Journal of Cleaner Production 211 (2019) 350–359

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Promotion policies for third party financing in Photovoltaic Poverty Alleviation projects considering social reputation

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ARTICLE INFO

Article history:
Received 24 May 2018
Received in revised form
17 September 2018
Accepted 19 November 2018
Available online 20 November 2018

Keywords:
Third-party financing
Photovoltaic poverty alleviation
Social reputation
Multiplex network
Agent-based modeling

ABSTRACT

As an integrated approach to renewable energy adoption and poverty alleviation, Photovoltaic Poverty Alleviation (PVPA) projects carry the weight of significance and expectation from the Chinese government and the public. However, fund shortages due to the high initial investment and long pay-back period for poor households has become the biggest bottleneck for PVPA implementation. Third-party financing was therefore introduced and the potential reputational benefits were promoted to encourage corporations to fund PVPA projects by attracting more investors. In the present study, an assessment of the combination of both the direct economic benefits from PV systems and the social reputational benefits was conducted. In order to simulate the impacts of the formation and dissemination of a corporation's reputation on the economic benefit, an agent-based model in a multiplex network is developed and applied. The results indicate that joining a PVPA project will promote the social reputation of third party investors and bring about potential profits. Meanwhile, information-targeted policies, including information exposure and encouraging social discussion, are required to sustain the profit benefits from reputational promotion. The two policies are shown to be effective when implemented separately, however, when the two polices are introduced simultaneously, the contribution of information exposure was overshadowed by the policy of encouraging social discussion.

1. Introduction

Along with the rapid development of the world economy, world energy consumption and carbon dioxide emissions have been increasing rapidly due to the ongoing reliance on traditional fossil fuels. However, the fact cannot be ignored that human society and its economic activities are speedily approaching and even exceeding the limits of global environmental capacity (Barbier and Burgess, 2017). The three dimensions of the triple bottom-line (economic, environmental, and social) have become widely accepted as the basis for assessing sustainable development (Tuazon et al., 2013). To achieve sustainable development goals and mitigate energy shortages, renewable energy, especially photovoltaics (PV), are expected to play a crucial role (Mauleón, 2017). According to BP Statistical Data, the growth of solar power accounted for about one third of the increase of global renewable energy in 2016 (BP, 2018). By the end of 2017, the total number of PV installations worldwide has reached 300 GW, of which China's PV power generation capacity ranked first in the world at 130 GW (National energy administration of China, 2018). PV power generation, especially distributed PV power generation, has shown huge development potential and great market prospects in China (Sun et al., 2017).

On the other hand, although remarkable progress has been made in combatting poverty in recent years, there were still 55.75 million impoverished people in China up to 2015. The Chinese central government aims at eradicating poverty by 2020, while increasing the annual income of impoverished people to over 3000 RMB per capita (State Council of China, 2016). Among the government efforts in poverty alleviation, the Photovoltaic Poverty Alleviation (PVPA) program has had great significance as a primary way of helping the poor to achieve sustainable income growth.

PVPA is carried out to encourage the poor in rural areas to make full use of their assets, such as rooftops, uncultivated land or waste slopes, for photovoltaic generation to achieve steady incomes. Via this approach it is anticipated that the targets of poverty alleviation

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https://doi.org/10.1016/j.jclepro.2018.11.179
0959-6526/

and renewable adoption can be achieved at the same time. In 2016, the Chinese government launched pilot projects of PVPA in several provinces according to the distribution of solar resources and population in poverty. If the local multi-year average of total solar radiation is more than 4500 MJ/m^2, and the registered impoverished people own land or roof resources suitable for the installation of PV equipment, these people would benefit from joining the project. With the PV system connected to the power grid, the poor can obtain profits from specific policy subsidies and sales of PV electricity (State Council of The State Council Information Office of the People's Republic of China, 2015). At present, the pilot PVPA projects derived their initial investment mainly from government special funds for poverty alleviation, which make up around 70% of the total (National Energy Administration, 2016). With a simple estimation according to current incentives, the government would require 10.5 billion RMB for the initial PVPA investment. Relevant associations or non-governmental organizations (NGO) also contribute a small amount, while the remaining funds needs to be provided through bank loans to the impoverished. However, since lower income will lead to an increase in individual investors' risk aversion (Cohn et al., 1975), poor households are unwilling to take the risk to apply for a loan. Especially because most of the loans offered to impoverished people need to be paid off within 3–5 years, which is much shorter than the payback period of a PVPA project. On the other hand, financial institutions such as China Development Bank and Agricultural Development Bank, are required by the government to secure funds, but these policy banks are not active for this kind of small project due to the lack of sufficient economic incentives. Facing with all these financing obstacles for PVPA, third party financing could be an effective solution.

Third party financing is where a third party is involved as a funder to join in the projects. In a typical PVPA project, the government or the grid operator and the involved poor household are the two parties directly involved in the investment. Platforms for financial leasing, or crowdfunding can be regarded as third parties (Davidson and Steinberg, 2013; Drury et al., 2012; Hong et al., 2018). Scholars have explored financing modes for sustainable innovations in general (Bocken et al., 2014; Boons and Lüdeke-Freund, 2013; Reim et al., 2015) or PV in particular (Strupeit and Palm, 2016). However, the situation is quite different for PVPA projects. The funds for PVPA will be provided under the supervision of the local alleviation office and used to build PV systems on spare space available to of impoverished people, such as roofs, yards, and uncultivated land. Once the PV systems are connected to the grid, the third parties will obtain the generated electricity for self-consumption or may obtain the profit from selling electricity as an investment return. Meanwhile, they have to pay the land rent to the involved poor households annually with a standard of 3000 RMB per household.

Private entities have already taken part in the initial investment for commercial PV projects in China (Zhang, 2016), while they are less active in investing in poverty alleviation projects, mainly because many corporations tend to prioritize current profit and explicit costs for the sake of maximization of shareholders' equity (Besley and Ghatak, 2007). In PVPA projects, the third party investors have to share the profit with the poor. According to a regulation released on April 16, 2018 (National Energy Administration and State Council of China, 2018), donations are encouraged to play an important role in PVPA. In these circumstances, donors cannot obtain any direct economic benefits from this project. Companies tend to prefer to obtain more explicit benefits (profits) in commercial projects, while neglecting the implicit benefits (Wahba, 2008). Meanwhile, there exists a positive relationship between corporate social performance and reputation (Brammer and Pavelin, 2006). Participating as a donor in PVPA projects will bring about potential benefits for a third party by improving their reputation and corporate image (CI) from the aspects of both social responsibility (CSR) and environmental responsibility (CER). Social responsibility indicates a company's commitment to minimizing or eliminating any harmful effects and maximizing its long-run beneficial impact on society (Halkos and Skouloudis, 2018). Furthermore, environmental responsibility refers to the company's obligation to protect the environment (Khajehpour et al., 2017). Blasi et al. found that CSR engagement usually raises firms' total stock returns and reduces financial risks (Blasi et al., 2018). Hori et al. even revealed a positive relationship between CSR recognition and energy saving, with policies that encourage companies to enhance their CSR activities in society encouraging effective energy-saving actions (Hori et al., 2014).

