Hongying Zhao

The Impact of Electricity Price Policy on the Economic Performance of Distributed Building Photovoltaic Systems across China

Hongying Zhao[1], Rebecca Yang[1], Trivess Moore[1] and Chengyang Liu[1]
[1]*Melbourne Institute of Technology, 124 La Trobe St, Melbourne, Australia*
E-mail: rebecca.yang@rmit.edu.au

Abstract

Distributed building PV systems are very promising renewable energy resources for urban areas. The Chinese government puts great efforts into developing and deploying building PV systems including building-attached photovoltaic systems (BAPV) and building-integrated photovoltaic system (BIPV). The national feed-in tariff policy provides a subsidy to improve the self-consumption of distributed building PV systems, which is greatly attractive to investors. For distributed building PV with high self-consumption ratio, the economic performance also closely ties to the electricity price policy. However, limited research has investigated the impacts of electricity price change on the economic performance of building PV applications across China. Hence, this study aims to bridge the gap by conducting a lifecycle cost-benefit analysis of various kinds of distributed building PV systems (both BAPV and BIPV) across China by considering the electricity price change. There are 12 cities selected to represent the majority of urban areas in China with diverse geographic conditions and electricity policy conditions. Five different building PV systems covering the most popular types of building PV systems in China are investigated. Net Present Value (NPV) per kW is employed to assess the economic performance. Through an established MATLAB program, the relationship between the changes of electricity price and the economic performance of each case in all selected cities are investigated and discussed. This study provides great insight for investors and policymakers regarding the investment choice and policy incentives of building PV applications when confronting high uncertainty of electricity price.

1. Introduction

Solar Photovoltaic (PV) application has experienced rapid growth, especially in China. The Chinese government has put great efforts into developing the distributed PV systems including Building-attached PV (BAPV) and Building-integrated PV (BIPV) since 2012 (Yuan et al. 2014). Policies play an important role in improving the financial attractiveness of distributed building PV systems. For distributed building PV projects in China, there are two main policies that can affect the economic benefit, namely Feed-in Tariff (FIT) policy and electricity price policy.

In China, FIT policy provides two benefit modes for distributed PV projects. The first mode is to treat the distributed PV as a traditional solar plant, where all generated power is sold to the grid at the price of local FIT. There have been many studies regarding the economic analysis of FIT price on PV projects (Rigter and Vidican, 2010; Ye et al., 2017; Zhang et al., 2016).

The second mode is called as “self-generated and self-consumed”, which is to encourage the distributed PV investors to consume the generated power by themselves. If there is any surplus energy, it can be sold to public grid at the price of local electricity wholesale price to make extra profit. As decentralized energy source, distributed PV project can fulfill its advantages under the second benefit mode. In order to promote the self-consumption, the Chinese government offers a 20-year subsidy for every unit generation of distributed building PV systems using this benefit mode, which is greatly attractive to investors. Meanwhile, investors can gain more economic benefit under the second benefit mode. For every kWh electricity generated by the building PV system and consumed by the building, the benefit will be the saved electricity bill (i.e. electricity retail price) and national subsidy provided by the government, which is much higher than the FIT price. As a result, the saved electricity bill makes up part of the economic benefit for the building PV systems using the "self-generated and self-consumed" mode. Hence, for distributed building PV with high self-consumption ratio like PV systems in commercial buildings, the economic performance mainly ties to the electricity policy which determines the retail electricity price and its adjustment. However, there is limited research investigating the impact of the electricity price policy on the economic performance of the distributed PV projects.

In China, the energy market and pricing mechanism have been regulated by the central government tightly for a long time (Wang and Zhang, 2016). The strict governance on the electricity price has prevented the electricity market from effective competition among market participants (Liu, 2015). From 2015, the Chinese government started to carry out a reform of the electricity market in order to liberalise the national electricity market. It is anticipated that the electricity price can be adjusted through a more market-oriented mechanism. The electricity system reform brings a high level of uncertainty of the electricity price change in China.

