on four identified barriers.

Thus, an effective information exchange platform is needed to facilitate the uptake of BIPV, which will be discussed in the following section.

5. Discussions

This study provides references for both policymaking and academic research on BIPV. Firstly, this study suggests it is of high importance to conduct lifecycle cost-benefit analysis of adopting BIPV and communicate the findings to the industry practitioners. This research has highlighted the significance of economic considerations in shaping the various stakeholders' opinions towards BIPV, as it is identified that the generation of renewable energy which brings economic benefits is the most influential driver for BIPV while the long payback period and high upfront cost are the strongest barriers. These factors are all related to the financial performance of BIPV systems. The payback period of BIPV systems is influenced by the initial investment and the monetary value generated by the system. It has been mentioned that there is controversy regarding the payback period of BIPV in literature, with the proposed payback period ranging from less than 10 years to as long as more than 50 years. It could possibly be explained by the fact that different BIPV systems require various levels of initial investment and different countries have varying levels of tariffs and incentive policies for electricity generated by BIPV, and thus the payback periods of BIPV systems varies significantly. The complexity of determining the payback period of BIPV systems is further intensified by the fact that every building has its unique location and the surrounding environment, which impacts the energy conversion efficiency of the PV modules and subsequently, the payback period of the system.

Therefore, it is not surprising that the industry hesitates to adopt BIPV systems as the economic performance of such systems is highly uncertain, subject to various factors. To facilitate the diffusion of BIPV in the industry, it is highly recommended to conduct lifecycle cost-benefit analysis and simulations of BIPV systems in different projects with various locations, thereby projecting the payback periods of BIPV for projects with various characteristics. It is of the same importance to also communicate such findings effectively to the industry. This study also identifies that the BIPV manufacturers do not perceive the economic performance of BIPV as a significant hindrance to BIPV. This suggests that information asymmetry may exist between BIPV manufacturers and other stakeholders such as developers. Thus, various communication channels, such as seminars linking the academics, BIPV manufacturers and other stakeholder groups, should be established to facilitate the information exchange in the industry. Only if the practitioners understand the costs and benefits associated with BIPV, and only if the benefits of adopting BIPV outweigh the associated cost, can industry practitioners proactively embrace BIPV technology.

The associated costs need to be reduced and the benefits need to be increased so that the economic performance of BIPV systems could be improved. With the increased scale of BIPV deployment and learning process, it is expected that the cost of BIPV will gradually decrease similar to other renewable energy technologies such as wind power. To increase the benefits brought by BIPV, the energy conversion efficiency of BIPV modules need to be further improved by research and development activities. Furthermore, the government could deliberately provide incentives for adopting BIPV. The government incentives have been proven to be effective in triggering the growth of the PV market [14]. Previous studies highlighted the implementation of BIPV is to a certain extent driven by government incentives [63]. Germany, for instance, provides loans at a low-interest rate for PV projects [64]. However, it is also important to note that stakeholders cannot entirely rely on government incentives to adopt BIPV. As the government has limited resources, strong incentive policy is hard to be sustainable, and once the incentives are provided it could become difficult to withdraw the incentives in the future without impacting the industry. In the case of Japan, when the subsidy value was reduced, the growth rate of PV installation began to fall [14]. Huge subsidies could also lead to fierce competition and overproduction, which is the current situation of the Chinese wind power industry and the PV manufacturing industry. Therefore, the government needs to be very cautious to propose economic incentive policy which is suitable for the local BIPV industry.

In Singapore, the development direction of the construction industry is largely driven by relevant governmental departments' initiatives and plans which are then conveyed to construction companies. Thus, it is crucial for the government to set up clear visions and goals for BIPV firstly. Such visions and goals should serve for the broader vision and planning of solar energy development in Singapore. Only if the government releases clear signals to the industry can the industry practitioners understand the strategic importance of BIPV development. After a clear vision for BIPV is established, the government could work on the relevant standards and guidelines for BIPV. This study identified that obtaining Green Mark certification is a strong driver for BIPV adoption. Mousa [39] emphasized the scoring systems in green building certification programs are influential to BIPV adoption. It could be studied to increase the points relevant to PV/BIPV adoption in the Green Mark scheme to stimulate BIPV adoption. Furthermore, in Australia, there is Best Practice Guideline for BIPV while in Europe there is EN 50583 for BIPV [1]. By contrast, Singapore lacks such guidance of BIPV for stakeholders and thus, it could be studied to propose such guidelines.

6. Conclusions

This study examined the barriers to and drivers for BIPV in Singapore based on a multi-stakeholder approach. The results of the survey indicate that the generation of renewable energy which brings economic benefits, achieving Green Mark certification and reducing CO_2 emissions are the three most influential drivers for the adoption of BIPV, while the long-term payback period, high upfront cost and low energy conversion efficiency are the three strongest barriers perceived by the respondents. ANOVA was adopted to investigate whether different stakeholder groups perceived the drivers and barriers differently. The results indicate that the various stakeholder groups have similar opinions on the drivers for BIPV without significant difference, while they do have different perceptions towards certain barriers. Unlike other stakeholder groups who rated economic issues as essential barriers, BIPV manufacturers do not perceive long-term payback period and high upfront costs as serious hindrances to BIPV. Similarly, engineers do not recognize the integration of BIPV to the grid and fluctuating energy generation due to weather as essential barriers, while architects believe so.

Recommendations are proposed to facilitate the development of BIPV. Firstly, lifecycle cost-benefit analysis of adopting BIPV in projects with different features should be conducted so that industry practitioners could understand the costs and benefits involved and estimate the payback period of the system. This requires the establishment of effective communication channels among various stakeholder groups to eliminate information asymmetry and disseminate the research findings. Secondly, the government could study on and issue incentive policies to stimulate the growth of the BIPV market. Such incentive policies need to be well designed based on rigorous analysis of local conditions.

Third, it is suggested that the government needs to propose a clear vision and development goals for BIPV and release the signal to the industry, and relevant guidelines of BIPV could be introduced to guide the industry practitioners in BIPV adoption. By identifying the significant drivers for and barriers to BIPV development and proposing the policy recommendations, this study provides references for various stakeholders to better understand the BIPV development in Singapore. This study also provides references for other countries which aim to promote BIPV.

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