Reputation plays an indispensable role in guiding social or economic decisions for individuals or other entities in society (Antonioni et al., 2016). Roberts and Dowling (2002) put forward that a good reputation as an intangible asset, is critical due to its potential for value creation and difficulty in being replicated by competing firms. Pellegrini et al. introduced a theoretical framework for the interactions between corporate reputation and environmental decision-making behavior and considered that a green image can generate a competitive advantage for a business (Pellegrini-Masini and Leishman, 2011). Therefore, it can be seen that a good reputation will benefit a corporation from three main aspects.

Firstly, corporations with good reputations can attract more investors, finance at lower cost and achieve higher market value. Corporate reputation has the capacity to generate sustainable competitive advantage over time, leading to a higher market value of their securities (Raithel and Schwaiger, 2015; Tischer and Hildebrandt, 2014). Khaqqi et al. (2018) built a case study involving three participants with different reputations on multichain, an open block chain platform, and found that good reputation gives participants the opportunity to choose better and faster trade offers in a financial market.

Secondly, a good reputation will attract more customers and promote product sales. A solid reputation is a competitive advantage for corporations to improve customer satisfaction (Gardberg and Fombrun, 2002; Wilson and Gotsi, 2001). Walsh and Beatty (2007) found that not only direct customer satisfaction, but also customers' reactions including loyalty, word of mouth and trust are closely associated with corporate reputation. Pigors and Rockenbach (2016) even prove that facing competition, products with higher reputations significantly increases consumers' propensity to purchase and thus succeed in lifting their sales.

Furthermore, corporations with good reputation can attract cooperative partners and employees. Results of Turban and Greening (1997) indicate that applicants will not only be attracted to firms with positive reputations but that they will actively pursue jobs with such firms. Zhang (2017) and Siegel (2009) suggested that firms adopting socially responsible behaviors may attract a higher quantity and quality of human resources through their positive corporate image. Dollinger et al. (1997) also believed that reputation is an important resource to attract an alliance partner for joint venture activity.

A corporation's reputation is built on the information of its past performance and stems from information exchange (Huck et al., 2010; Van Nieuwerburgh and Veldkamp, 2010). Therefore, computational models of reputation have been considering two aspects: direct interactions of the corporation with consumers and

the information exchange among members of society (Sabater and Sierra, 2002). Social networks are frequently used to simulate the formation and dissemination of reputation (Antonioni et al., 2016; de Paulo and Porto, 2017; Hu et al., 2012). Investors in financing markets can get information from media such as government websites and newspapers directly, but also exchange information through connections in social networks. Wang et al. (2018) developed an innovation diffusion model for PV market based on a scale-free network. Goffman and Newill (1964) used to the analogy between the spread of an infectious disease and information transmission. The epidemic model has gained increasing attention in simulating information dissemination under the expansion of social networks. Generally, epidemic spread can be characterized by two models, the: SIS (Susceptible- Infected-Susceptible) model and SIR (Susceptible- Infected-Refractory) model (Zhou et al., 2007). The former describes the phenomenon whereby a susceptible node can become infected and an infected node can recover and return to the susceptible status (Olinky and Stone, 2004). The latter is different from the SIS model in that the infected nodes will not return to the susceptible status but take on a refractory status (May and Lloyd, 2001). The basic SIS model and SIR model are feasible to simulate the dissemination of simple information.

However, more complex information requires consideration of different factors, for example the bandwagon effect and the penguin effect indicate that behavior can also affect other members (Huck et al., 2010). Especially in financing markets, the promotion of perceived reputation may not directly lead to investment behavior for a certain investor. In this case, the revenue of a target corporation won't change immediately. Considering the difference between behavior and information, a multiplex social network is introduced. Multiplex networks are particularly crucial when they overlap and interact to create processes that cannot be explained by a single network alone (Granell et al., 2013). In a multiplex network, different connection reflect the diverse relationships among participants in the network (Heaney, 2014). Using a multiplex network, two dynamic processes are analyzed in the present paper: the information dissemination and behavior interaction.

Based on the simulation result for the social network of the corporation's investors or shareholders, the potential benefits from reputational promotion can be calculated by the incremental of investors and the potential revenue from each shareholder. Following this, third party corporation investment decisions are evaluated considering both indirect reputational benefits and direct benefits of PVPA projects. Furthermore, policy recommendations are proposed based on the comparison among scenarios with different policy sets, including information exposure, encouraging social discussion and their joint scenario.

2. Methodology

2.1. Model framework

To evaluate the comprehensive motivation for third party corporations to fund PVPA projects, direct economic benefits from the PV system and potential benefits from reputational promotion are both taken into consideration as shown in Fig. 1.

In the present study, third parties are introduced as the main sponsors to cope with the financing difficulty of PVPA projects. After gathering the poverty information and solar resource endowment in poverty-stricken area, the local poverty alleviation office will set a PVPA plan and call for bids on their official website. Institutions and corporations, such as crowdfunding platforms, can provide funds for PVPA projects as third parties. The funds will be operated under the supervision of the local alleviation office and be used to build the PV system on the available space of impoverished people. The third party will obtain self-consumed electricity or the profit from selling it to the grid. In each year of the project's lifetime, the third-party corporation has to pay rent to the involved poor households with a standard of 3000 RMB per household.

Additionally, the benefits of joining PVPA projects also include the effects of reputational promotion based on the financing market. Once the news that the corporation is taking part in PVPA investment is published through social media, its reputation also starts to alter. Some investors will obtain the information from media directly then spread it through social networks. However, the information diffusion may not result in promotion of corporate's profit if the investor's behavior has not been influenced. Therefore, a multiplex social network is applied to simulate the effects of reputation. In this network, each node represents an institutional or individual investor and has two attributes: information and behavior. The information attribute describes whether the investor knows that the corporation has joined a PVPA as a third party. The behavior indicates whether the investor will invest in this corporation. Therefore, there are two statuses of each attributes: i) Considering the information, nodes can be informed or uninformed, noted as I and N; ii) From the perspective of behavior, nodes can be active or inactive, noted as A and U respectively. The inactive investor indicates that he/she will not invest in the targeted corporation in this period, rather than literally “inactive” in the financing market. Thus, there are four combined statuses of nodes in the whole network which are dynamically transformed. Through the agent-based simulation (for details please refer to Section 2.3), the total number of nodes with investment behavior in each period can be obtained. Multiplied by the averaged net revenue created by each investor's fund, the revenue from reputational promotion can be estimated.

