Crowdfunding for solar photovoltaics development: A review and forecast

Lu, Yujie; Chang, Ruidong; Lim, Suxann

Published in:
Renewable and Sustainable Energy Reviews

DOI:
10.1016/j.rser.2018.05.049

Crowdfunding for Solar Photovoltaics Development: A Review and Forecast

Yujie Lu [a]; Ruidong Chang [b,*]; Lim Suxann [a]

[a] Department of Building, School of Design and Environment, National University of Singapore, 4 Architecture Dr, Singapore 117566

[b] Centre for Comparative Construction Research, Faculty of Society and Design, Bond University, 14 University Dr, Robina Queensland, Australia 4226

Abstract

Solar Photovoltaics (PV) has become one of the major trends in the energy sector for the past decade. Due to the high upfront capital expenditure needed for solar installations, new investment models and financing options have emerged in recent years. While solar financing has received increasing attention, little research has been done to explore the use of crowdfunding for PV development. This study presents a review of the crowdfunding concepts in general and crowdfunding of renewable energy specifically, and provides a system dynamics model to simulate the development potential of Solar Crowdfunding (SCF) by taking Singapore as an example. The model simulated a three-stage SCF development including the determination of potential SCF adopters, factors affecting the adoption of SCF, and factors affecting the success of SCF. The results show that under different scenarios, SCF can potentially generate a cumulative amount of $177-278 million US Dollars by the end of 2050, accounting for 2.5%-4% of the total cumulative funds needed for PV installations expected in the year 2050 in Singapore. This study enriches the existing studies on solar financing and provides references for policy makers, academics and industry practitioners interested in SCF.

Keywords: PV; crowdfunding; solar power; renewable energy; financing; Singapore

1. Introduction

Growing environmental concerns have motivated policy makers to propose incentives and plans to diversify their energy portfolio by shifting from the dominant use of non-renewable to renewable energy. Many countries have also been supporting the use of these technologies by providing public

Abbreviations: PV, Photovoltaics; SCF, Solar Crowdfunding; HDB, Housing and Development Board; FiTs, Feed-in tariffs; MAS, Monetary Authority of Singapore; BAS, baseline scenario; ACC, accelerated scenario.

[*] Corresponding author, Tel: +65 97758896
E-mail addresses: rchang@bond.edu.au (R. Chang)

financing and subsidies [1-3]. Hence, significant progress in the development of renewable energy in terms of production and consumption has made the industry prominent in recent years [4,5].

Among the various renewable technologies, photovoltaics are the most popular, followed by the wind and to a much lesser extent biomass and hydropower [6]. Solar photovoltaics (PV) technology is the conversion of sunlight into energy without the use of mechanics and does not produce environmental emissions. Hence, it has been recognized as a clean and renewable energy source with huge potential. An increasing number of countries has tried to promote the use of this energy source within their borders. Solar PV adoption has grown significantly in the year 2014, whereby an estimated amount of 40 GW of solar PV was installed among the total global energy capacity of 117 GW. The majority of new adoptions came from countries like Japan, China, and the United States, with Latin America, Africa and the Middle East experiencing growth in the solar PV market as well [7].

In Singapore, due to various constraints, other renewable energy sources including geothermal energy, hydroelectric power, or wind energy does not hold as much potential as compared to solar PV technology [1]. Fig.1 illustrates the annual installed capacity and the cumulative installed PV capacity in Singapore from 2009 to 2015. In 2014, the Singapore government announced the plans to increase the amount of solar energy adopted by governmental agencies. The target was to hit 350 MWp by 2020, which would amount to 5% of the forecasted electricity demand in Singapore [8]. As such, several initiatives have been set up by Singapore, including solar test bedding to be conducted by the Housing and Development Board (HDB) to gather technical knowledge on the installation of extensive solar systems in its precincts [9], and the SolarNova Singapore program launched to assist in the coordination and the collation of demands for solar PV adoption across the Government buildings involved [10]. It has been discovered that HDB buildings in Singapore have good PV integration potentials [11].

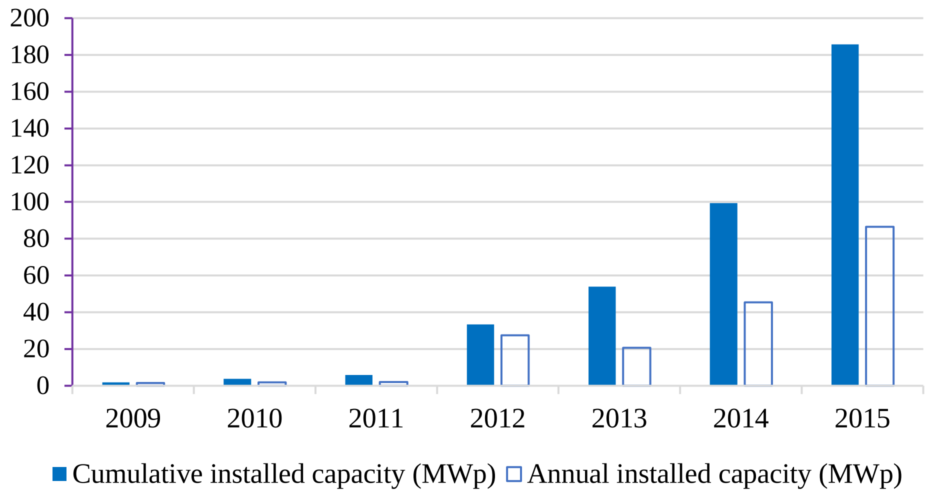

Fig.1. Annual and cumulative installed capacity for solar PV electricity in Singapore (2009-2015) [12]

The downside to this technology, however, lies in the fact that its cost has been less competitive as compared to other electricity generation options [13]. Traditionally, Solar PV projects have been driven significantly by policy support such as PV Feed-in Tariffs (FiTs) provided by governments [7]. As such, studies have been made to determine if alternative solar financing methods such as Power Purchase Agreements (PPA), Solar Leasing, Crowdfunding or other hybrid models that leverage on private capital are feasible compared to the traditional PV FiTs. Alternative solar financing methods have been established over recent years. One relatively new solar financing method that has seldom been studied is Solar Crowdfunding (SCF). Several studies have been conducted on crowdfunding for other applications of renewable energy. For instance, based on qualitative methods, Dilger [14] explored the potential of crowdfunding for the business model of energy cooperatives, indicating that although most cooperatives are not familiar with crowdfunding, the potential exists for crowdfunding to support energy cooperatives, especially the equity-based crowdfunding. Zhu et al. [15] developed a game model to investigate the potential of crowdfunding in supporting the construction of charging piles for electric vehicle (EV). Similarly, Zhang et al. [16] employed the SWOT analysis to examine the potential of using crowdfunding to support the development of distributed PV water pumping systems in China. However, there are few studies specifically investigating crowdfunding for solar PV.

More importantly, even though the studies above contribute to the understanding of crowdfunding in the energy-related area, there are few quantitative studies on crowdfunding. The several available quantitative studies on crowdfunding mostly utilize data from crowdfunding platforms, with few studies forecasting the development potential of crowdfunding [17,18]. It has been argued that more research on the mechanisms, including the potential factors influencing the success of crowdfunding campaigns is urgently needed [19]. It seems that although millions of crowdfunding investors have generated over a billion dollars in crowdfunding investments and donations [20], there is still lack of the academic knowledge in the dynamics of successful crowdfunding, [21] the potential of crowdfunding, and specifically the crowdfunding for solar PV, namely SCF.

To respond to the above gaps of knowledge, this study aims to review the concepts and various models of solar crowdfunding in general and propose a system dynamics model to simulate the potential of SCF by taking Singapore as an example. The focus of this study is to explore the various factors that impact the success of solar crowdfunding and create a system dynamics model that would not only show the causal relationships between the various impacting factors, but also could predict the development potential of solar crowdfunding. By doing so, this study contributes to the policy-making of financing for solar PV.

2. Solar crowdfunding

2.1 Crowdfunding concept and development

Governments across the globe have been offering incentives to encourage solar installations on private properties. For instance, the Non-business Energy Property Tax Credit [22] offering incentives of 10% of the cost up to US$500 or a specific amount from $50-$300 for an existing home is just one of the many schemes provided by the US government. Table 1 below summarizes the various financing models supporting solar systems in buildings [23].

Table 1. A review of solar financing methods

Solar Financing Method	Description	Advantages
Municipalities / Local Government	• A government funds solar project where the source of funds come from government bonds • Government funds solar developer through funds gathered from government bonds. Solar developer design, install and operate the system and sell the electricity produced to the government through a solar power purchase agreement	• Low cost, longer repayment period, no upfront cost • Low cost, no upfront cost, no operation & maintenance costs of solar systems for site hosts
Third Party Ownership: Solar Leasing / Solar PPAs	• Solar developer buys and installs solar PV system. The solar lessee does not pay the upfront cost but pay fixed monthly installments over a specific period (typically 15 – 20 years) to consume the electricity generated	• Reduction or elimination of upfront cost, reduction of technological risk, and elimination of maintenance cost
Utility-Sponsored Model	• Utility company install and maintain solar PV and sell electricity to consumers	• Low-cost capital due to economies of scale • Lower transaction costs as customers pay through utility bill • Grid integration benefits based on an assessment of good and more efficient sites to install solar
Volume purchase	• Homeowners around a neighborhood come together to install solar PV as a community	• Economies of scale (higher discounts) • Increased willingness due to joint decision making
Solar Crowdfunding	• Funds for solar installation raised by individual investors through a platform	• Individual investors are independent of financial market conditions • Useful for small projects that cannot attain bank loans • Low-cost capital

Among the above financing approaches, solar crowdfunding has received increasing attention. In recent years, crowdfunding has emerged as a new and non-traditional way for securing funds without having to seek out traditional sources of investment [21]. Crowdfunding refers to the effort made by individuals or groups to generate funds for their projects by collecting small contributions from a large group of individuals through the use of the internet, and without the intervention of financial intermediaries [21]. In other words, crowdfunding users tap the crowd by raising money directly from individuals [24], usually through the use of the Internet. It involves two-sided market dynamics where the crowdfunding platform essentially brings together two different but interrelated groups of customers [25]. The platform could be in various forms such as the website or even an intermediary or broker who could connect the investors with the investees [26].

Traditional forms of crowdfunding may involve the sourcing of funds from known and related investors such as family members, communities, and friends [27]. Technological advancements have brought forth web-based crowdfunding which reaches out to a vast number of unrelated investors through the Internet [30]. As more and more crowdfunding platforms emerge, various types of campaigns also emerge. Some will only release funds to the campaigners if the targeted funding amount is reached while others would release the funds to the campaigner even if the funding target is not met [31].

The study [32] offered a systematic timeline for crowdfunding projects, including 1) the pre-crowdfunding period, where the campaigner identifies a source of financing, selects a crowdfunding platform, and sets his targeted amount for the campaign; 2) the crowdfunding period, where investors will invest in the project within the set time-frame, and once the targeted amount is reached, or when the time frame is over, the platform will distribute the contracts between the campaigner and the crowd; and 3) the post-crowdfunding period where the campaigner uses the money to fund his project, and the platform continue to facilitate the distribution of financial reward to the investors.