A number of factors can cause the fluctuation of the retail electricity price and it is hard to forecast the change in electricity price. In economic analysis model of PV application, it is a common practice to treat the electricity price as a fixed value or a fixed rate of change over time to simplify the electricity price modeling (Sommerfeldt and Madani, 2017). Many studies have considered the electricity price change by involving a single price evolution rate (Lacchini and Rüther, 2015; Rodrigues et al., 2016; Vilaça Gomes et al., 2018). However, limited research has taken into consideration the difference of the electricity price change between different geographic locations in a nation. In the context of China, the electricity tariff for retail is still under the control of the central government, which varies between provinces and municipalities (Zhang et al., 2018). China is large in territory with diverse climatic and policy conditions. Different cities have their own electricity price policy and growth rate (Wang and Zhang, 2016). There is a lack of research investigating the influence of the electricity price change on the economic performance of distributed building PV projects across China.

On the other hand, a lot of studies analysis the system performance and the environmental benefit of BAPV and BIPV in China. However, the application level of BIPVs in China is low due to the unawareness of additional benefit of BIPVs (Zhang et al., 2015). There is limited research comparing the economic performance of different building PV applications across China. Most economic studies focus on the BAPV systems (Rodrigues et al., 2017; Rodrigues et al., 2016; Yuan et al., 2014). Only two studies have compared the performance of different PV applications, but each focuses on only one city, namely Shanghai (Wang et al., 2016) and Xi'an (Wei et al., 2014).

Hence, this study aims to bridge these gaps by conducting a lifecycle cost-benefit analysis of various kinds of distributed building PV systems (both BAPV and BIPV) in the context of China by considering the electricity price change. Five different building PV systems covering the most popular types of building PV systems in China are investigated. These 12 cities cover the majority of climatic conditions and solar conditions in China, making the study applicable to most urban areas in China. In order to study the impact of electricity price change on the economic performance, the study examines a wide range of electricity price growth rate covering all the cities and provinces in China. A MATLAB program is established to conduct the economic evaluation, using Net Present Value (NPV) per kW as the economic indicator. The study reveals the relationship between the NPV per kW and tariff growth rate of all five kinds of building PV applications in 12 representative cities of China. Based on the findings, recommendations for investors and policymakers are provided.

The structure of this paper is as follows: Section 2 is the detailed explanation of the research process; Section 3 provides the results and discussion, and Section 4 is the conclusion.

2. Research process

In this section, the research process is explained in detail. There are two main steps: (1) the selection of suitable PV projects and representative cities, and (2) the economic analysis considering the tariff growth rate.

2.1. PV project selection and city selection

The research intends to cover the most popular building PV systems in China based on the study of Zhang et al. (2015). Hence, real-world projects are provided by a green building design and construction company, and five different building PV scenarios are developed as shown in Table 1. These building PV systems are all installed on the commercial buildings. Scenario 1 in case a and Scenario 4 in case c are all roof BAPV with different system capacity. Scenario 2 and Scenario 3 in case b are developed from one case with different original design assumption. Scenario 2 assumes that the roof BIPV replaces concrete roof while Scenario 3 assumes that BIPV is substituted for glazing roof. Scenario 5 in case c is a façade BIPV replacing window.

Table 1. Summary of the background of three projects

Case Building	a	b		c	
Scenario	1	2	3	4	5
Application	BAPV	BIPV	BIPV	BAPV	BIPV
PV Type	Roof	Roof	Roof	Roof	Façade (Window)
Cell type	Poly-Si	Quasi-mono-Si	Quasi-mono-Si	Mono-Si	Thin-film
Capacity (kW)	2,825.4	60	60	28.08	50.58
Solar cell Area (A) (m2)	18,025.83	914.76	914.76	183.84	865.48
Array Tile	Local latitude	0	0	Local latitude	90
Efficiency (r)	16%	17%	17%	18%	10%
Construction Cost (RMB)	20,605,098	2,157,000	2,157,000	315,628	769,107
Construction cost RMB/kW (BIPV without offsets)	7,293	35,950	35,950	11,240	15,206
Construction cost RMB /kW (BIPV with offsets)	7,293	29,812	17,352	11,240	7,506

China is large in territory with diverse geographic conditions and policy conditions. In this study, there are 12 representative cities selected based on the solar intensity level and climatic zone, which can cover the majority of urban areas in China. Table 1 illustrates the solar irradiation distribution and the building climate zones in China. The 12 cities are demonstrated in the figure. The detailed analysis of electricity price policy in 12 cities is conducted as shown in Table 2. The local electricity price is obtained from government websites. The local electricity price growth rate is calculated based on the study of Wang and Zhang (2016). For the sake of further analysis, the local electricity price and its growth rate are ranked from high to low.