2.2. Net present value analysis for direct economic benefits

The direct economic benefits for the third party are described in equation (1.1). Once joining, the third party provides funds for the initial investment, which is the unit capital cost *capex* multiplied by the installed capacity *PS*. Meanwhile the third party will receive the PV installation incentive which is calculated through a unit subsidy, *sub*. The maintenance and operation costs are paid at the beginning of each year with a unit level of *opex*. At the end of each year within the project lifetime, the third party will receive a return of self-consumed electricity or sell it to the grid. The price is nominally the feed-in-tariff (FIT_t) and the selling volume is the product of annual utilization hours U_t and project scale *PS*. According to relevant policy (Ministry of Finance of China et al., 2016), the Value Added Tax (VAT) for PV stations would be levied at a discount, *dis*, of the normal VAT rate, t*ax*. The annual performance decay ratio of the PV equipment is *Dec*. Moreover, the sponsor has to pay the poverty alleviation funds to the poor at the end of each year, which is the product of annual income incremental standard for each household, *poa*, and the total amount of involved poor households, *hoh*.

$$\pi_{direct} = \sum_{t=1}^{T} U_t \cdot PS \cdot FIT_t \cdot [1 - tax \cdot (1 - dis)] \cdot \frac{1 - Dec}{(1+d)^t} - capex \cdot PS - \sum_{t=1}^{T} PS \cdot \frac{opex}{(1+d)^{t-1}} + PS \cdot \frac{rcycle}{(1+d)^T} - \sum_{t=1}^{T} poa \cdot \frac{hoh}{(1+d)^t} \tag{2.1}$$

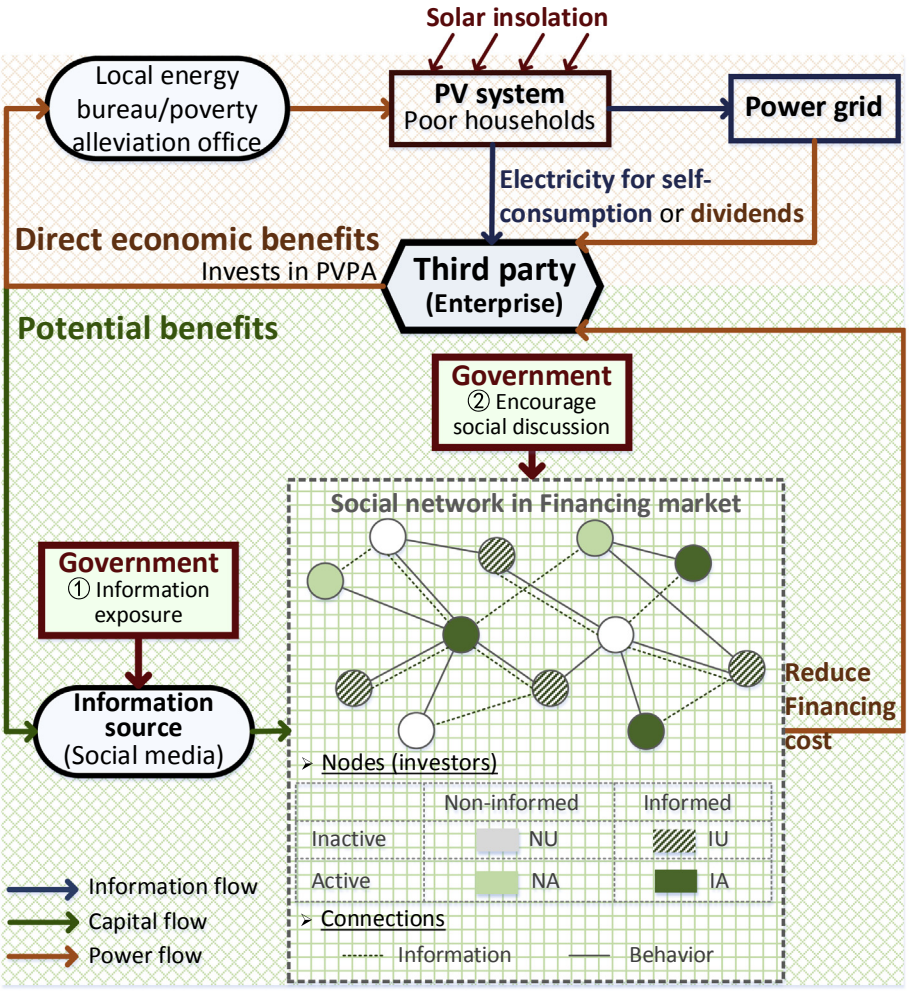

Fig. 1. Framework of benefits assessment.

2.3. Multiplex network simulation for potential benefits of reputational promotion

In the present paper, potential investors in a corporation's financing market are viewed as nodes in a multiplex network. However, how is their behavior affected by the information they have and how do they interact with each other? An agent-based model is applied as shown in Fig. 2.

At the first stage, the initial status of each node is set, which indicates investors' reactions when they first hear that their targeted corporation has joined in a PVPA project. Next, their information status is identified. An informed node has a probability of $\gamma_i t$ to forget the information where γ_i is positive. If an investor is un-informed or forgets, then the information status might be changed through communication with connected investors. The probability of an informed investor to share the information with an un-informed investor is β_i. Thus the information status for each node can be identified and produces the behavior status. Similarly, the informed nodes have a probability of δ_n to change the investment behavior in period t. An inactive investor may change his decision for other reasons instead of being affected by the connected investors, like cultural identity or macroeconomic factors. In this model, these various factors are simplified as probability μ_{ia} and μ_{na}. Where the subscripts n and i indicate whether investor's information status will influence his investment decision. Since informed investors have more positive news for targeted corporations (that they have joined a PVPA) than the un-informed, μ_{ia} would be greater than or at least equal to μ_{na}. For the inactive investors who didn't become active spontaneously and the active investors who give up investment, their behavior status may be changed in the interaction with connected nodes. The probability of an inactive investor to be influenced by an active investor is β_a, which indicates the herding effect or penguin effect in the financing market. After that, the behavior status for each node in period t is also confirmed. The model then progresses to the next loop in period t+1, until it reaches the last period T.

At present, potential investors can obtain this information from the government website of the involved poor areas in the PVPA or from the website of the target corporation itself. However, the access to information is relatively limited, since few people pay attention to the poor areas' websites. Therefore, information-targeted policies are proposed, as shown in Table 1, to facilitate the transmission of reputation. In the first policy named Information Exposure, the central government will publish a funders' list for PVPA projects periodically on its portal sites. Thus, at the beginning of each period, a certain proportion of nodes will grasp the information from the government website. In the second policy, another information-targeted policy is introduced to encourage social discussion of PVPA relevant topics through the state-controlled media. The probability of an un-informed node being