With the uprising of technology and social media, the potential power of the public has become more prevalent, contributing to the birth of non-conventional financing methods such as crowdfunding. Crowdfunding has several significant differences as opposed to other existing financial mechanisms. Firstly, crowdfunding is not limited by geographical and relational constraints as the internet could be accessed to almost a third of the world's population [27]. The use of internet platforms reduces transaction costs and significantly extend the scope of investors, enabling much more people to participate in the financing process [33,34]. Secondly, in conventional financing, a small number of professional investors such as banks contribute large amounts to the projects, while in crowdfunding, a large number of individuals contribute small amounts individually but collectively are capable of financing both small and large projects [35]. Therefore, crowdfunding has exceptional accessibility to investors with less administrative requirements and could finance very small projects which would normally be neglected by traditional investors such as banks. Furthermore, by involving local communities in the funding process, crowdfunding is suitable for projects which bring not only economic benefits but also social and environmental values [36], and thus it helps to tackle the issue of "not in my backyard" [37]. By linking crowdfunding with the user innovation phenomenon, the study [38] indicates that crowdfunding platforms may give rise to the more widespread occurrence of user entrepreneurs. Crowdfunding has been therefore argued as a positive financial instrument for developing renewable energy [39-41].

Crowdfunding campaigns may range from inventions and entrepreneurial ventures to renewable energy installation and charity work. As the popularity of crowdfunding increased, many entities started to initiate new campaigns to either release a new product or create awareness and expand into new markets. For instance, loan-based crowdfunding has been used to install microgrids for communities in Kenya to allow them access to energy [7]. The development of crowdfunding has been increasing over the years, from US$53 million in 2010 to over US$16 billion in 2014 as shown in Fig. 2.

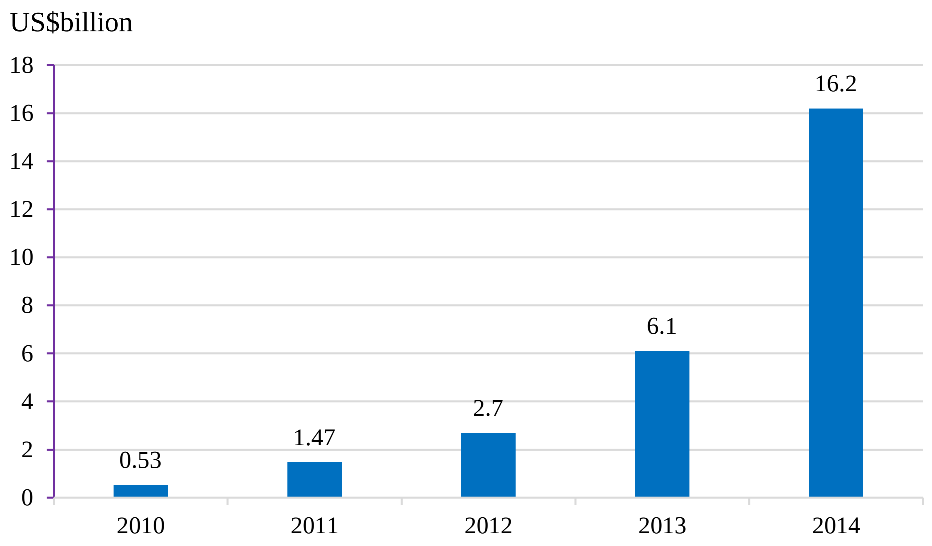

Fig. 2. Crowdfunding volume worldwide in (US$) billion [42]

2.2 Crowdfunding models and the renewable energy sector

Crowdfunding models available in the market range from donation (non-financial) crowdfunding, and investment (financial) crowdfunding, that raises capital by selling financial instruments, as shown in Table 2 [27,43].

The basic features of non-financial and financial crowdfunding are as follows:

- Non-financial crowdfunding relies on funders who do not expect financial returns [44]. One example of this model is civic crowdfunding whereby citizen's contributions fund public works or service for the community. For instance, Philadelphia city raised 12,875 US$ to plant 15,000 trees, and Rotterdam raised funds to build a wooden pedestrian bridge which length is based on the amount funded, with the Louvre raising 1 million US$ from more than 2700 donations to buy a painting by Lucas Cranach [6].
- Financial crowdfunding, on the other hand, includes models such as lending-based, equity-based, and royalty-based crowdfunding [45]. The World Bank’s study on crowdfunding illustrates the different crowdfunding models and their features, as shown in Table 2.

Table 2. Characteristics of different crowdfunding models

Crowdfunding model	Business model	Features	Advantages	Disadvantages
Non-financial	Donation-based	• Philanthropic contributions without expectations of monetary returns	• No risk	• Donors do not acquire security interest. Difficult to raise substantial capital for campaigns
	Reward-based	• Funders would receive a token of appreciation or pre-purchase the product or service. Firms raise money through pre-sales	• Low risk, however, exposed to fraud risk. Campaigners do not need to provide financial returns	• Small potential return, no security, hence no accountability. Difficult to raise substantial capital if the product does not appeal to masses
Financial	Equity-based	• Investors would receive equity instruments or profit sharing arrangements	• Potential for sharing profitability of the venture. Unlimited potential for funding, and may attract a large number of investors	• The potential loss of investment. Equity holders will be repaid later than creditors in events of bankruptcy. Securities related laws for crowdfunding may be complicated
	Lending-based	• Investors receive a debt instrument that promises periodic repayment of principal on a fixed interest rate	• The pre-determined rate of returns. Debt holder will be repaid first before equity holders in events of bankruptcy. Secured status makes it easier for campaigners to raise funds	• The crowdfunding investors may be subordinated to the senior creditors. Start-up failure risk is similar to equity investments, but with a capped potential return
	Royalty-based	• Investors are given a share in the intellectual property and paid a royalty interest in the intellectual property. The pay-out varies depending on the revenue in that period	• Unlimited potential gain, although the rate of gain is predetermined. Less risky as compared to equity-based crowdfunding, but riskier than lending-based crowdfunding	• The potential loss in investment is comparable to equity-based investments, although investment promises fewer returns as compared to equity-based crowdfunding. The business could stop paying royalties if it chooses not to use the intellectual property

[27]

Fig.3 below gives an overview of the crowd-funded amount gathered by the different crowdfunding models available in the market over the last few years, with the lending-based model being the most popular and the one with the highest growth rate. Table 3 lists the top crowdfunding platforms focused on renewable energy projects.

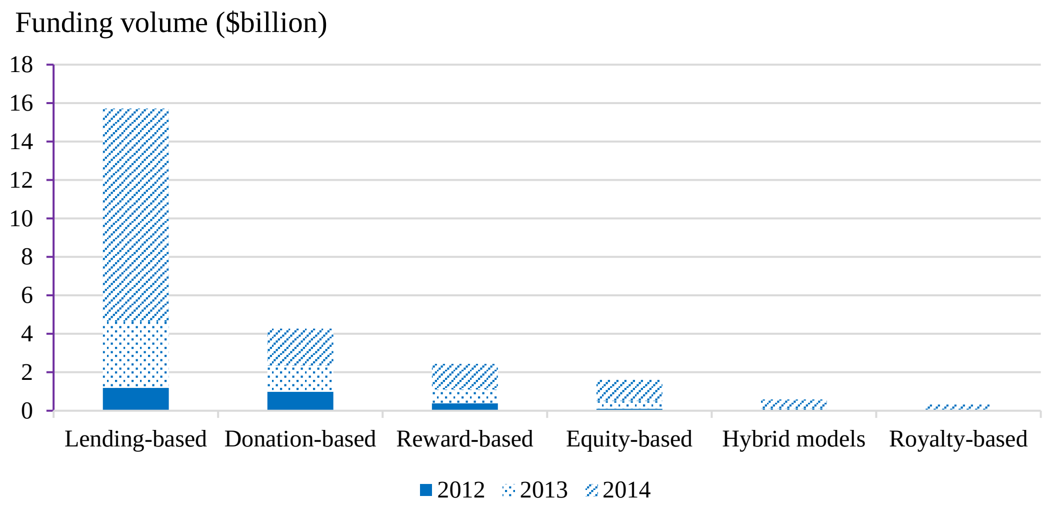

Fig.3 Funding volumes by crowdfunding model (US$) billion [6]

Table 3 Top crowdfunding platforms focused on renewable energy projects

Country	Platform	Start year	Amount raised (US$)
UK	TrillionFund	2011	$122,020,183
UK	Abundance	2009	$18,537,748
NL	Windcentrale	2010	$17,535,000
US	Village Power	2014	$5,377,400
DE	Econeers	2013	$4,792,900
DE	LeihDeinerUmweltGeld	2013	$4,676,000
NL	Duurzaam Investeren	2014	$3,390,100
UK	Microgenius	2011	$2,489,970
NL	GreenCrowd	2012	$2,143,478
DE	Bettervest	2013	$1,987,300
NL	WeShareSolar	2012	$1,987,300
DE	Greenvesting	2009	$1,145,620
FR	Lendosphere	2014	$1,133,930
UK	Solar Schools	2013	$860,576
US	SunFunder	2011	$511,438
PT	Coopernico	2013	$382,263
US	Collective Sun	2014	$382,007
DE	greenXmoney	2014	$363,559
FR	Lumo	2012	$233,800
US	Re-Volv Solar Seed Fund	2011	$130,631
US	Divvy Green	2014	$13,444
FR	Enerfip	2015	$9,235
US	Cleanreach	2014	$6,991
US	Mosaic	2013	NA

[49]

Data from the Indiegogo platform, a US-based crowdfunding platform, indicates that countries with low-level individualism and high oil price are suitable for developing clean-tech crowdfunding [46]. As a very new area of study, crowdfunding of renewable energy has received very little attention from existing studies [46]. Crowdfunding is regarded as a potential instrument that could support renewable energy projects to address climate change [14,28,47]. For instance, aiming at making solar panels for road and path-construction ready, the project of Solar Roadway funded US 2.2 million from 48473 supporters [48]. As shown in Table 3, the top crowdfunding platform focusing on renewable energy projects emerged around 2010, with the TrillionFund raising more than US$ 100 Million. This shows the potential of crowdfunding for renewable energy.

2.3 Stakeholders of Solar Crowdfunding in Singapore

As this study focuses on a specific genre, solar crowdfunding, not all the crowdfunding models discussed above are applicable for solar projects. Royalty-based crowdfunding and rewards-based crowdfunding have seldom been used for solar projects by the crowdfunding platforms. By contrast, lending and equity-based crowdfunding are the mainstream approaches for financing distributed solar systems in the crowdfunding platforms. Therefore, only lending and equity-based crowdfunding are explored in this study, with Fig.4 below illustrating the different parties involved in SCF.