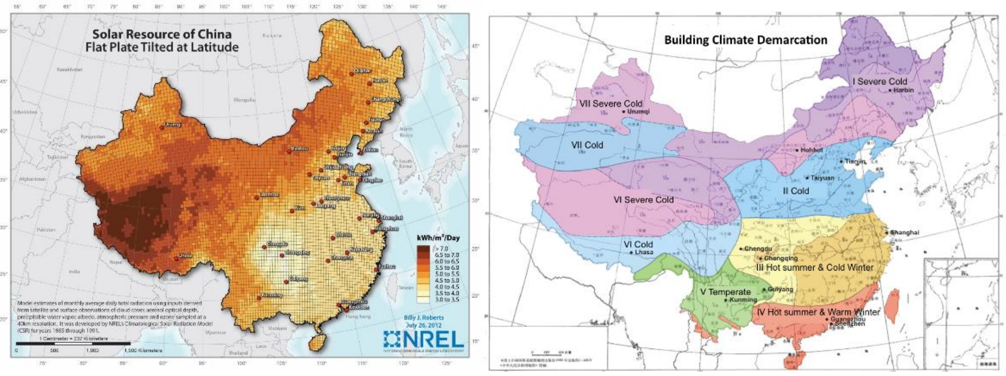

Figure 1. The solar irradiation distribution map and the building climate zones in China (source: NREL 2012; GB50352-2005)

Table 2. Summary of city information

City	Local Electricity Policy	Local Electricity Price RMB /kWh		Local Electricity Price Growth Rate		Local Subsidy Policy	National Subsidy Policy
		Value	Rank	Value	Rank		
Urumqi	Fixed price	0.5850	12	0.59%	9		For self-consumed part 20-year subsidy: RMB 0.37/kWh
Kunming	Fixed price	0.6550	11	2.08%	5		
Guiyang	Fixed price	0.7224	10	2.60%	4		
Hohhot	Fixed price	0.7440	9	-0.08%	11		
Chengdu	Fixed price	0.7799	8	-0.37%	12		
Chongqing	Fixed price	0.7925	6	0.07%	10		
Shenzhen	Fixed price	0.8616	5	2.04%	6		
Harbin	Fixed price	0.8665	4	1.12%	8		
Guangzhou	Fixed price	0.8983	3	2.04%	6	One-off subsidy: RMB 0.2 /w (max 2,000,000)	
Taiyuan	3-period price	0.6963 (11-18;7-8) 1.0076 (8-11;18-23) 0.4068 (23-7)	7	4.72%	2		
Tianjin	3-period price	0.8367 (7-8 11-18)	2	3.17%	3		

		1.2035 (8-11;18-23) 0.5522(23-7)					
Shanghai	2-season 2-period price	Summer (July, August, September) 1.095(6-22) 0.541(22-6) Other Seasons 1.060(6-22) 0.506(22-6)	1	7.51%	1	5-year subsidy: RMB 0.25/kWh	

2.2. Economic performance under different conditions

The economic performance of PV projects can be evaluated through various methods (Sommerfeldt and Madani, 2017). In this study, Net Present Value (NPV) per kW is selected to assess the economic performance of all the building PV systems in 12 cities. Equation 1 presents the calculation of the NPV in the study respectively. To standardize the comparison between each scenario with different PV capacities, NPV per kW is employed instead of NPV.

$$\boldsymbol{NPV} = -\boldsymbol{C_0} + \sum_{n=1}^{N} \frac{\boldsymbol{B_n}}{(\boldsymbol{1}+\boldsymbol{r})^{\boldsymbol{n}}} - \sum_{n=1}^{N} \frac{\boldsymbol{M_n}}{(\boldsymbol{1}+\boldsymbol{r})^{\boldsymbol{n}}} \qquad (1)$$

Where C_0 is the net construction cost as shown in Table 1, $\mathrm{B(n)}$ is the benefit generated by the PV system, Mn is the maintenance cost, which is assumed to be the cost of changing the inverters every 10 years, and r is the discount rate, which is set to be 2.25%.