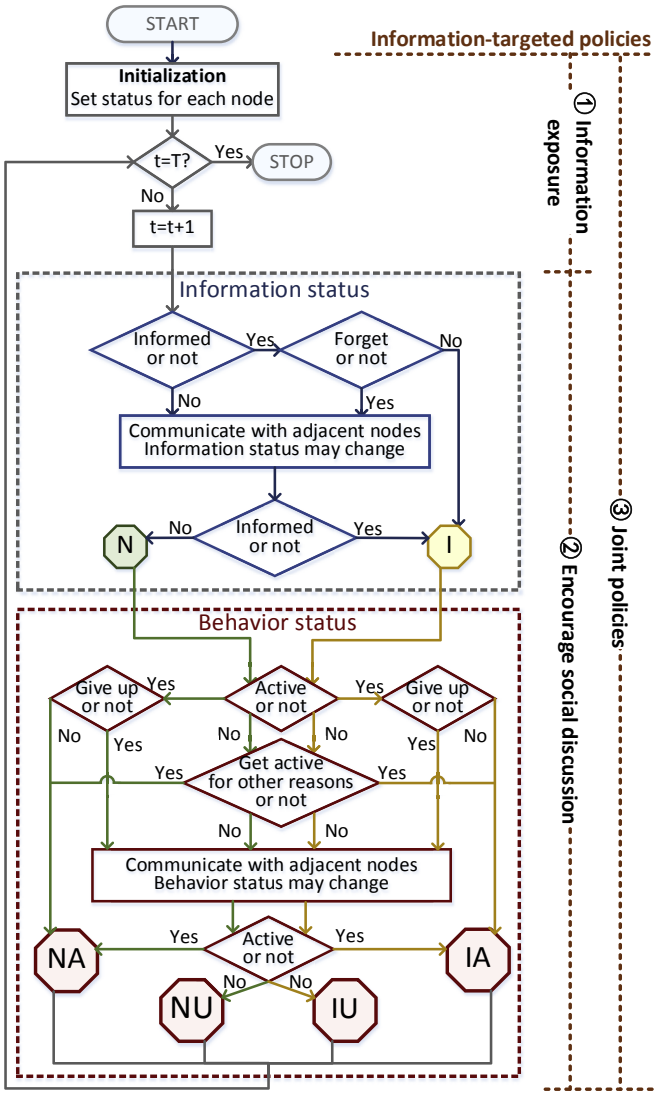

Fig. 2. Flow chart of the agent-based simulation for multiplex network.

affected by others is thereby increased. In the last scenario named Joint Policies, the two information-targeted policies are implemented simultaneously. In addition, to avoid opportunistic investor joining in poverty alleviation projects, we assume that there is a government regulation specifying the least contribution of a third party in PVPA. The third party investors who provide only a minority of the required funds but expect to gain reputation would be excluded.

3. Data

3.1. Data for PVPA project

The data for direct profit assessment of PVPA projects is shown in Table 2. Taking a PVPA project with the capacity of 1 MW as an example, the initial investment would be about 9 million RMB. Combined, the central and local government would cover around 5.5 million RMB on average and the third-party corporation is introduced to meet the financing gap. The project lifetime is 25 years. After 25 years, the generating capacity is anticipated to decline by 20%. All the electricity generated will be sold to the power grid at the Feed-in Tariff (FiT) level set by the government. There are three categories of PV power generation areas according to the different level of annual generation hours (National Development and Reform Commission, 2013). PVPA projects have been launched in areas with more than 1400 generation hours. Therefore, only the first level and the second level of PV power generation will be involved in PVPA projects. Accordingly, the FiT is set according to the different levels of solar resource, at 0.80 RMB/kWh and 0.88 RMB/kWh in level 1 and level 2 areas respectively (National Development and Reform Commission, 2015). The cost for maintenance, overhaul, malfunction and waste treatment are taken into consideration with a percentage of the initial investment as Gerilemanda (2016) and distributed equally across each year of the lifetime of the project. What's more, the incremental tax is paid at a 50% discount (State Administration of Taxation, 2014). After paying the costs and tax, the remaining revenue from selling electricity will be granted to poor households.

3.2. Data for social network

In the present study, the Chinese equity market is used as an example of a financing market. The data for the degree distribution refers to ZHANG et al. (2014). The initial values of other parameters are also shown in Table 3, and sensitivity analysis is conducted to verify the robustness of the results.

To calculate the total profit due to reputational promotion, the net revenue created by each shareholder's fund is crucial. As shown in Fig. 3, eighteen representative listed companies from six different categories are selected, including internet technology, finance, fossil fuel, electricity, photovoltaics, and Blue-chip corporations. Among them, PV is an emerging and promising industry but with weak profitability, which has a similar situation with the internet technology in China. At present, China's financial sector is generally good and stable in profitability, especially the stocks of state-owned commercial banks. Except for industry categories, Blue-chip stocks are also chosen for their trait of reliability and the ability to operate profitably in good times and bad. The stocks of fossil fuel and electricity sector represent the traditional energy industries in China. The stock categories refer to *Industry Classification* and all raw data are derived from the *Wind database*. The net revenue per shareholder in Fig. 3 equals to the net profit of each corporation weighted to its proportion of equity in the total asset, and then divided by the number of shareholders, with an average from 2015 to 2016.

4. Results

4.1. Direct economic benefits

Once a corporation offers funds to a PVPA projects, they will

Table 1
Information-targeted policies.

Scenarios	Changed parameter
Information Exposure	The additional proportion of informed nodes at the beginning of each period θ_i is increased exogenously
Encourage Social Discussion	Infection ratio for the information network β_i is increased
Joint Policies	The additional proportion of informed nodes at the beginning of each period θ_i and the infection ratio β_i are both increased

Table 2
Parameters for PVPA project cash flow assessment.

Parameter	Implication	Value
capex	Equipment and installation cost	9000 RMB/kW
opex	Cost rate for operation, maintenance et al.	11%
D	Discount rate	6%
Dis	Tax discount	50%
PL	Project lifetime	25 years
U_1	Annual utilization hours in area 1	1400 h
U_2	Annual utilization hours in area 2	1200 h
FIT_1	FIT in area 1 in 2017	0.65 RMB/kWh
FIT_2	FIT in area 2 in 2017	0.75 RMB/kWh
PS	Installation capacity	10 MW
Dec	Decay ratio in 25 years	20%
Tax	Value Added Tax	17%
Poa	Income incremental standard for each poor household	3000 RMB/year

Table 3
Parameters in social network.

Parameter	Implication	Value
k	Clustering coefficient	0.774
l	Average length	1.102
ϵ	Exponent of degree distribution	2.39
β_i	Infection probability for information status	0.01
β_a	Infection probability for behavior status	0.05
γ_i	Parameter of forgetting function	0.5
μ_{ia}	Probability for an informed node to become active spontaneously	0.2
μ_{na}	Probability for an un-informed node to become active spontaneously	0.1
δ_n	Probability of give up the investment behavior	0.5
nl	Number of loops	100
N	Numbers of nodes	1000
M	Financing market scale	10,000

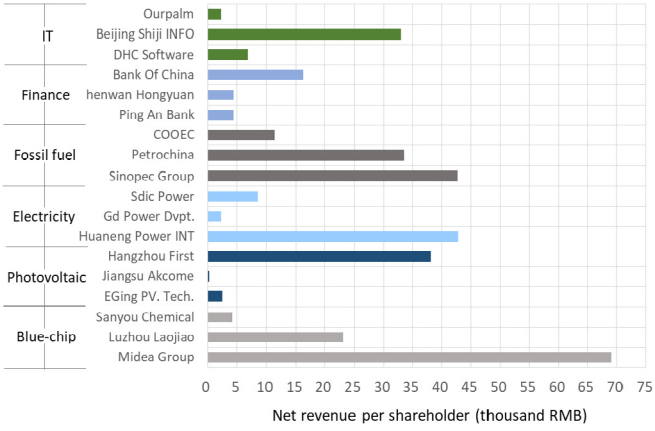

Fig. 3. Data of net revenue per shareholder.