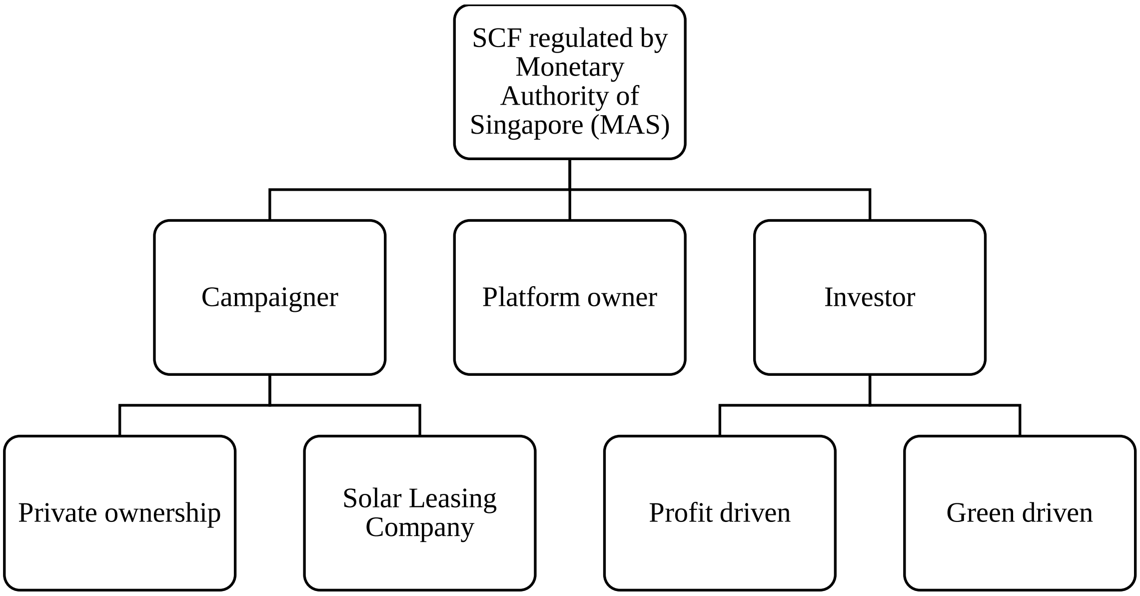

Fig.4. Parties Involved in SCF

- Monetary Authority of Singapore (MAS) regulates the stakeholder network involved in SCF. All crowdfunding platforms, including SCF platforms, must be licensed by MAS to operate in Singapore. It is required by MAS that crowdfunding owners must ensure proper segregation of investors' investments and keep proper records of transactions [50]. If a licensed platform owner breached the rules of MAS, various interventions would be taken including enhanced audits or even the revocation of the license [50]. It is also required by MAS that platform owners need to disclosure key risks of investments to investors, who are encouraged to read and understand the risks. However, similar to any other investments, investors in crowdfunding bear responsibility for their decisions.

- The platform owner refers to the party who acts as the intermediary bringing the campaigner and investors together usually through the means of the internet. The platform owner would be the one governing the features of the crowdfunding website and ensuring the ease of access to the website for all parties. The platform owner charges a platform cost from the successfully-funded projects.
- The campaigner is the party who seeks the funds for his/her projects. These campaigners may be owners of the solar PV system or solar leasing companies who seek to finance for their solar projects. These campaigners may be regarded as the main source of incoming projects that are placed on the crowdfunding platform. Without them, the platform will not be successful due to the lack of projects that contribute to the system. The attractiveness of SCF when compared to other competing methods of solar financing would affect the campaigner's decision on whether to adopt SCF as their financing method.
- The investor, on the other hand, is the party who provides the funds needed for each project. Two vastly different factors may drive SCF investors. The first would be green driven, that is, as solar projects contribute to a more green and sustainable world by providing clean energy, investors who are environmental-centered may choose to put their investment in a project that serves to protect the environment in the long run. Another type of investors is the profit-driven investors, who seek financial returns on their investment. Hence, these investors may choose SCF as their choice of investment if it is more profitable than a comparable investment such as government bonds or stocks.

Regarding the type of campaigners, a private owner is one who owns the solar PV system and also directly uses the energy generated from the system. According to the Year Book of Statistics 2015 [51], Private residential properties of detached, semi-detached, and terrace houses amount to over 71,000 units in 2014. These units would be the potential solar adopters in Singapore. Out of this pool of solar adopters, some would self-fund their projects; others would choose to take loans from banks or other financial vehicles such as SCF.

If the homeowners do not want to own the solar PV system privately, they may choose to engage a solar leasing company to install and maintain the system, while billing them the electricity cost at the end of each month based on their usage. A solar leasing company is one that owns various solar PV systems around the country and earns revenue from the sale of electricity to consumers. The HDB has initiated the Solar Nova project in June 2015 [52] in which the solar leasing company may choose to place a part of their solar projects on SCF platforms as an alternative source of financing. Table 4 below shows the different SCF models and processes that are applicable to the two types of campaigners.

Regarding the investors, crowdfunding investors are motivated by various reasons, including rewards or monetary returns, supporting a cause, being part of a community and helping others [53-55].

Other reasons include financial value, social value, emotional value and personal utility that drives participation [56]. These factors could be summarized into two main categories, namely profit-related factors, and green-related factors, leading to the profit-driven investors and green driven investors [24].

Profit-driven investors are those who are motivated by financial rewards from the investment. That is, the financial value that this investment entails. These investors would look at various investment opportunities, calculate the profits and opportunity costs, determine the profitability of the various options, and then decide whether or not to invest in SCF. Green driven investors, on the other hand, may not look that closely at the financial rewards. Rather, they would consider factors such as the type of project, in this case, a solar project, and how it helps people or the environment, taking into account the social value, emotional value, and personal utility.

After identifying these various stakeholders and the processes of solar crowdfunding in Singapore, a model for forecasting the development of solar crowdfunding could be established, which is explained in the following section.

Table 4 Applicable SCF Models for Different Campaigners

<table>
<tr><th colspan="2" rowspan="2">Model / Process</th><th colspan="2">Campaigner</th></tr>
<tr><th>Private Ownership</th><th>Solar Leasing Company</th></tr>
<tr><td rowspan="5">Loan-based SCF</td><td>Campaigns</td><td colspan="2">• Owner / Solar Leasing Companies place project on SCF platform to attain loans required for solar PV installation</td></tr>
<tr><td>Acquiring Funds</td><td colspan="2">• Investors loan money to the owner through SCF platform</td></tr>
<tr><td>Utilizing Funds</td><td colspan="2">• Owners / Solar Leasing Company use funds collected from SCF to install the solar PV system</td></tr>
<tr><td>Business Contract</td><td>• Not applicable</td><td>• Solar company signs a contract with building occupants to lease the solar PV system or sell the electricity generated by the system to them at a discounted rate</td></tr>
<tr><td>Loan Repayment</td><td>• Savings on owner’s electricity will be used to repay the loan (over the agreed number of years/period)</td><td>• Revenue generated from solar leasing or sale of electricity will be used to repay the loan (over the agreed number of years/period)</td></tr>
<tr><td rowspan="6">Equity-based SCF</td><td>Initial Investment</td><td colspan="2">• Owner of the building / Solar Leasing Company would purchase and install the system</td></tr>
<tr><td>Campaigns</td><td colspan="2">• Owners / Solar Leasing Company places the project on SCF platform for equity-crowdfunding</td></tr>
<tr><td>Transfer of Ownership</td><td colspan="2">• Investors who invest in campaign become owners of the Solar PV system and will pay for the installation, maintenance and all other costs of Solar PV system</td></tr>
<tr><td>Re-investment</td><td>• Not applicable</td><td>• Solar Leasing Company uses the amount collected from the crowdfunding to make other investments or build other solar PV systems</td></tr>
<tr><td>Business Contract</td><td colspan="2">• Investors sign a solar leasing agreement or sell the electricity to the building occupant at a discounted rate</td></tr>
<tr><td>Returns on Investment</td><td colspan="2">• Revenue from solar leasing/sale of electricity will become their returns on investment</td></tr>
</table>

3. Methodology

3.1 Concepts of system dynamics

The simulation model proposed in this study is developed based on system dynamics, a method developed by Jay Forrester in the 1960s to examine complex systems [57]. System dynamics is typically used to understand the effects of policies ranging from public policies to business policies [58]. It could produce reliable forecasts of trends based on the understanding of market behavior [59]. The system dynamics model has been used in numerous domains, such as project planning and control [60,61], the national energy policy in the US [62], intervention policies for urban transport system in China [63], waste management systems to forecast municipal solid waste in Berlin [64], sustainable management of urban water distribution networks [65], knowledge management [66,67], sustainability performance assessment and projections of various systems such as infrastructure projects [17,68-73] and supply chain management systems [74,75]. Solar crowdfunding is a complicated process involved with various stakeholders interacting with each other. As a well-established methodology, system dynamics aim to model systems of high complexity through the use of causal loop diagrams and stock-loop diagrams [76]. Hence, system dynamics is a useful tool to explore the overall dynamics of the industry, a market, or any other complex systems.

To forecast the potential of solar crowdfunding in Singapore, this study adopts system dynamics to map the causal links and relationships between different factors that affect solar crowdfunding, thereby generating a model holistically representing the SCF market. This model of the SCF marketplace would then be used to simulate the potential of SCF in Singapore. The model establishment process begins with the formation of a causal loop diagram to first showcase the causal relationships between the factors affecting SCF. The causal loop diagram could portray a clear picture of causal relationships between the factors affecting SCF. It is, however, unable to carry out a quantitative simulation of the potential of SCF. Therefore, the stock and flow diagram was then constructed with the assignment of mathematical equations to individual factors so that the potential of SCF can be simulated. The causal loop diagram abstracts the feedback loops of the systems which determine the behaviors of the systems, while the stock-loop diagram is developed based on the causal loop diagram for quantitative simulation and analysis. Detailed guidelines on how to construct an SD model could be found in [77].

3.2 Causal Loop Diagram

In order to create a model that can simulate the potential of the SCF market, this study adopts a holistic perspective of SCF covering the determination of the potential SCF users, the adoption of SCF as a financing method, and the success of the SCF campaigns. The developed causal loop diagram is shown in Fig. 5.