In this study, all the PV scenarios in 12 cities are 100% self-consumption for the annual energy generation of the PV system is greater than the annual building energy consumption based on the Standard for Energy Consumption of Building (GB/T 51161-2016). Thus, the benefit equation of all the scenarios is shown as follows:

$$\mathbf{B(n)} = \sum_{n=1}^{N} \sum_{h=1}^{8760} \mathbf{ep_h} \times (\mathbf{1} + \Delta\mathbf{ep})^{\mathbf{n}} \times \mathbf{E(h)} + \sum_{h=1}^{8760} \boldsymbol{Sb_n} \times \mathbf{E(h)} + \mathbf{sb}_{\boldsymbol{l}} \qquad (\mathbf{2})$$

Where n is the number of the year, ep_h is the electricity price of that hour, $\Delta\mathrm{ep}$ is the compounded growth rate of the electricity price of the city, E(h) is the hourly energy generation, Sb_n is the unified national subsidy provided by the government lasting for 20 years, and Sb_l is the extra subsidy provide by the local government. Table 2 provides the summary of the electricity price and subsidy policy in 12 cities.

To the PV generation, the following equation is used.

$$\boldsymbol{E(h)} = \boldsymbol{A} \times \boldsymbol{r} \times \boldsymbol{h} \times \boldsymbol{PR} \qquad (\mathbf{3})$$

Where E(h) is the energy output in kWh, A is the total solar cell area in m2, r is the PV product efficiency in percentage, h is the hourly solar radiation in kWh/m2, and PR is the system performance ratio. The corresponding statistics of h used for each scenario in 12 cities are collected from a popular solar modelling tool – PVWatts (NREL, 2018). The PR in the study is assumed to be 86%, which is the default value of the PVWatts Calculator taking into consideration dust loss, shading loss and other system losses (NREL, 2018). A, r and the PV panel tilt angle of each scenario are summarized in Table 1. The lifespan of all the PV projects is 25 years. The annual degradation rate of the PV system is assumed to be 0.07%.

The calculation is performed by the established MATLAB program. In order to investigate the impact of the electricity price change on the economic performance of the PV projects, the program generates the result of NPV per kW of each scenario in each city by changing the electricity growth rate in a given range while keeping other variables the same. The range of tariff growth rate is from -1.37% (i.e. the average of all negative tariff growth rates in China) to 7.52% (i.e. the highest tariff growth rate), based on the study of Wang and Zhang (2016).

3. Results and discussion

The results of the NPV per kW of each scenario in 12 cities are shown in Figure 2. In the figure, the triangle on each line represents the NPV per kW of the city using the local tariff growth rate as shown in Table 2. Each line illustrates the changing trend of the NPV per kW in each city. There are similarity and difference among the five graphs. In order to better understand the causes of the results, we should also look back to the specific background of each city. Table 3 provides the amount of total energy generation of 5 scenarios in 12 cities throughout the whole lifespan and the ranks.