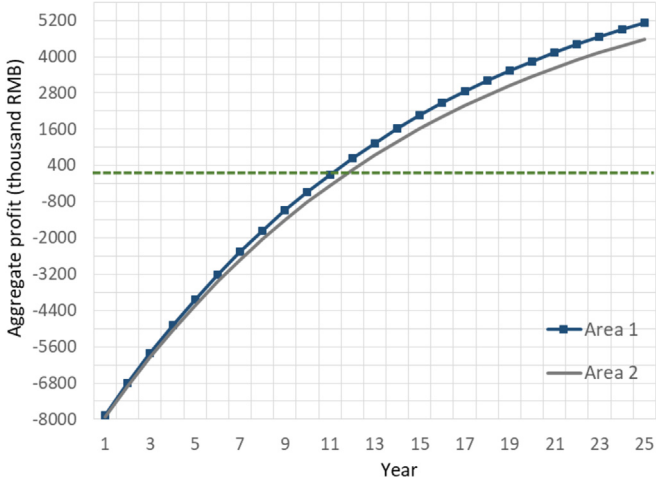

Fig. 4. The direct economic benefit in PV projects.

receive the self-consumed electricity or the profit from selling electricity to the grid. To assess the direct economic benefits of joining PVPA, the self-consumed electricity is converted to economic revenue. The assessment of annual aggregate profit without the expenditure of poverty alleviation is shown in Fig. 4. Different lines indicate different resource categories according to solar radiation. Generally, although the FIT level in area 1 is less than in area 2, the investment return in area 1 is slightly higher. In the first eleven years of the PVPA projects in both areas, the income would be negative due to the large initial investment. The breakeven point occurs in the twelfth year, and then the project becomes profitable. The profit is increasing for the annual cash inflow, however the increasing rate declines due to the PV equipment decay. The net present value of the total profit of a 10 MW PV project would reach 5.12 and 4.57 million RMB in area 1 and area 2 respectively, without considering the poverty alleviation fund.

4.2. Potential benefits of reputational promotion

As shown in Fig. 5, after the target corporation joins in PVPA, the joining ratio of investors will dramatically increase at the first four weeks. The joining ratio indicates the proportion of investors joining PVPA projects. Then it begins to decrease and eventually stabilizes at around 17.6% from the twentieth week. The green line represents the situation of non-information, which means that even if the target corporation didn't take part in PVPA, the joining

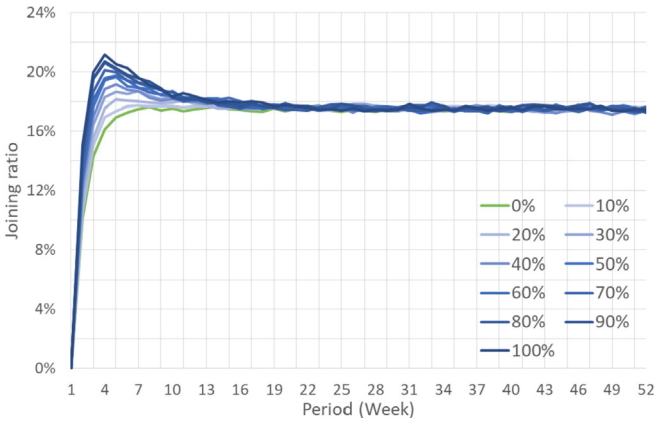

Fig. 5. Numbers of active nodes with different proportions of informed nodes in initialization stage.

ratio is still 17.6%. The other lines are the Reference Scenario with different levels of informed investors. From the second week to the twentieth week, the numbers of nodes with investment behavior is positively related to the proportion of informed nodes in the initialization stage. When all the nodes are fully informed with the news, the joining ratio of the investors would increase to 21.1% at the fourth week. At the same period, this only reaches 16.1% in un-information scenario. The maximal difference of these two scenarios is 5.0%. The maximal difference between the two scenarios comes from the information dissemination. When the informed level is 0% at the beginning, there is no information about the PVPA investment in the market. As the informed level increasing, the joining ratio will also raise because of the reputational promotion effect. Multiply the maximal difference of joining ratio by the market scale, the numbers of investors activated by the information of PVPA projects can be obtained. Then multiplied by the net revenue from each shareholder in Fig. 3, the revenue from reputational promotion varies from 1.5 million RMB to 34.5 million RMB considering different capital operating ability for each corporation. This means that if a corporate invests in a PVPA project, at most it can afford the poverty alleviation funding of 5000 to 115,000 households. Otherwise a commercial PV project would be more profitable. If a corporation decides to donate to a PVPA project, all they can obtain is the revenue from reputation, which varies according to their capital operating ability. However, the advantage of reputational promotion is only maintained for several weeks. To guarantee sustainable long-term reputational promotion, relevant policies are required.

4.3. Sensitivity analysis

To better understand the robustness of the model, sensitivity analyses for the major parameters were conducted as shown in Fig. 6. The green line in Fig. 6 (a) or (b) represents the initial value for each parameter. When the parameter of forgetting γ_i is zero, all the nodes will remember the information forever. Under this circumstance, the joining ratio will keep increasing to 36.3% after 52 weeks. However, when there is a probability of forgetting, it will be stable at around 17.6%. This means that except for the extreme situation, the state level of active nodes number is not sensitive to the forgetting ratio.

According to Fig. 6 (b), the convergence level of active nodes largely depends on the infection ratio β_a. $\beta_a = 0$ means there is no herd effect in the social network. Potential investors make decisions only by themselves. In this case, the joining ratio stays at 11.1%. When an inactive node is perfectly affected by the active node ($\beta_a = 100\%$), the number of active nodes will reach 615 then keep stabilize at 550.

In Fig. 6 (c), a joint sensitivity analysis of the investment behavior sustainability is conducted. When all the nodes continue their investment behavior from their initial time of investment ($\mu_{na} = \mu_{ia} = 0$), the active nodes will ultimately cover the whole social network. Oppositely, when the investment behavior is completely unsustainable ($\mu_{na} = \mu_{ia} = 1$), the convergence level of the joining ratio will stay at 13.4%. Taking the two parameters separately, the active nodes are largely affected by the probability of an informed node to give up investment, μ_{ia}, while it is insensitive to μ_{na} if μ_{na} is larger than zero. When an un-informed node never gives up its investment behavior ($\mu_{na} = 0$), no matter whether the informed node gives up or not, the convergence level will rise to more than 47.9%.

4.4. Information-targeted policy simulation

To promote reputation dissemination, two information-targeted policies are proposed. In the policy of information exposure, the government will publish the list of PVPA funders periodically. The additional proportion of informed nodes at the beginning of each period θ_i is therefore increased. With this policy, the convergence level of active nodes is elevated as shown in Fig. 7. If θ_i increases to 10%, the joining ratio of investors will reach 24.1%.

The second policy is to encourage social discussion of PVPA relevant topics through the state-controlled media. The probability of an un-informed node being affected by others is therefore increased. As shown in Fig. 8, with the infection ratio β_i raised from 0 to 10%, the convergence level also increases from 17.6% to 30.0%. Compared with the policy of information exposure, a 10% rate for θ_i has a similar promotion effect of reputation dissemination with the infection ratio β_i of 4%.

To determine the combined effect of two information-targeted polices, a joint simulation of the two policies was conducted. Although the joining ratio is positively related to the two policies separately, when they are implemented simultaneously, the policy of information exposure is only effective when θ_i is less than 5% as shown in Fig. 9. When θ_i exceeds 5%, the number of active nodes becomes insensitive to the change of infection ratio β_i. The convergence level would reach 30.5% when β_i and θ_i are both equal to 10%, which is higher than the separate policies.