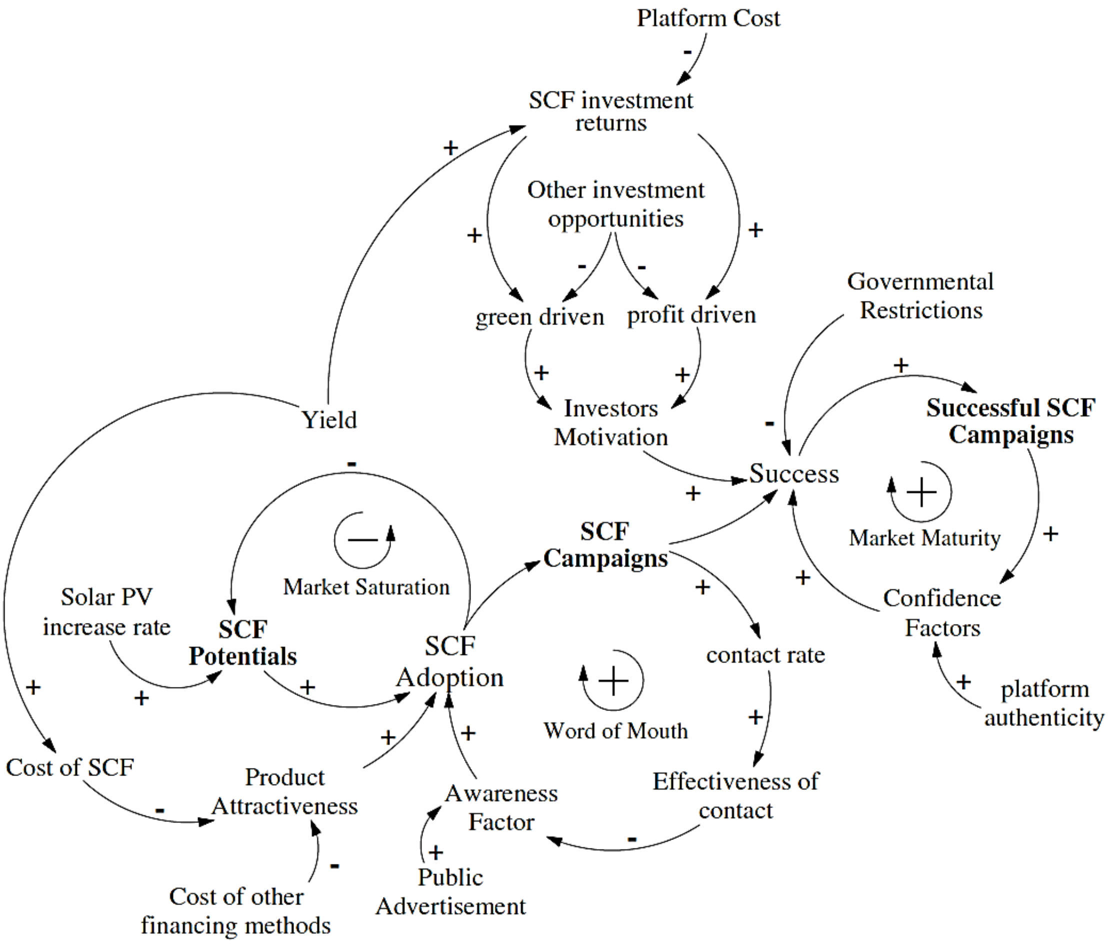

Fig. 5. Causal Loop Diagram (CLD)

Regarding the stage of determining the potential SCF users, the potentials refer to the total number of solar projects which have yet to adopt any form of solar financing. These solar projects have a choice to choose SCF as their financing vehicle, or other forms of solar financing methods. This pool of potentials could be forecasted based on the rate of increase in the solar adoption. A market saturation feedback loop is present in this diagram, which represents the occurrence of market saturation where the potential SCF adopters decrease as a result of more projects adopting SCF.

At the stage of adopting SCF, a part of the potentials will choose to adopt SCF as their financing vehicle. Hence, after determining the potentials, the model examines factors that could affect the decision of this group of SCF potentials. The factors include the awareness of SCF and the attractiveness of SCF. The SCF adoption is primarily dependent on the knowledge of SCF. This knowledge is associated with the awareness of SCF, which could start off low as only a small percentage of people would be familiar with SCF. Nonetheless, as more people become aware of SCF through public advertisement, the word of mouth loop is formed. Illustrated in Fig. 5, when there are more adopters, the number of SCF campaigns increase, and as the number of campaigns increase, there would be more people that will be aware of SCF, who would tell others about it, hence increasing awareness through the word of mouth loop.

All the projects that have become SCF campaigns will be those who have chosen to use SCF as their financing vehicle after giving consideration to the factors in the preceding stage. The adopters become SCF campaigners as they place their projects on the SCF platform to campaign for funds. Historically, not all crowdfunding campaigns are successfully funded. Some may not reach their funding targets as investors decide not to fund their campaigns. The factors affecting the decision of investors which determines the success of the SCF campaigns are considered in the model, including the investors' motivation, confidence factors, as well as governmental restrictions.

3.3 Stock and Flow Diagram

Following the three-stage process, the model consists of three stocks, namely SCF Potentials, SCF Campaigns, and SCF Funded as shown in Fig. 6. The SCF Campaign stock will start with the [SCF Adoption] variable, which provides for a number of adoptions for each year. This stock is subsequently split into successful campaigns and unsuccessful campaigns. The unsuccessful campaigns will go into a sink fund while the successful campaigns would be transferred into the SCF Funded stock via the success rate. The SCF Funded stock will then accumulate the number of successful campaigns throughout the years and show the cumulative success of SCF. The SCF Funded can then be compared to the overall kW of solar PV systems that are expected to be installed over the same period, to determine the overall percentage of solar PV installed that is funded by SCF. The data was collected from various sources and literature. This model adopts the 3-stage development of solar power in Singapore suggested by the Solar Roadmap, which includes short-term (2016 to 2020); mid-term (2021 to 2030); and long-term (2031 to 2050). A 35-year projection was set in the model, with the first year being 2016.

Before conducting the quantitative simulation, the validity of the system dynamics model should be examined. Following the guidance of [77], the validity of the model in this study was examined through four steps, including (1) the causal loop diagram describing the solar crowdfunding process in Singapore must contain all important factors that correspond to the research aims; (2) the equations in the stock-flow diagram must match with the causal loop diagram; (3) the model must be dimensionally consistent; and (4) the model should be tested under extreme conditions. The causal loop diagram is developed based on the literature and Singapore context reviewed in the previous sections, and by checking all the factors in the causal loop diagram, it was confirmed that each factor is necessary to model the solar crowdfunding. In this study, the equations in the stock-flow diagram are developed based on each feedback loop and contain all the factors in the causal loop diagram, and thus match the causal loop diagram. To confirm the model is dimensionally consistent, the 'units check' function of the Vensim software was used which confirms all measurement units of the variables. The extreme condition tests should be performed to alter the values of some important variables to examine the changing behavior of the systems [78]. It was found that the model presents logical behaviors under extreme conditions. The above tests confirm the validity of the developed model for simulating solar crowdfunding in Singapore.

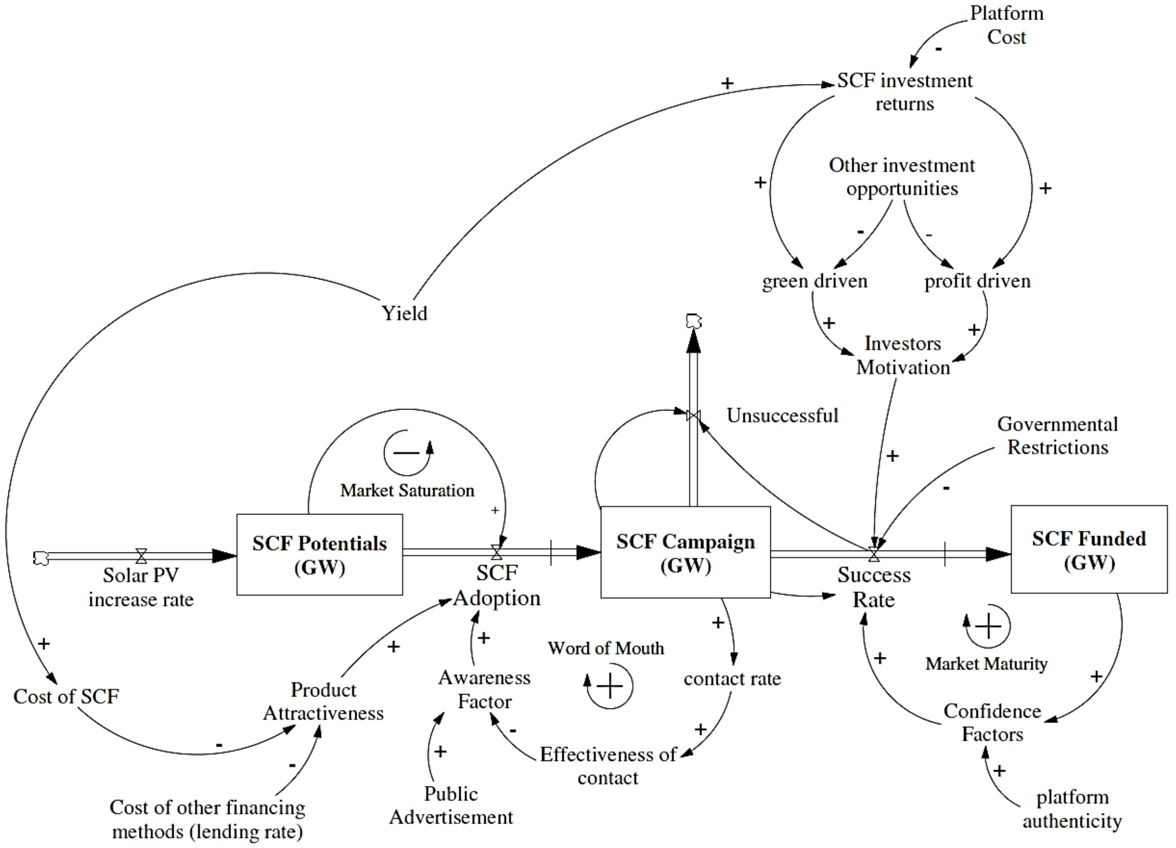

Fig. 6. Stock and Flow Diagram

4. Results and discussion

4.1 Impacts of solar development speed on solar crowdfunding

In Singapore, the future cumulative solar PV has been studied by Solar Energy Research Institute of Singapore in the Solar Photovoltaics Roadmap of Singapore [79]. The forecast considers three factors, namely area efficiency, expected technological advancements, and space constraints in Singapore. The solar roadmap [79] investigates two scenarios, namely the Baseline Scenario (BAS) and the Accelerated Scenario (ACC). Based on these two scenarios, two sets of data were generated with different solar increase rates in the solar roadmap, as shown in Table 5. Table 6 presents the forecasted solar PV installation in the two scenarios.

Table 5. Solar growth rates per year of the two scenarios

Period	BAS	ACC
2016 to 2020	68.5%	75.5%
2020 to 2030	16.53%	16.09%
2030 to 2050	2.59%	4.69%

Table 6. Solar PV installation (GWp) of the two scenarios

Year	BAS	ACC
2012	0.01	0.01
2020	0.65	0.9
2030	3	4
2050	5	10

Fig. 7. shows the differences between the SCF potentials simulated in the two scenarios of BAS and ACC. It shows that the SCF potentials follow similar trend during the short-term, mid-term and long-term segments at years 1 to 5, 6 to 15, and 16 to 35 respectively.

- In the short-term segment, the curve in both scenarios started off at different points in year 1, but was relatively close together, albeit the higher increase rate in the ACC scenario. In year 1, the ACC scenario had a 17.7% higher potential than the BAS scenario, and that percentage difference continued to increase over the span of the short-term segment. By year 5, the ACC scenario had 38.8% more SCF potentials as compared to the BAS scenario.
- The mid-term segment shows a relatively similar increase between the two scenarios with the ACC curve having an average of 36.2% higher potentials as compared to the BAS scenario. It is also worth noting that the difference between the BAS and ACC scenario in the mid-term segment was on a constant decrease from 38.8% in year 5 to 33.5% in year 15, giving a total of 5.3% decrease in the percentage difference by the end of the mid-term segment. Nevertheless, the ACC scenario continues to have a higher potential than the BAS.
- In the long-term segment, however, the ACC scenario started to have an increased percentage difference when compared to the BAS scenario, with a 35.8% difference in year 16 compared to the 33.0% difference in year 15. This increasing percentage difference subsequently continued over the course of the long-term segment and ended with the ACC scenario becoming approximately twice the amount of potentials when compared to the BAS scenario.