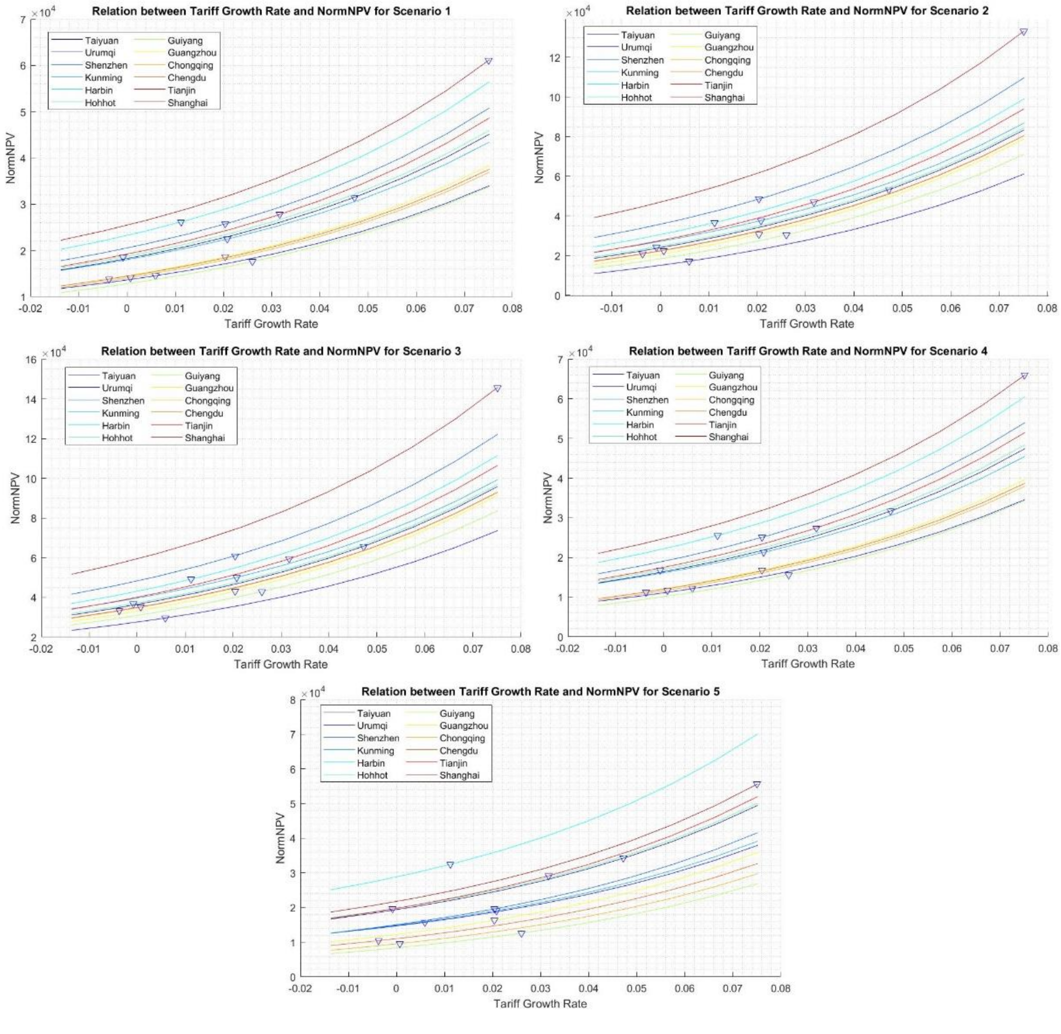

Figure 2. Relationship between tariff growth rate and NPV per kW of all five building PV applications in 12 cities

Table 3. Summary of the 25 years' energy generation in 12 cities and their ranks

City	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	Output	Rank	Output	Rank	Output	Rank	Output	Rank	Output	Rank
Urumqi	48092285	6	2312236	6	2312236	6	546870	6	613252	3
Hohhot	50522977	3	2352968	4	2352968	4	551163	3	617135	2
Harbin	52932524	2	2319267	5	2319267	5	555418	2	643143	1
Taiyuan	48740273	4	2274184	7	2274184	7	548014	4	612926	4
Tianjin	43664456	8	2097291	11	2097291	11	539050	8	593667	6
Shanghai	46199702	7	2369064	3	2369064	3	543529	7	582937	7
Chengdu	40990967	9	2186486	8	2186486	8	534329	9	567799	9
Chongqing	39845702	11	2155379	9	2155379	9	532306	10	559172	12
Shenzhen	48536026	5	2516981	2	2516981	2	547655	5	579325	8
Guangzhou	36774678	12	1902819	12	1902819	12	526882	12	562231	10
Kunming	53634896	1	2673963	1	2673963	1	556660	1	603163	5
Guiyang	40121265	10	2141589	10	2141589	10	532793	11	559544	11

For all five scenarios in 12 cities, it is obvious that the relationship between tariff growth rate and the NPV per kW is not linear. Instead, the lines within the given range fit cubic function. Hence, the NPV per kW rises significantly as the tariff growth rate increases. When comparing between each scenario, generally speaking, the tariff growth rate has a greater impact on the NPV per kW of Scenario 2 and Scenario 3. For each scenario, there are some cities whose NPV per kW are affected more greatly by the tariff growth rate than other cities.