5. Conclusions and discussion

To promote third-party financing in PVPA in China, a comprehensive assessment of both direct economic benefits and potential benefits from reputational promotion was conducted. An agent-based model of the multiplex network, integrating heterogeneous connections of information and behavior, was developed and applied to study the effect of reputational promotion in the PVPA financing market. Four key conclusions were obtained:

i) According to the cash flow assessment in the present paper, the annual aggregate profit of a 10 MW PV project is negative for the first eleven years. The project becomes profitable from the twelfth year and the profit continues to increase thereafter. The net present value across the life of the project would reach 5.12 and 4.57 million RMB in area 1 and area 2 respectively, without considering the poverty alleviation fund.
ii) As for the potential benefits from reputational promotion, a saturation rate of 17.6% of investors will invest in the corporation at the end of the simulation, regardless of whether

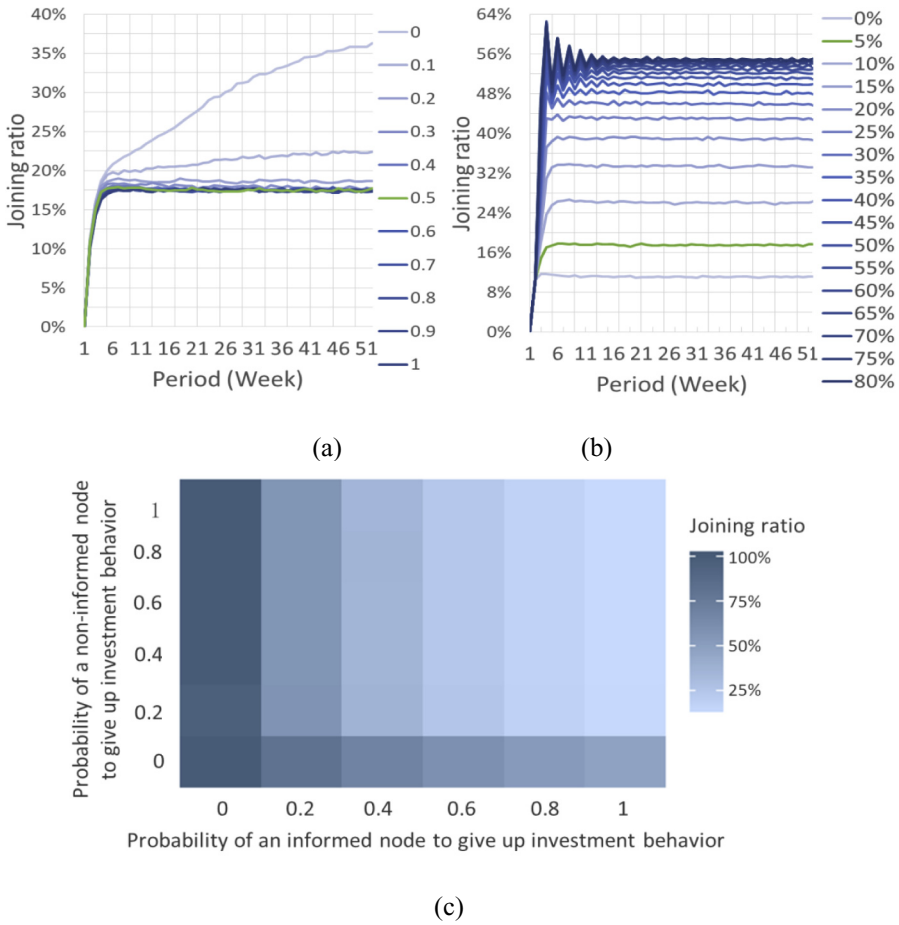

Fig. 6. Sensitivity analysis of (a) parameter in forget function γ_i, (b) behavior infection ratio β_a and (c) sustainability of investment behavior.

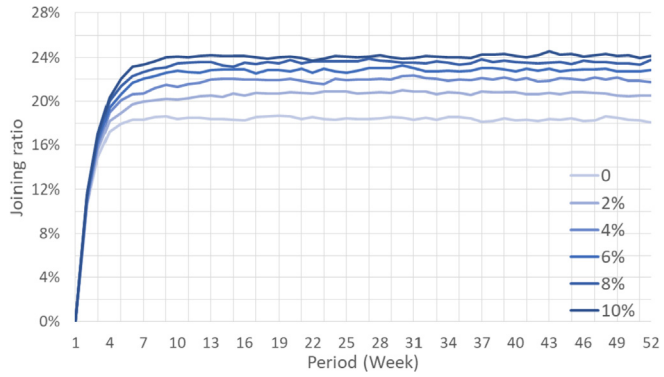

Fig. 7. Policy simulation of information exposure.

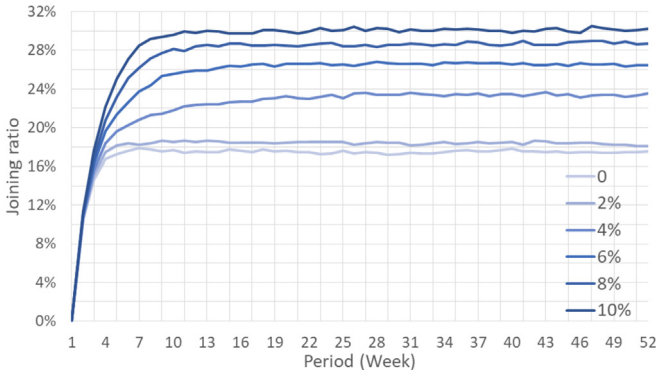

Fig. 8. Policy simulation of encourage social discussion.

there is information about PVPA or not. The maximal difference of convergence levels of joining ratio is 5.0% across different levels of information exposure. The revenue from reputational promotion would therefore vary from 1.5 million RMB to 34.5 million RMB considering different funds operating ability for each corporation, accounting for the poverty alleviation funds of 5000 to 115,000 households. Otherwise PVPA projects will be less attractive compared with a commercial PV project. Funding the PVPA projects are more beneficial for the corporations with better skills at fund operating.

iii) According to the simulation of potential profit from reputational promotion, the news of the target corporation joining PVPA is only effective for the first 20 weeks. Therefore, the simulation of two information-targeted polices were conducted. The policy of information exposure can raise the convergence level of joining ratio from 16.7% to 24.1%, while the policy of encouraging social discussion raises it to 30.0%. In the combination of the two policies, the additional proportion of informed nodes at the beginning of each period θ_i and the infection ratio in the information network β_i are increased respectively. A rate of 10% for θ_i has a similar

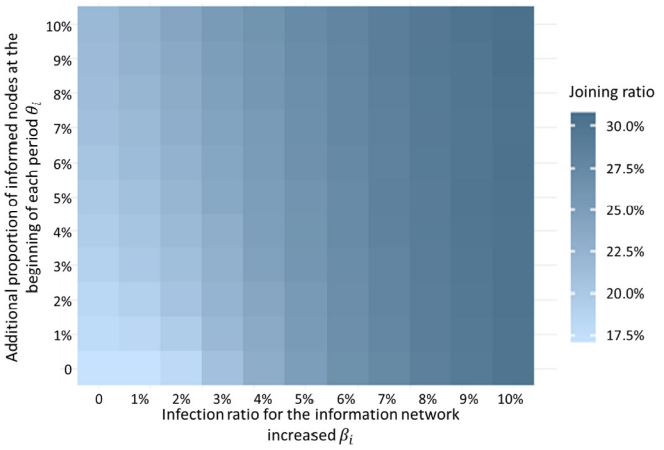

Fig. 9. Joint simulation of two policies.