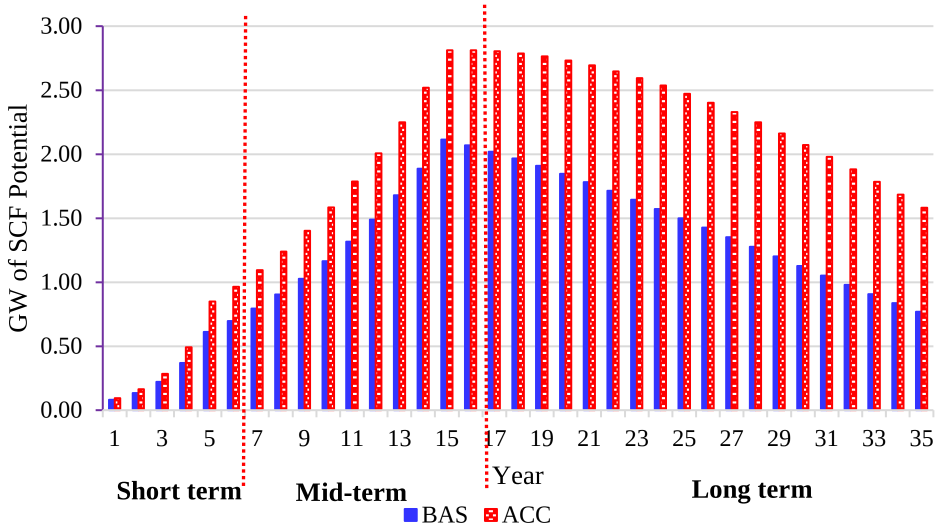

Fig. 7. A comparison between the SCF potentials (GW) over a 35-year period for the BAS & ACC scenario

Fig. 8. shows the difference between the simulated amount of SCF campaigns in the BAS and ACC scenarios. Both the BAS and the ACC curve seems to follow the same trend in the short and mid-term segments. However, the ACC shows a longer increasing trend in the long term as compared to the BAS scenario which plateaued and decreased in the long term. The BAS scenario has a shorter period of increase, and by year 23, the BAS curve starts on a decreasing trend. In year 2, the BAS scenario had 2.03 MW of solar campaigns while the ACC scenario had 2.39 MW of solar campaigns that adopted SCF as their financing method. At year 35, the BAS scenario had 89.2 MW of campaigns while the ACC scenario had 179.5 MW of campaigns, which is about double the BAS scenario.

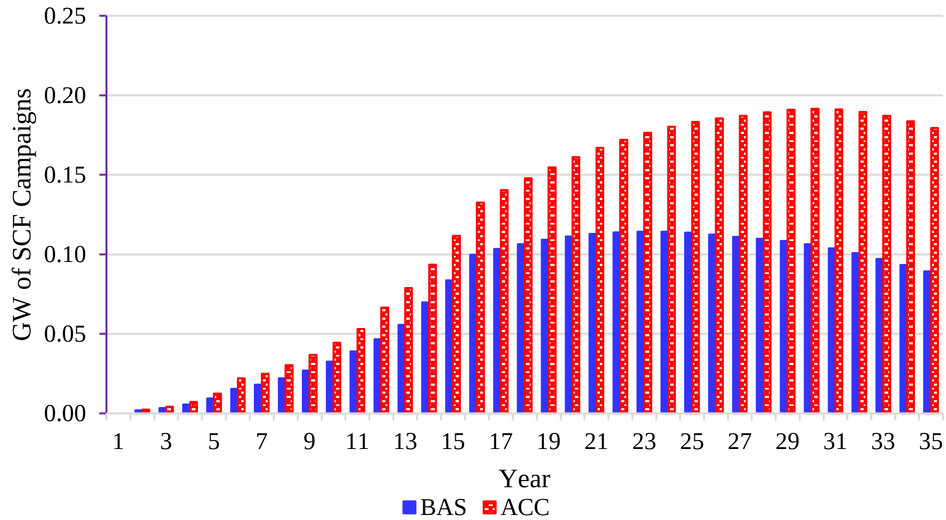

Fig. 8. A comparison between the simulated SCF Campaigns per year (GW) over a 35-year period for the BAS & ACC scenario

Fig. 9 shows the number of successful SCF campaigns that were funded via SCF per year, while Fig. 10 shows the cumulative number of successful SCF campaigns of the BAS and ACC scenarios. At year 3, the ACC scenario had 223.7 kW funded while the BAS scenario had 190.1 kW funded. The cumulative amount at the end of year 35 was 295.7 MW for ACC, and 189.6MW for the BAS scenario. Hence, if the ACC scenario happens in the year 2050, where the solar installation is forecasted to be 10 GW [79], 2.96% of the total solar projects in Singapore will be financed by SCF as compared to the 3.79% in the BAS scenario. Nonetheless, even though the ACC scenario only provides funds for the 2.96% of Singapore's solar projects, it would still have funded 106.1 MW more solar projects than that of the BAS scenario.

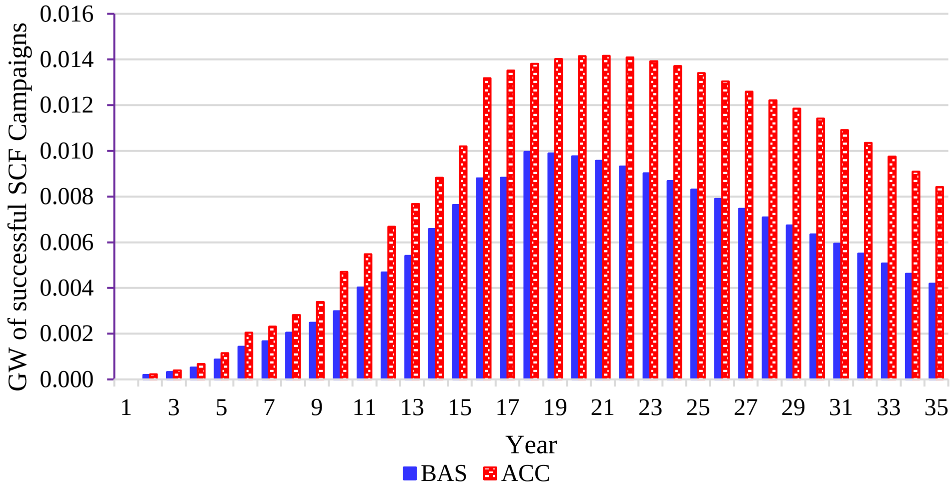

Fig. 9. A comparison between the Successful Campaigns per year (GW) over a 35-year period for the BAS & ACC scenario

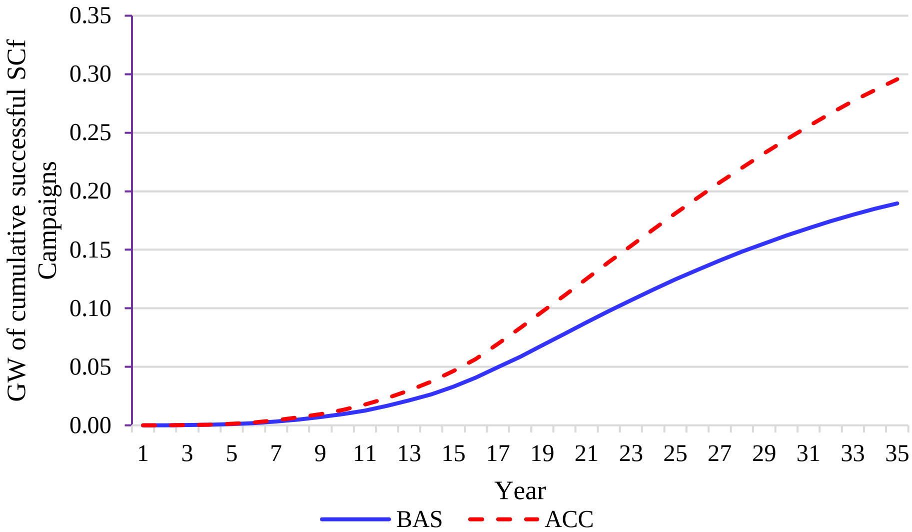

Fig. 10. A comparison between the Cumulative Successful Campaigns (GW) over a 35-year period for the BAS & ACC scenario

Based on the study by Solar Energy Research Institute of Singapore [79], the prices of PV in the BAS scenario is US$1.07, US$0.88, and US$0.74 in 2020, 2030, and 2050 respectively (USD/Wp) and the price of PV in the ACC model is US$0.99, US$0.81, and US$0.66 in 2020, 2030, and 2050 respectively (USD/Wp). Based on these values, the cumulative amount generated by SCF in the two scenarios is calculated as shown in Fig. 11, with the ACC increasing at a much higher pace as compared to the BAS scenario. However, due to the price difference at each period, the tail ends of the two curves in Fig. 11 shows a slight plateau.

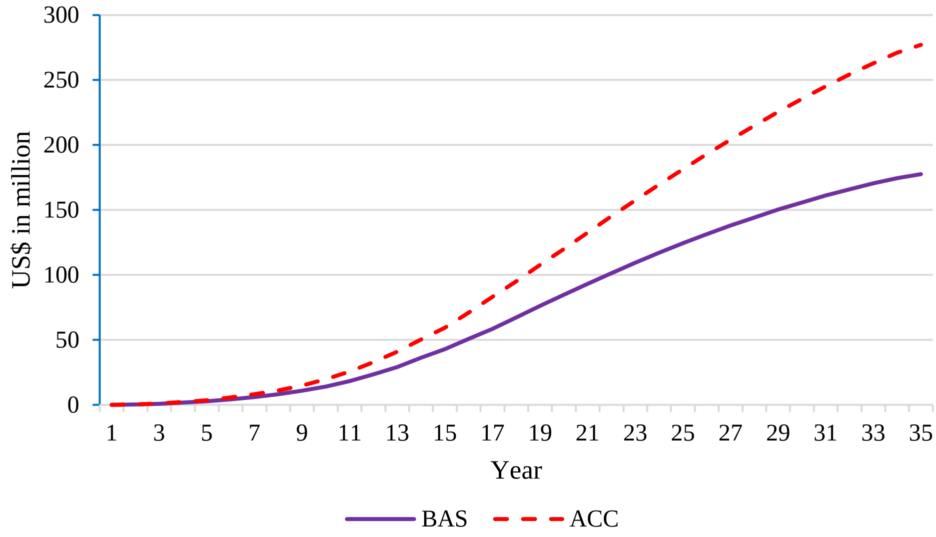

Fig. 11. A comparison between the cumulative amount generated (in US$) over a 35-year period for the BAS & ACC scenario

Table 7 Funding collected from solar crowdfunding in the BAS and ACC scenario

Results	*Scenario*	*Short Term (Year 1-5)*	*Mid-Term (Year 6-15)*	*Long Term (Year 16-35)*
Cumulative amount required (US$)	BAS	$667,935,746	$3,333,320,999	$5,462,702,150
	ACC	$888,127,250	$4,023,168,088	$9,753,554,113
Cumulative amount collected (US$)	BAS	$2,702,832	$42,906,338	$177,571,581
	ACC	$3,442,913	$59,386,146	$277,119,477
% of total funds needed	BAS	0.405%	1.29%	3.25%
	ACC	0.388%	1.48%	2.84%

Based on the 5GW and 10GW solar potential for the BAS and ACC scenarios respectively shown in Table 6, Singapore's solar projects would need approximately US$5,463 million for the BAS scenario and US$9,753 million for the ACC scenario to finance the solar installation. Based on this simulation, crowdfunding in the ACC scenario will generate about 2.84% as compared to the 3.25% of the required solar installation cost in the BAS scenario. Table 7 gives a summary of the funds collected from solar crowdfunding in the various periods for both the BAS and the ACC scenario.