Among all five the graphs, the graph of Scenario 5 is apparently different from other scenarios, which is mainly because Scenario 5 is the façade building PV while the others are roof PV systems. Furthermore, the graphs of Scenario 1 and Scenario 4 are quite similar and so are the graphs of Scenario 2 and Scenario 3 because Scenario 1 and Scenario 4 are roof BAPVs while Scenario 2 and Scenario 3 are roof BIPVs. For all roof building PV systems, Shanghai is the city with the highest NPV per kW among all the cities under the same tariff growth rate. Shanghai is also the city that NPV per kW is affected most greatly by the electricity price growth rate. However, for Scenario 5 – façade BIPV, Harbin excels Shanghai and becomes the city with the highest NPV per kW and greatest sensitivity to the tariff growth rate. According to Table 3, Harbin has the highest energy generation using the façade BIPV because of its highest latitude among all 12 cities.

For all the roof PV scenarios, Kunming has the highest energy generation among all the cities and almost the lowest electricity price as shown in Table 3 and Table 2. The lines of Shanghai, Shenzhen, Harbin and Tianjin of four scenarios are all above the line of Kunming. The electricity prices of the four cities are among the top five highest. Meanwhile, except for Tianjin, the electricity generation of Shanghai, Shenzhen and Harbin is relatively high. On the other hand, Urumqi and Guiyang are worth analysing for they are the lowest two lines of the four roof PV scenarios. The energy generation of Urumqi is medium while that of Guiyang is quite low as shown in Table 3. However, the electricity price of Guiyang is higher than that of Urumqi. For the two roof BAPVs (i.e. Scenario 1 and Scenario 4), although the line of Urumqi is above the line of Guiyang in the given range, the distance between the two lines becomes smaller as the tariff growth rate increase, which indicates that the NPV per kW of Urumqi is less affected by the tariff growth rate. The situation of two roof BIPVs (i.e. Scenario 2 and Scenario 3) is the opposite, where the line of Guiyang is always higher than the line of Urumqi and the gap between the two lines becomes bigger. However, the result also indicates that the tariff growth rate has less impact on the NPV per kW of Urumqi for roof building PV scenarios.

When it comes to the façade building PV scenario (i.e. Scenario 5), the cities with the lowest energy output represent the four lowest lines, below the line of Urumqi. Guiyang is the city with the lowest NPV per kW and the least sensitivity to the electricity price change.

4. Conclusion

The Chinese government has put great efforts into developing the distributed PV systems and self-consumption of generated power. For distributed building PV with high self-consumption ratio, the economic performance ties closely to the electricity price policy. However, limited research has investigated the impacts of electricity price change on the economic performance of different kinds of building PV applications across China. In China, the retail electricity price is under the strict control of the government. An electricity system reform is ongoing, which aims to shift the electricity market from regulated toughly by the government to oriented mainly by the market. Hence, it becomes harder to predict the electricity price trend. Currently, there has been limited research investigating the impact of the change of retail electricity price on the economic performance of 5 types of building PV systems in China. This study examines that economic performance of 5 kinds of building PV system in 12 representative cities of China, taking a given range of tariff growth rate into consideration. The main findings are as follows:

- The relationship between NPV per kW and the tariff growth rate of all five scenarios in 12 cities complies with the cubic function in the given range, which indicates that the NPV per kW rises faster as the tariff growth rate increases.
- The economic performance of different types of building PV applications differs under the change of retail electricity price growth rate. In general, Roof BAPV and Rood BIPV share similarity while façade BIPV is quite different.
- For roof BAPV and roof BIPV, Shanghai has the greatest economic performance while the electricity price growth rate has the largest impact on the NPV per kW in Shanghai. Urumqi is the opposite.
- For façade BIPV, Harbin is the city with the highest NPV per kW and the greatest sensitivity to the tariff growth rate while Guiyang is the opposite.