promotional effect on reputation dissemination as an infection ratio β_i of 4%. After combining the two policies, the policy of information exposure is only effective when β_i is less than 5%. On the other hand, the second policy, encouraging social discussion, can significantly promote the investment behavior. The results indicate that when combining the two policies, the promotion effect of information exposure will be full covered by the policy of encouraging social discussion.

iv) Sensitivity analyses were conducted for the consideration of robustness of the model outcomes. If there is no forgetting mechanism in the information network, the number of active nodes continues increasing. As long as there is a probability of forgetting the information, the convergence level would be stable after the sixth period. The convergence level is positively related to the behavior infection ratio β_a, which indicates the behavior imitation and herd effect is beneficial to reputation dissemination. Besides, the investment ratio is insensitive to the probability of an un-informed potential investor to give up investment behavior μ_{na}, while it is negatively related to the probability of an informed investor μ_{ia} to give up the investment. In particular, when μ_{na} is zero, no matter whether the informed investor gives up or not, the joining ratio will rise to 47.9%.

This study is mainly aimed at proposing a new perspective for investors in decision making and providing policy recommendations for government to take advantage of non-fiscal policy to achieve the objectives. Moreover, it can also explain why nowadays many corporations are willing to take party in charities: some of them may focus on the potential profit brought by the improvement of their corporate identity and social reputation.

However, there are still some limitations in the present study. On one hand, reputation composition is comprehensive and the actual value is difficult to obtain, for example how to assess the value of customers' loyalty or how to estimate the benefits of increasing cooperation partners is a complex issue that needs to be further investigated. On the other hand, the net profit of common shareholders' equity by the number of shareholders is applied as an approximation in this paper. A more precise and practical assessment of these data still requires further empirical studies.

Acknowledgement

The authors gratefully acknowledge the financial support of the National Natural Science Foundation of China (Grant No. 71774171) and Beijing Municipal Social Science Foundation (Grant No. 18GLC084).

References

Antonioni, A., Sánchez, A., Tomassini, M., 2016. Cooperation survives and cheating pays in a dynamic network structure with unreliable reputation. Sci. Rep. 6, 27160. https://doi.org/10.1038/srep27160

Barbier, E.B., Burgess, J.C., 2017. Natural resource economics, planetary boundaries and strong sustainability. Sustainability 9, 1858. https://doi.org/10.3390/su9101858

Besley, T., Ghatak, M., 2007. Retailing public goods: the economics of corporate social responsibility. J. Publ. Econ., Celebrating the 20th Anniversary of Bergstrom, Blume, and Varian's "On the Private Provision of Public Goods" 91, 1645–1663. https://doi.org/10.1016/j.jpubeco.2007.07.006

Blasi, S., Caporin, M., Fontini, F., 2018. A multidimensional analysis of the relationship between corporate social responsibility and firms' economic performance. Ecol. Econ. 147, 218–229. https://doi.org/10.1016/j.ecolecon.2018.01.014

Bocken, N.M.P., Short, S.W., Rana, P., Evans, S., 2014. A literature and practice review to develop sustainable business model archetypes. J. Clean. Prod. 65, 42–56. https://doi.org/10.1016/j.jclepro.2013.11.039

Boons, F., Lüdeke-Freund, F., 2013. Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. Journal of Cleaner Production, Sustainable Innovation and Business Models 45, 9–19. https://doi.org/10.1016/j.jclepro.2012.07.007

BP, 2018. Energy Outlook 2018.

Brammer, S.J., Pavelin, S., 2006. Corporate reputation and social performance: the importance of fit. J. Manag. Stud. 43, 435–455. https://doi.org/10.1111/j.1467-6486.2006.00597.x

Cohn, R.A., Lewellen, W.G., Lease, R.C., Schlarbaum, G.G., 1975. Individual investor risk aversion and investment portfolio composition. J. Finance 30, 605–620. https://doi.org/10.1111/j.1540-6261.1975.tb01834.x

Davidson, C., Steinberg, D., 2013. Evaluating the impact of third-party price reporting and other drivers on residential photovoltaic price estimates. Energy Pol. 62, 752–761. https://doi.org/10.1016/j.enpol.2013.07.112

de Paulo, A.F., Porto, G.S., 2017. Solar energy technologies and open innovation: a study based on bibliometric and social network analysis. Energy Pol. 108, 228–238. https://doi.org/10.1016/j.enpol.2017.06.007

Dollinger, M.J., Golden, P.A., Saxton, T., 1997. The effect of reputation on the decision to joint venture. Strat. Manag. J. 18, 127–140. https://doi.org/10.1002/(SICI)1097-0266(199702)18:2<127::AID-SMJ859>3.0.CO;2-H

Drury, E., Miller, M., Macal, C.M., Graziano, D.J., Heimiller, D., Ozik, J., Perry IV, T.D., 2012. The transformation of southern California's residential photovoltaics market through third-party ownership. Energy Pol. 42, 681–690. https://doi.org/10.1016/j.enpol.2011.12.047

Gardberg, N.A., Fombrun, C.J., 2002. The global reputation quotient project: first steps towards a cross-nationally valid measure of corporate reputation. Corp. Reput. Rev. 4, 303.

Gerilemanda, 2016. A Study on the Investment Benefit and Financial Support of Distributed Photovoltaic Power Generation. North China Electric Power University.

Goffman, W., Newill, V.A., 1964. Generalization of epidemic theory: an application to the transmission of ideas. Nature 204, 225.

Granell, C., Gómez, S., Arenas, A., 2013. Dynamical interplay between awareness and epidemic spreading in multiplex networks. Phys. Rev. Lett. 111, 128701. https://doi.org/10.1103/PhysRevLett.111.128701

Halkos, G., Skouloudis, A., 2018. Corporate social responsibility and innovative capacity: intersection in a macro-level perspective. J. Clean. Prod. 182, 291–300. https://doi.org/10.1016/j.jclepro.2018.02.022

Heaney, M.T., 2014. Multiplex networks and interest group influence reputation: an exponential random graph model. Social Networks, Special Issue on Political Networks 36, 66–81. https://doi.org/10.1016/j.socnet.2012.11.003

Hong, T., Yoo, H., Kim, J., Koo, C., Jeong, K., Lee, M., Ji, C., Jeong, J., 2018. A model for determining the optimal lease payment in the solar lease business for residences and third-party companies – with focus on the region and on multi-family housing complexes. Renew. Sustain. Energy Rev. 82, 824–836. https://doi.org/10.1016/j.rser.2017.09.068

Hori, S., Shinozaki, M., Nogata, D., Fujita, T., 2014. The role of CSR in promoting companies' energy-saving actions in two Asian cities. Energy Pol. 69, 116–121. https://doi.org/10.1016/j.enpol.2014.01.030

Hu, D., Zhao, J.L., Cheng, J., 2012. Reputation management in an open source developer social network: an empirical study on determinants of positive evaluations. Decis. Support Syst. 53, 526–533. https://doi.org/10.1016/j.dss.2012.02.005

Huck, S., Lünser, G.K., Tyran, J.-R., 2010. Consumer networks and firm reputation: a first experimental investigation. Econ. Lett. 108, 242–244. https://doi.org/10.1016/j.econlet.2010.04.017

Khajehpour, H., Saboohi, Y., Tsatsaronis, G., 2017. Environmental responsibility accounting in complex energy systems. J. Clean. Prod. 166, 998–1009. https://doi.org/10.1016/j.jclepro.2017.08.013

Khaqqi, K.N., Sikorski, J.J., Hadinoto, K., Kraft, M., 2018. Incorporating seller/buyer reputation-based system in blockchain-enabled emission trading application.