4.2 Impacts of platform cost distribution on solar crowdfunding

In the BAS scenario, the platform cost is purely distributed to the investors, which is a common approach adopted by existing crowdfunding platforms. The different distribution arrangements of platform cost could impact on the potential and success of SCF, which should be investigated. This section analyzes three scenarios, namely the Investors (BAS) scenario, whereby the platform fee is charged solely to the investors, the Campaigner scenario, where the platform fee is charged to the campaigners, and lastly, the Equal scenario, where campaigners and investors are charged equally.

Fig. 12 illustrates the SCF Potentials in the three scenarios of platform cost distribution. It shows that the short and early mid-terms seem to be largely unaffected by the different scenarios while in the later part of the mid-term and the long-term periods, there seems to be more SCF potential when the platform cost is solely charged to the campaigners. This is contrasts to Fig. 13, which shows that in the mid-term and early long term, there seems to be a higher amount of campaigns in the BAS scenario, which distributes the platform cost solely to the investor. However, after year 30 there are more SCF campaigns for the scenario where the platform cost is charged purely to the campaigner.

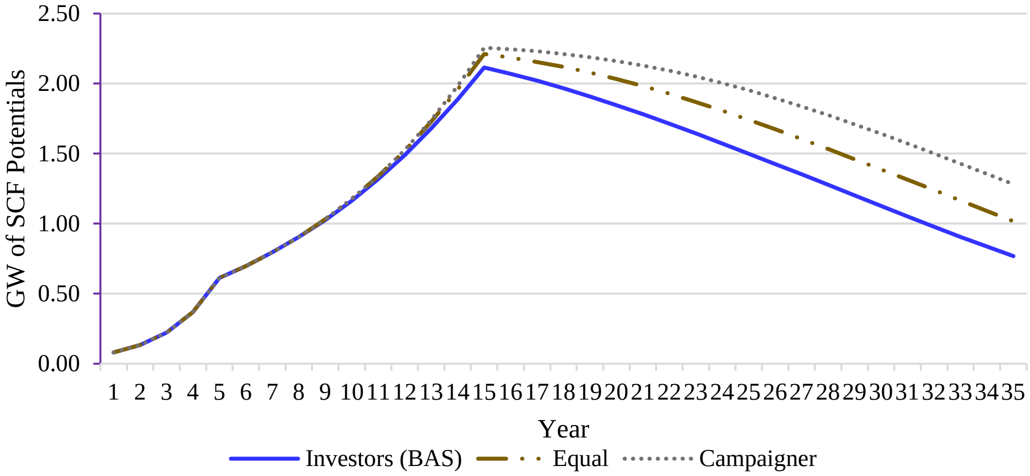

Fig 12. A comparison between the SCF Potentials (GW) over a 35-year period for the scenarios at different platform cost distributions

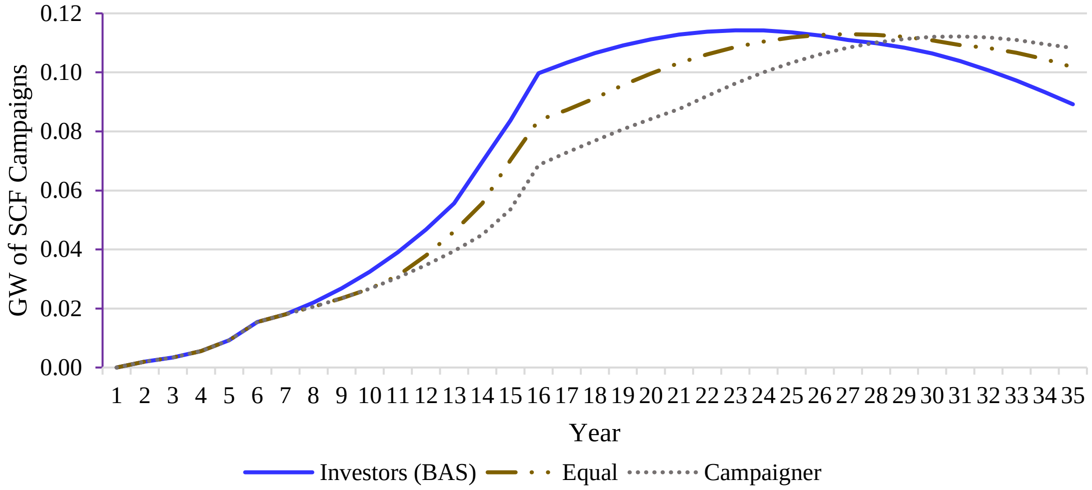

Fig. 13. A comparison between the SCF Campaigns (GW) over a 35-year period for the scenarios at different platform cost distributions

In terms of the successful campaigns per year as shown in Fig. 14, in short to mid-term period, there is a higher success rate in the campaigner scenario. However, between years 11 to 18, the BAS scenario has slightly more successful campaigns as compared to the other scenarios before declining sharply while the campaigner scenario continued to increase for another 7 years before slowly declining. Therefore, the campaigner scenario could generate more successful campaigns than the other two scenarios in the long term. Fig. 15. shows the cumulative amount of successful SCF campaigns over the time periods, which follow a relatively similar trend up to year 25, where the BAS scenario started to plateau. In contrast, the equal and campaigner scenarios continued to increase at similar rates. At the end of 35 years, the campaigner scenario had a 16.3% higher amount of successful campaigns as compared to the BAS scenario. Hence, it can be concluded that by charging the platform cost solely to the campaigners, a higher amount of successful campaigns can be achieved in the long run.

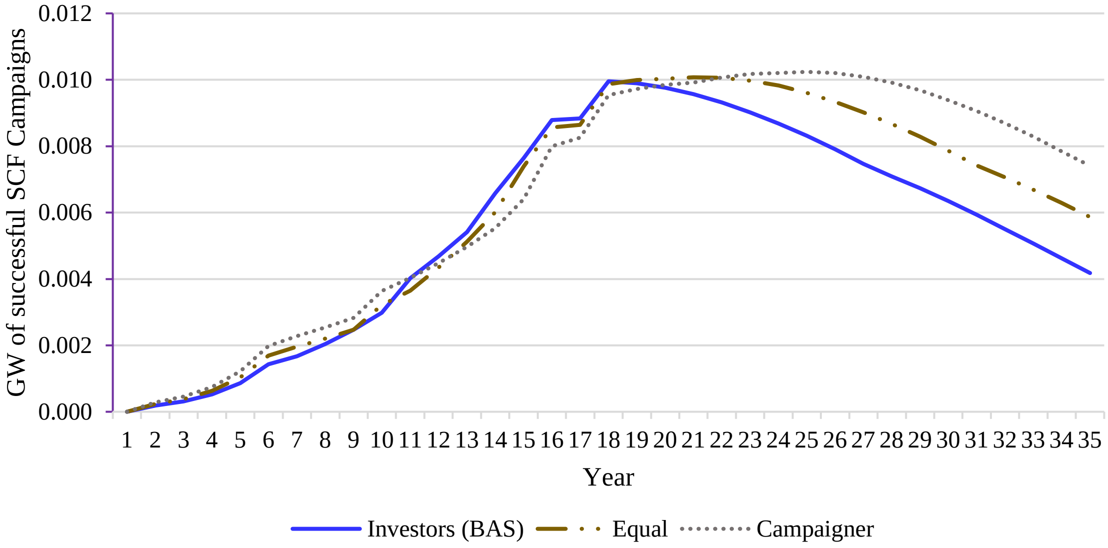

Fig. 14. A comparison between the Successful Campaigns per year (GW) over a 35-year period for the scenarios at different platform cost distributions

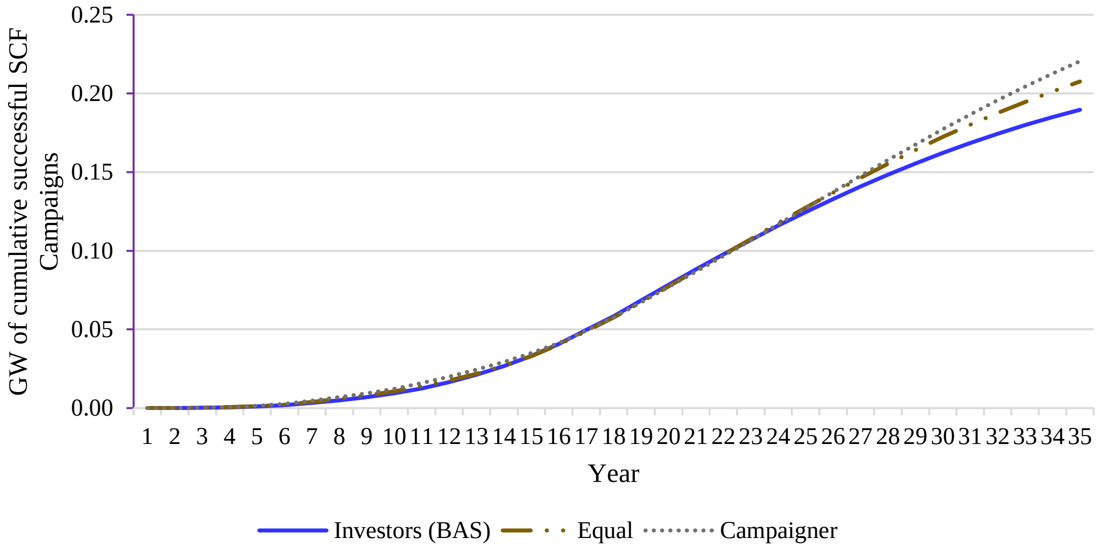

Fig. 15. A comparison between the Cumulative Successful Campaigns (GW) over a 35-year period for the scenarios at different platform cost distributions

Table 8 summarizes the cumulative amounts collected at different time periods in the various scenarios. The results show that under different scenarios, SCF can potentially generate a cumulative amount of US$177-278 million by the end of 2050, accounting for 2.5%-4% of the total cumulative funds needed for solar installations expected in the year 2050 in Singapore. The modeling shows that the amount generated via SCF is generally less than 5% of the total amount needed for solar installation but using SCF to tap on the crowd could give investors the sense of ownership to renewable energy projects, which increase the public awareness of sustainable development and green technologies.