Based on the above findings, recommendations are generated for both policymakers and investors to better boost the uptake of building PV applications in China. For those scenarios with high NPV per kW and high sensitivity, the PV investment would become more favourable when the electricity price is expected to experience significant rise in the future. Thus, investors should pay more attention to the outlook of electricity price. At the same time, the policymakers should be more cautious about the adjustment of retail electricity policy for the overall economic benefit of building PV projects will be greatly influenced. Also, under the current electricity price growth rate, some scenarios in some cities are not suitable for the investment compared with other cities. The research reveals that the investment of PV application with high sensitivity to the electricity price change can be encouraged by the policymakers when there is high possibility that electricity price will increase greatly in the future.

References

He, Y., Pang, Y., Li, X. and Zhang, M, 2018, 'Dynamic subsidy model of photovoltaic distributed generation in China', *Renewable Energy*, 118, p555-564.

Lacchini, C. and Rüther, R, 2015, 'The influence of government strategies on the financial return of capital invested in PV systems located in different climatic zones in Brazil', *Renewable Energy*, 83, p786-798.

Liu, X 2015, 'A new chapter in China's electricity market reform', available from: <http://theasiadialogue.com/2015/11/20/chinas-new-chapter-on-its-electricity-market-reform/> (accessed 1 June 2018).

NREL, 2018, 'PVWatts Calculator', available from: <http://pvwatts.nrel.gov/> (accessed 20 May 2018).

Rigter, J. and Vidican, G, 2010, 'Cost and optimal feed-in tariff for small scale photovoltaic systems in China', *Energy Policy*, 38(11), p6989-7000.

Rodrigues, S., Chen, X. and Morgado-Dias, F, 2017, 'Economic analysis of photovoltaic systems for the residential market under China's new regulation', *Energy Policy*, 101(Supplement C), p467-472.

Rodrigues, S., Torabikalaki, R., Faria, F., Cafôfo, N., Chen, X., Ivaki, A. R., Mata-Lima, H. and Morgado-Dias, F, 2016, 'Economic feasibility analysis of small-scale PV systems in different countries', *Solar Energy*, 131, p81-95.

Sommerfeldt, N. and Madani, H, 2017, 'Revisiting the techno-economic analysis process for building-mounted, grid-connected solar photovoltaic systems: Part one – Review', *Renewable and Sustainable Energy Reviews*, 74(Supplement C), p1379-1393.

Vilaça Gomes, P., Knak Neto, N., Carvalho, L., Sumaili, J., Saraiva, J. T., Dias, B. H., Miranda, V. and Souza, S.M, 2018, 'Technical-economic analysis for the integration of PV systems in Brazil considering policy and regulatory issues', *Energy Policy*, 115, p199-206.

Wang, F. and Zhang, B, 2016, 'Distributional incidence of green electricity price subsidies in China', *Energy Policy*, 88, p27-38.

Wang, W., Liu, Y., Wu, X., Xu, Y., Yu, W., Zhao, C. and Zhong, Y, 2016, 'Environmental assessments and economic performance of BAPV and BIPV systems in Shanghai', *Energy and Buildings*, 130(Supplement C), p98-106.

Wei, H., Liu, J. and Yang, B, 2014, 'Cost-benefit comparison between Domestic Solar Water Heater (DSHW) and Building Integrated Photovoltaic (BIPV) systems for households in urban China', *Applied Energy*, 126(Supplement C), p47-55.

Ye, L.-C., Rodrigues, J. F. D. and Lin, H. X, 2017, 'Analysis of feed-in tariff policies for solar photovoltaic in China 2011–2016', *Applied Energy*, 203, p496-505.

Yuan, J., Sun, S., Zhang, W. and Xiong, M, 2014, 'The economy of distributed PV in China', *Energy*, 78, p939-949.

Zhang, M. M., Zhou, D. Q., Zhou, P. and Liu, G. Q, 2016, 'Optimal feed-in tariff for solar photovoltaic power generation in China: A real options analysis', *Energy Policy*, 97, p181-192.

Zhang, S., Andrews-Speed, P. and Li, S, 2018, 'To what extent will China's ongoing electricity market reforms assist the integration of renewable energy?', *Energy Policy*, 114, p165-172.

Zhang, W., Hao, B., Li, N., Liu, S. and Yao, C, 2015, 'Investigation on Photovoltaic Application in Buildings in China', *Energy Procedia*, 70, p673-682.