Appl. Energy 209, 8–19. https://doi.org/10.1016/j.apenergy.2017.10.070
Mauleón, I., 2017. Photovoltaic investment roadmaps and sustainable development. J. Clean. Prod. 167, 1112–1121. https://doi.org/10.1016/j.jclepro.2017.08.148
May, R.M., Lloyd, A.L., 2001. Infection dynamics on scale-free networks. Phys. Rev. E 64, 066112. https://doi.org/10.1103/PhysRevE.64.066112
Ministry of Finance of the People's Republic of China, State Administration of Taxation of the People's Republic of China, 2016. Notice on Implementation of the VAT Policy on Photovoltaic Power Generation.
National Development and Reform Commission, 2015. Notice on Perfecting the Benchmark Tariff Policy of Photovoltaic and Onshore Wind Power Generation.
National Development and Reform Commission, 2013. Notice on Promoting the Healthy Development of Photovoltaic Industry by Leveraging Price Leverage.
National Energy Administration, of the P.R. of C, 2018. Energy Situation in 2017.
National Energy Administration, of the P.R. of C., The State Council, of the P.R. of C, 2018. Management Measures for Photovoltaic Poverty Alleviation Power Station.
National Energy Administration of the People's Republic of China, 2016. Photovoltaic Poverty Alleviation Has Become a New Path for Rural Development.
Olinky, R., Stone, L., 2004. Unexpected epidemic thresholds in heterogeneous networks: the role of disease transmission. Phys. Rev. E - Stat. Nonlinear Soft Matter Phys. 70, 030902.
Pellegrini-Masini, G., Leishman, C., 2011. The role of corporate reputation and employees' values in the uptake of energy efficiency in office buildings. Energy Pol. 39, 5409–5419. https://doi.org/10.1016/j.enpol.2011.05.023
Pigors, M., Rockenbach, B., 2016. Consumer social responsibility. Manag. Sci. 62, 3123–3137. https://doi.org/10.1287/mnsc.2015.2279
Raithel, S., Schwaiger, M., 2015. The effects of corporate reputation perceptions of the general public on shareholder value. Strat. Manag. J. 36, 945–956.
Reim, W., Parida, V., Örtqvist, D., 2015. Product–Service Systems (PSS) business models and tactics – a systematic literature review. Journal of Cleaner Production, Special Volume: Why have 'Sustainable Product-Service Systems' not been widely implemented? 97, 61–75. https://doi.org/10.1016/j.jclepro.2014.07.003
Roberts, P.W., Dowling, G.R., 2002. Corporate reputation and sustained superior financial performance. Strat. Manag. J. 23, 1077–1093.
Sabater, J., Sierra, C., 2002. Reputation and social network analysis in multi-agent systems. In: Proceedings of the First International Joint Conference on Autonomous Agents and Multiagent Systems: Part 1, AAMAS '02. ACM, New York, NY, USA, pp. 475–482. https://doi.org/10.1145/544741.544854.
Siegel, D.S., 2009. Green management matters only if it yields more green: an economic/strategic perspective. Acad. Manag. Perspect. 23, 5–16.
State Administration of Taxation, 2014. About the State Grid Corporation to Purchase Distributed Photovoltaic Power Generation Project Invoices and Other Issues.
Strupeit, L., Palm, A., 2016. Overcoming barriers to renewable energy diffusion: business models for customer-sited solar photovoltaics in Japan, Germany and the United States. Journal of Cleaner Production, Advancing Sustainable Solutions: An Interdisciplinary and Collaborative Research Agenda 123, 124–136. https://doi.org/10.1016/j.jclepro.2015.06.120
Sun, L., Huang, Y., Liu, S., Chen, Y., Yao, L., Kashyap, A., 2017. A completive survey study on the feasibility and adaptation of EVs in Beijing, China. Appl. Energy 187, 128–139. https://doi.org/10.1016/j.apenergy.2016.11.027
The State Council Information Office of the People's Republic of China, 2016. To Lift 70 Million Improverish People Out of Poverty in 4 Years. State Council.
The State Council Information Office of the People's Republic of China, 2015. SCIO Briefing on Poverty Alleviation and Development.
Tischer, S., Hildebrandt, L., 2014. Linking corporate reputation and shareholder value using the publication of reputation rankings. J. Bus. Res. 67, 1007–1017. https://doi.org/10.1016/j.jbusres.2013.08.007
Tuazon, D., Corder, G.D., McLellan, B.C., 2013. Sustainable development: a review of theoretical contributions. International Journal of Sustainable Future for Human Security 1, 40–48.
Turban, D.B., Greening, D.W., 1997. Corporate social performance as a competitive advantage in attracting a quality workforce. Bus. Soc. 40, 254–280. https://doi.org/10.1177/000765030003900302
Van Nieuwerburgh, S., Veldkamp, L., 2010. Information acquisition and under-diversification. Rev. Econ. Stud. 77, 779–805. https://doi.org/10.1111/j.1467-937X.2009.00583.x
Wahba, H., 2008. Does the market value corporate environmental responsibility? An empirical examination. Corp. Soc. Responsib. Environ. Manag. 15, 89–99. https://doi.org/10.1002/csr.153
Walsh, G., E. Beatty, S., 2007. Customer-based corporate reputation of a service firm: scale development and validation. J. Acad. Market. Sci. 35, 127–143. https://doi.org/10.1007/s11747-007-0015-7
Wang, Ge, Zhang, Qi, Li, Yan, Li, Hailong, 2018. Policy simulation for promoting residential PV considering anecdotal information exchanges based on social network modelling. Appl. Energy 223, 1–10.
Wilson, A., Gotsi, M., 2001. Corporate reputation management: "living the brand. Manag. Decis. 39, 99–104.
Zhang, C., 2017. Political connections and corporate environmental responsibility: adopting or escaping? Energy Econ. 68, 539–547. https://doi.org/10.1016/j.eneco.2017.10.036
ZHANG, L., YANG, Z., LU, F., 2014. Empirical analysis of relevance of stock indicators based on complex network theory. Chinese Journal of Management Science 85–92.
Zhang, S., 2016. Innovative business models and financing mechanisms for distributed solar PV (DSPV) deployment in China. Energy Pol. 95, 458–467. https://doi.org/10.1016/j.enpol.2016.01.022
Zhou, J., Liu, Z., Li, B., 2007. Influence of network structure on rumor propagation. Phys. Lett. 368, 458–463. https://doi.org/10.1016/j.physleta.2007.01.094