Table 8 Summary cumulative amounts collected at different time periods in the various scenarios

Results	Scenario	Short Term (Year 1-5)	Mid-Term (Year 6-15)	Long Term (Year 16-35)
Cumulative amount required (US$)	*BAS*	$667,935,746	$3,333,320,999	$5,462,702,150
	ACC	$888,127,250	$4,023,168,088	$9,753,554,113
Cumulative amount collected (US$)	*BAS*	$2,702,832	$42,906,338	$177,571,581
	ACC	$3,442,913	$59,386,146	$277,119,477
	Equal	$3,271,164	$42,572,870	$194,814,239
	Campaigner	$3,874,865	$44,028,357	$207,875,583
% of total funds needed	*BAS*	0.405%	1.29%	3.25%
	ACC	0.388%	1.48%	2.84%
	Equal	0.490%	1.28%	3.57%
	Campaigner	0.580%	1.32%	3.81%

It is increasingly discussed in the media that crowdfunding represents an alternative means to finance environmental ventures and clean technologies. Crowdfunding is still fairly new in the solar financing world, especially in Singapore. Hence few studies have sought to examine its potential in the solar market, and there are no relevant studies in the Singapore context. Furthermore, few studies investigate the mechanisms of SCF considering the feedback loops existing in the crowdfunding process, which is considered in this study through the use of system dynamics. By forecasting the development potential of crowdfunding for solar PV in Singapore using system dynamics, this study contributes to the understanding of crowdfunding for renewable energy in general, and for solar power in Singapore in particular.

However, risks also exist in crowdfunding, such as the high possibility of fraud and legitimate uncertainty of crowdfunding platforms [16]. The risk of fraud cannot be ignored as crowd funders have little bargaining power toward the campaigners in terms of project agreements which lead to information asymmetries [80]. Investors in crowdfunding seem also paid little attention to the project risks probably because of their limited contribution of a low amount of money [37]. Furthermore, since crowdfunding requires web-based platforms which younger people have more skills on, international surveys indicate that around half of crowd funders are younger than 35 years [28,29]. Investors in crowdfunding could also suffer from the insufficient information on the campaigners as there is a limited requirement for the campaigners to provide information for investors to make informed evaluations of the project [50]. This issue is further intensified by the fact that crowdfunding tends to attract start-ups and small-medium sized enterprises which may not have established a track record or only have unaudited financial statements [50]. Thus, it may be difficult for investors involved in crowdfunding to make assessments of projects based on adequate and reliable information, which is simply not available to them. Moreover, intellectual property issues also exist in crowdfunding. Innovative ideas, such as projects with new solar PV technologies, promoted in crowdfunding platforms need to be protected with a patent before releasing in the platform, as someone could see and copy the innovative ideas in their own projects.

Because there is a serious lack of data regarding the possibility of fraud and other risk factors in crowdfunding, this study did not incorporate the effect of fraud in the modeling process, which is a limitation of this study and should be responded if data is available in the future. Future studies should identify the risks involved for each party including the platform owner, campaigner, and investors and find ways to mitigate those risks. Similarly, as different countries may have various government policies, crowdfunding in different countries may have operating details different from the processes modeled in this paper. Costs of PV also vary significantly influenced by the network and spatial distribution of PV [81]. Therefore, future studies should also adjust and apply the model to other countries that are keen to develop solar power, such as China, Nigeria, Pakistan and India [82-92], to enable international benchmarking of crowdfunding for renewable energy.

5. Conclusions

Solar energy has developed rapidly during the past decade. Since crowdfunding taps on investments from the public, it could potentially contribute to the financing of solar projects. Due to its novelty, crowdfunding for renewable energy has received little attention from existing studies. This study aims to provide not only a review of crowdfunding concepts in general and for renewable energy specifically, but also a system dynamics model for forecasting the potential of solar crowdfunding in Singapore. The system dynamics model provides an amalgamation of a three-stage SCF process including the determination of potential SCF adopters, factors affecting the adoption of SCF, and factors affecting the success of SCF. Each stage considers various factors that form feedback loops impacting the SCF market.

The proposed model was simulated in Vensim PLE software to forecast the development of SCF in 35 years to 2050 in Singapore. Various scenarios were considered and compared in the simulation. Specifically, the base (BAS) and accelerated development (ACC) of solar power proposed by the Solar Energy Research Institute of Singapore were inputted in the model and the results show that by the end of 2050, crowdfunding could generate around US$ 177 million and US$ 278 million in the BAS and ACC scenario respectively, accounting for 3.25% and 2.84% of the amount needed. The impact of platform cost distributions on the SCF development was also simulated, revealing that by charging the platform cost solely to the campaigners, a higher amount of successful campaigns can be achieved in the long run, since the campaigner scenario had a 16.3% higher amount of successful campaigns as compared to the BAS scenario. These results indicate that crowdfunding could complement traditional financing approaches for solar PV, and the platform cost should be charged to campaigners to facilitate successful campaigns.

This study has significant implications for crowdfunding of renewable energy. The crowdfunding concepts and development, the various crowdfunding approaches for renewable energy, and the key stakeholders involved in crowdfunding were reviewed in this study, providing a reference for policymakers and industry practitioners to understand the main approaches and processes involved in crowdfunding. There is a lack of studies on the factors impacting the success of crowdfunding campaigns. By using the system dynamics as the research method which illustrates the complex mechanisms of solar crowdfunding, this study contributes to the understanding of the factors impacting the success of crowdfunding campaigns in general. This study also enriches the existing very limited studies of crowdfunding on renewable energy. The simulation approach of this study provides an innovative perspective to understand the detailed mechanisms and complexity involved in crowdfunding, complementing the qualitative methods which were commonly used in existing studies.

The proposed system dynamics model can also be further enriched or extended to investigate crowdfunding development for other types of renewable energy in various countries. It is important to note that as a very new area of study, crowdfunding of renewable energy needs to be further investigated by future studies through both empirical and theoretical analysis, to reveal the various strengths, weaknesses and risk factors associated with it. By investigating SCF using system dynamics, this study reveals the research area of crowdfunding for renewable energy. It is expected that through both theoretical and empirical analysis of future studies, crowdfunding for renewable energy could be further understood.

References

1. Doshi, T.K., et al., *The Economics of Solar*. 2011, Solar Energy Research Institute of Singapore: Singapore.
2. Zhao, Z.-Y., Y.-L. Chen, and R.-D. Chang, *How to stimulate renewable energy power generation effectively?–China's incentive approaches and lessons.* Renewable energy, 2016. **92**: p. 147-156.
3. Zhao, Z.-Y., R.-D. Chang, and G. Zillante, *Challenges for China' s energy conservation and emission reduction.* Energy Policy, 2014. **74**: p. 709-713.
4. Zhao, Z.-Y., R.-D. Chang, and Y.-L. Chen, *What hinder the further development of wind power in China?—A socio-technical barrier study.* Energy Policy, 2016. **88**: p. 465-476.
5. Chang, R.-D., et al., *Evolving theories of sustainability and firms: History, future directions and implications for renewable energy research.* Renewable and Sustainable Energy Reviews, 2017. **72**: p. 48-56.
6. Candelise, C., *Crowdfunding and the Energy Sector*. 2015, CEDRO: Lebanon.
7. REN21. *Renewables 2015 Global Status Report*. 2015; Available from: http://www.ren21.net/wp-content/uploads/2015/07/REN12-GSR2015_Onlinebook_low1.pdf.
8. Energy Market Authority. *Solar Photovoltaic Systems*. 2015; Available from: https://www.ema.gov.sg/Solar_Photovoltaic_Systems.aspx.

9. Channel NewsAsia. *Punggol steps closer to being net zero energy town*. 2013 January 24; Available from: http://wildsingaporenews.blogspot.sg/2013/01/punggol-steps-closer-to-being-net-zero.html.
10. Iswaran, S. *Speech By Mr S Iswaran, Minister in the Prime Minister's Office and Second Minister for Home Affairs and Trade and Industry, at the Opening Ceremony of the Asia Clean Energy Summit on 28 October 2014*. www.ema.gov.sg, 2014.
11. Kosorić, V., et al., *General model of Photovoltaic (PV) integration into existing public high-rise residential buildings in Singapore–Challenges and benefits.* Renewable and Sustainable Energy Reviews, 2018. **91**: p. 70-89.
12. Energy Market Authority. *Singapore energy statistics 2016*. 2017; Available from: https://www.ema.gov.sg/Singapore_Energy_Statistics.aspx.
13. Baziliana, M., et al., *Re-considering the economics of photovoltaic power.* Renewable Energy, 2012: p. 329 - 338.
14. Dilger, M.G., T. Jovanović, and K.-I. Voigt, *Upcrowding energy co-operatives–Evaluating the potential of crowdfunding for business model innovation of energy co-operatives.* Journal of Environmental Management, 2017. **198**: p. 50-62.
15. Zhu, L., et al., *Application of Crowdfunding on the Financing of EV's Charging Piles.* Energy Procedia, 2016. **104**: p. 336-341.
16. Zhang, C., et al., *Analysis of Distributed Photovoltaic Financing: A Case Study Approach of Crowd-funding with Photovoltaic Water Pumping System in Microgrids.* Energy Procedia, 2016. **103**: p. 387-393.
17. Musango, J.K., et al., *A system dynamics approach to technology sustainability assessment: The case of biodiesel developments in South Africa.* Technovation, 2012. **32**(11): p. 639-651.
18. Pitschner, S. and S. Pitschner-Finn, *Non-profit differentials in crowd-based financing: Evidence from 50,000 campaigns.* Economics Letters, 2014. **123**(3): p. 391-394.
19. Bartenberger, M. and P. Leitner. *Crowdsourcing and crowdfunding: approaches to foster social innovation*. in *Proceedings of the IADIS International Conference Web Based Communities and Social Media 2013*. 2013.
20. Burtch, G., A. Ghose, and S. Wattal, *An Empirical Examination of the Antecedents and Consequences of Contribution Patterns in Crowd-Funded Markets.* Information Systems Research 24(3), 2013: p. 499-519.
21. Mollick, E., *The dynamics of crowdfunding: An exploratory study.* Journal of Business Venture, 2014: p. 1-16.
22. Energy Star. *Federal Tax Credits for Consumer Energy Efficiency*. 2015 June; Available from: http://www.energystar.gov/about/federal_tax_credits.
23. Tongsopit, S., N. Sugiyama, and S. Chunhachoti-ananta, *A Review of Business Models for Distributed Solar Power Deployment in the US and Japan: Lessons and Prospects for Thailand.* Thai Solar PV Roadmap, Bangkok, 2013.
24. Schwienbacher, A. and B. Larralde, *Crowdfunding of Small Entreprenurial Finance*, in *Handbook of Entrepreneurial Finance*. 2010, Oxford University Press: France.
25. Osterwalder, A. and Y. Pigneur, *Business model generation: a handbook for visionaries, game changers, and challengers*. 2010: John Wiley & Sons.
26. Tomczak, A. and A. Brem, *A conceptualized investment model of crowdfunding.* Venture Capital, 2013: p. 335-359.
27. World Bank. *Crowdfunding's Potential for the Developing World*. 2013; Available from: http://documents.worldbank.org/curated/en/409841468327411701/pdf/840000WP0Box380crowdfunding0study00.pdf.
28. Von Ritter, K. and D. Black-Layne, *Crowdfunding for Climate Change: A new source of finance for climate action at the local level? ECBI policy brief European Capacity Building Initiative*. 2013, Oxford.
29. Berglin, H. and C. Strandberg, *Leveraging customers as investors: the driving forces behind crowdfunding*. 2013.
30. Agrawal, A.K., C. Catalini, and A. Goldfarb, *The geography of crowdfunding (No. w16820).* 2011, National Bureau of Economic Research: Cambridge.

31. Cumming, D.J., G. Leboeuf, and A. Schwienbacher, *Crowdfunding Models: Keep-it-All vs. All-or-Nothing*. 2014, EUROFIDAI-AFFI Paper: Paris.
32. Meeuwsen, R.J.M.M., *Crowd Funding & Renewable Energy Projects*. 2013.
33. Agrawal, A.K., C. Catalini, and A. Goldfarb, *The geography of crowdfunding*. 2011, National Bureau of Economic Research.
34. Younkin, P. and K. Kashkooli, *What problems does crowdfunding solve?* California Management Review, 2016. **58**(2): p. 20-43.
35. Lehner, O.M., *Crowdfunding social ventures: a model and research agenda.* Venture Capital, 2013. **15**(4): p. 289-311.
36. Ibrahim, N., *The model of crowdfunding to support small and micro businesses in Indonesia through a web-based platform.* Procedia Economics and Finance, 2012. **4**: p. 390-397.
37. Bonzanini, D., G. Giudici, and A. Patrucco, *The Crowdfunding of Renewable Energy Projects.* Handbook of Environmental and Sustainable Finance, 2015: p. 429.
38. Brem, A., V. Bilgram, and A. Marchuk, *How crowdfunding platforms change the nature of user innovation–from problem solving to entrepreneurship.* Technological Forecasting and Social Change, 2017.
39. Chiang, A., *How entrepreneurs can crowdfund renewable energy projects.* J. Bus. Entrepreneurship & L., 2014. **8**: p. 659.
40. Ottinger, R.L. and J. Bowie, *Innovative Financing for Renewable Energy.* Pace Envtl. L. Rev., 2015. **32**: p. 701.
41. Zheng, R., et al. *A Crowdfunding Model for Green Energy Investment*. in *IJCAI*. 2015.
42. Massolution. *2015CF crowdfunding industry report*. 2015; Available from: http://reports.crowdsourcing.org/index.php?route=product/product&product_id=54.
43. Meyskens, M. and L. Bird, *Crowdfunding and value creation.* Entrepreneurship Research Journal, 2015. **5**(2): p. 155-166.
44. Mollick, E., *The dynamics of crowdfunding: An exploratory study.* Journal of Business Venturing, 2014. **29**(1): p. 1-16.
45. Ahlers, G.K., et al., *Signaling in equity crowdfunding.* Entrepreneurship Theory and Practice, 2015. **39**(4): p. 955-980.
46. Cumming, D.J., G. Leboeuf, and A. Schwienbacher, *Crowdfunding cleantech.* Energy Economics, 2017. **65**: p. 292-303.
47. Vasileiadou, E., J. Huijben, and R. Raven, *Three is a crowd? Exploring the potential of crowdfunding for renewable energy in the Netherlands.* Journal of Cleaner Production, 2015. **30**: p. 1-14.
48. Hörisch, J., *Crowdfunding for environmental ventures: an empirical analysis of the influence of environmental orientation on the success of crowdfunding initiatives.* Journal of Cleaner Production, 2015. **107**: p. 636-645.
49. Renewable Energy Crowdfunding Conference, *Renewable Energy Crowdfunding Overview and Map*. 2015: London.
50. MoneySENSE. *Crowd Funding*. 2017 [cited 2018 5/6]; Available from: http://www.moneysense.gov.sg/understanding-financial-products/investments/guides-and-articles/crowdfunding.aspx.
51. Department of Statistics Singapore, *Yearbook of Statistics Singapore*. 2015: Singapore.
52. Housing & Development Board. *HDB calls first solar leasing tender that combines demand across govt bodies*. 2015 June 5; Available from: https://www.edb.gov.sg/content/dam/edb/en/news%20and%20events/News/2015/press-release/Joint-Release-First-SolarNova-tender.pdf.
53. Gerber, E. and J. Hui, *Crowdfunding: Motivations and Deterrents for Participation*. 2012.
54. Strandberg, C. and H. Berglin, *Leveraging customers as investors: The driving forces behind crowdfunding*. 2013.
55. Parasuraman, A., et al., *Crowd-funding: transforming customers into investors through innovative service platforms.* Journal of Service Management, Vol. 22 Iss 4, 2011: p. 443 - 470.
56. Harms, M., *What Drives Motivation to Participate Financially in a Crowdfunding Community?* 2007: Amsterdam.

57. Yuan, H. and J. Wang, *A system dynamics model for determining the waste disposal charging fee in construction.* European Journal of Operational Research, 2014. **237**(3): p. 988-996.
58. Sterman, J.D., *Business Dynamics Systems Thinking and Modeling for a Complex World*. 2010: Tata McGraw-Hill.
59. Lyneis, J.M., *System dynamics for market forecasting and structural analysis.* System Dynamics Review, 2000: p. 3-25.
60. Son, J. and E.M. Rojas, *Impact of optimism bias regarding organizational dynamics on project planning and control.* Journal of Construction Engineering and Management, 2010. **137**(2): p. 147-157.
61. Zhao, W., H. Ren, and V. Rotter, *A system dynamics model for evaluating the alternative of type in construction and demolition waste recycling center–The case of Chongqing, China.* Resources, Conservation and Recycling, 2011. **55**(11): p. 933-944.
62. Naill, R.F., *A system dynamics model for national energy policy planning.* System Dynamics Review, 1992: p. 1-19.
63. Wang, J., H. Lu, and H. Peng, *System Dynamics Model of Urban Transportation System and Its Application.* Journal of Transportation Systems Engineering and Information Technology, 2008. **8**(3): p. 83-89.
64. Karavezyris, V., K.-P. Timpe, and R. Marzi, *Application of system dynamics and fuzzy logic to forecasting of municipal solid waste.* Mathematics and Computers in Simulation, 2002. **60**(3-5): p. 149-158.
65. Rehan, R., et al., *Development of a system dynamics model for financially sustainable management of municipal watermain networks.* Water Research, 2013. **47**(20): p. 7184-7205.
66. Schiuma, G., D. Carlucci, and F. Sole, *Applying a systems thinking framework to assess knowledge assets dynamics for business performance improvement.* Expert Systems with Applications, 2012. **39**(9): p. 8044-8050.
67. Chen, L. and P.S. Fong, *Visualizing evolution of knowledge management capability in construction firms.* Journal of Construction Engineering and Management, 2012. **139**(7): p. 839-851.
68. Yao, H., et al., *Simulating the impacts of policy scenarios on the sustainability performance of infrastructure projects.* Automation in Construction, 2011. **20**(8): p. 1060-1069.
69. Egilmez, G. and O. Tatari, *A dynamic modeling approach to highway sustainability: Strategies to reduce overall impact.* Transportation Research Part A: Policy and Practice, 2012. **46**(7): p. 1086-1096.
70. Lee, S., et al., *Dynamic and multidimensional measurement of product-service system (PSS) sustainability: a triple bottom line (TBL)-based system dynamics approach.* Journal of Cleaner Production, 2012. **32**: p. 173-182.
71. Jin, W., L. Xu, and Z. Yang, *Modeling a policy making framework for urban sustainability: Incorporating system dynamics into the Ecological Footprint.* Ecological Economics, 2009. **68**(12): p. 2938-2949.
72. Xu, Z. and V. Coors, *Combining system dynamics model, GIS and 3D visualization in sustainability assessment of urban residential development.* Building and Environment, 2012. **47**: p. 272-287.
73. Zhang, X., et al., *A prototype system dynamic model for assessing the sustainability of construction projects.* International Journal of Project Management, 2014. **32**(1): p. 66-76.
74. Sarimveis, H., et al., *Dynamic modeling and control of supply chain systems: A review.* Computers and Operations Research, 2008. **35**(11): p. 3530-3561.
75. Vlachos, D., P. Georgiadis, and E. Iakovou, *A system dynamics model for dynamic capacity planning of remanufacturing in closed-loop supply chains.* Computers & Operations Research, 2007. **34**(2): p. 367-394.
76. Yuan, H., *A model for evaluating the social performance of construction waste management.* Waste management, 2012. **32**(6): p. 1218-1228.
77. Sterman, J.D., *Business dynamics: systems thinking and modeling for a complex world*. 2000, London: McGraw-Hill.
78. Yuan, H., et al., *A dynamic model for assessing the effects of management strategies on the reduction of construction and demolition waste.* Waste Management, 2012. **32**(3): p. 521-531.

79. Luther, J. and T. Reindl, *Solar Photovoltaic (PV) Roadmap for Singapore (A Summary)*. 2013, National Climate Change Secretariat (NCCS): Singapore.
80. Giudici, G., *Equity crowdfunding of an entrepreneurial activity*, in *University Evolution, Entrepreneurial Activity and Regional Competitiveness*. 2016, Springer. p. 415-425.
81. Horowitz, K.A., et al., *Distribution system costs associated with the deployment of photovoltaic systems.* Renewable and Sustainable Energy Reviews, 2018. **90**: p. 420-433.
82. Tahir, Z.R. and M. Asim, *Surface measured solar radiation data and solar energy resource assessment of Pakistan: A review.* Renewable and Sustainable Energy Reviews, 2018. **81**: p. 2839-2861.
83. Ozoegwu, C.G., C.A. Mgbemene, and P.A. Ozor, *The status of solar energy integration and policy in Nigeria.* Renewable and Sustainable Energy Reviews, 2017. **70**: p. 457-471.
84. Rathore, P.K.S., et al., *Solar power utility sector in india: Challenges and opportunities.* Renewable and Sustainable Energy Reviews, 2018. **81**: p. 2703-2713.
85. Shahsavari, A. and M. Akbari, *Potential of solar energy in developing countries for reducing energy-related emissions.* Renewable and Sustainable Energy Reviews, 2018. **90**: p. 275-291.
86. Kar, S.K., A. Sharma, and B. Roy, *Solar energy market developments in India.* Renewable and Sustainable Energy Reviews, 2016. **62**: p. 121-133.
87. Urban, F., S. Geall, and Y. Wang, *Solar PV and solar water heaters in China: Different pathways to low carbon energy.* Renewable and Sustainable Energy Reviews, 2016. **64**: p. 531-542.
88. Li, Y., et al., *Market structure and performance: An empirical study of the Chinese solar cell industry.* Renewable and Sustainable Energy Reviews, 2017. **70**: p. 78-82.
89. Zhang, S. and Y. He, *Analysis on the development and policy of solar PV power in China.* Renewable and Sustainable Energy Reviews, 2013. **21**: p. 393-401.
90. Ohunakin, O.S., et al., *Solar energy applications and development in Nigeria: Drivers and barriers.* Renewable and Sustainable Energy Reviews, 2014. **32**: p. 294-301.
91. Sher, H.A., et al., *Pakistan's progress in solar PV based energy generation.* Renewable and Sustainable Energy Reviews, 2015. **47**: p. 213-217.
92. Shukla, A.K., et al., *Solar PV and BIPV system: Barrier, challenges and policy recommendation in India.* Renewable and Sustainable Energy Reviews, 2018. **82**: p. 3314-3322.