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ENGINEERING MANAGEMENT TREATISES

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Economic Analysis of Residential Distributed Solar Photovoltaic

Abstract Under the huge challenges of global energy conservation, emission reduction and energy security, distributed solar photovoltaic industry has become the key means to achieve economic restructuring and low carbon economy. Based on System Advisor Model software, the authors choose Baoji as the sample plot. Household load, unit investment, loan interest rate and loan fraction are used as influence factors to analyze the economic benefits of distributed solar photovoltaic in China. The result demonstrates that government incentives help to increase the profitability of distributed solar photovoltaic by a large extent; other factors that influence the profitability includes household load, unit investment cost, loan interest rate and loan fraction.

Keywords: distributed solar photovoltaic, internal rate of return, price ladder, government incentives

1 Introduction

Distributed solar photovoltaic refers to the electricity generating system which is built on the user demand side, converting solar energy into electricity using semiconducting materials. China is currently experiencing rapid development of urbanization, along with the requirement for abundant energy supply. With the increasing demand for energy diversification and environmental protection, the development and utilization of distributed solar photovoltaic has become a policy priority of renewable energy development in China since 2012, and ambitious planning for it has been formulated and updated. Recently, the government has introduced a number of preferential policies to promote the distributed photovoltaic industry. In August 2013, a national unified policy of 0.42CNY/kW was put into implementation according to "The Notice on Leveraging the Healthy Development of Photovoltaic Industry by Tariff Policy" issued by National Development and Reform Commission (2013). Local governments at provincial and municipal levels also formulated various policies to provide capital subsidies or extra generation subsidies.

Because distributed solar photovoltaic is a relative new industry, lack of necessary understanding leaves end users who are considering the installation of photovoltaic system confused as to whether such an investment makes economic sense; thus, the development speed of distributed solar photovoltaic in China is much lower than expected even if it is believed that China has bright prospects of growth in photovoltaic power development. Based on the natural environment and subsidy policy of Baoji, this paper focuses on the economic analysis of residential distributed solar photovoltaic with the aim to show the development prospects of distributed photovoltaic and to provide reference for scientific and engineering applications.

2 Parameter selection for simulation model

The financial performance of solar photovoltaic system varies dramatically depending on its system design, component performance and levels of solar intensity. In this paper, the System Advisor Model (SAM) software (National Renewable Energy Laboratory, 2014) is used to simulate the distributed photovoltaic system. In the simulation model, the authors use Canadian Solar CS6P-230P as solar modules, Sunny Boy series as inverters. Meteorological data is from the Solar and Wind Energy Resource Assessment (SWERA) No. 570160 stations. System tilt angle is set as 34.35°N, which is the latitude of

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Baoji. Unit investment cost is 10,000CNY/kW and annual O&M costs are 124.34CNY/kW. The national and provincial solar photovoltaic subsidies are 0.42CNY/kW and 1CNY/W respectively. Project operation period is fixed at 25 years with a system performance degradation rate of 0.5%, inverter needs to be replaced in the 12th year. Since the monthly electricity sales from residential distributed photovoltaic systems are less than 20,000CNY, VAT is exempt. Inflation and income tax are not taken into consideration as well.

Since this paper focuses merely on residential distributed solar photovoltaic systems, the annual power consumption the authors analyze falls into the range of 1,000kWh to 5,000kWh, and the installed capacity of solar photovoltaic systems is between 1kW and 6kW.

3 Economic influencing factors

3.1 Power consumption

The financial returns of distributed solar photovoltaic systems come from three parts: saved electricity cost, revenue from electricity sales and government incentives. The feed-in tariff of Shaanxi Province is 0.3974CNY/kWh (The People's Government of Shaanxi Province, 2014) while national subsidy is 0.42CNY/kWh. Due to the ladder-type price policy, saved electricity is relatively complicated to calculate and discussion on different scenarios is needed.

Price ladder of Shaanxi residential electricity is divided into three levels according to annual household power consumption. When annual power consumption is below 2,160kWh, price is 0.4983CNY/kWh, between 2,161kWh and 4,200kWh is 0.5483CNY/kWh and above 4,201kWh is 0.7983CNY/kWh. Thus, the electricity price may be different with and without photovoltaic systems (Table 1).

Financial returns of distributed solar photovoltaic systems vary with different household loads. The specific relationships are shown in Table 2.

Internal rate of return (IRR) has a direct impact on project earnings. Now the authors use six different sizes of solar photovoltaic systems ranging from 0.92kW to 5.97kW to analyze the changes of IRR caused by annual electricity consumption. Results are shown in *Figure 1*.

As can be seen from *Figure 1*, the curve of IRR shows a piecewise linear upward trend with the increase in power consumption. Different design, price, performance and other aspects lead to different relationship between IRR and power consumption. When system capacity is bigger than 3.22kW in Baoji, the relation curves are almost the same: IRR decreases as system capacity increases; when system capacity is less than 3.22kW in Baoji, the relationship between IRR and system capacity is hard to determine.

3.2 Investment cost

The capital cost of distributed solar photovoltaic includes solar photovoltaic modules, grid inverters, power distribution equipment, cables, construction and installation, among which solar modules make up approximately 50%–60% of the total cost. According to the "Renewable Power Generation Costs in 2014" released by the International Renewable Energy Agency (2015), the cost of solar modules worldwide have fallen 75% so far since the end of 2009, and there still shows a continuing decline. To illustrate how the decline in the cost of investment impact IRR, sensitivity analysis is provided as in *Figure 2*.

The sensitivity analysis uses 10,000CNY/kW as the standard unit cost, 0.92kW, 3.22kW, and 4.14kW are the three sizes of distributed solar photovoltaic systems used to analyze under different loads.

As can be seen from Table 3, IRR declines as investment costs increase. For the system with fixed capacity, the bigger annual power consumption, the lower sensibility of unit investment cost on IRR; for the system with fixed annual power consumption, the bigger system size, the higher sensibility of unit investment cost on IRR.

3.3 Debt financing

Debt financing, which is not considered in previous analysis, has a significant impact on the economic benefits of distributed solar photovoltaic systems. Here the authors take 0.92kW photovoltaic system as an example to illustrate the influence on IRR caused by loans in different conditions: annual power consumption of 500kW & 1,000kW, and unit investment cost of 10,000CNY/W & 11,000CNY/W.

As can be seen from *Figure 3*, a higher debt proportion may improve or reduce IRR of own capital with the same loan interest, this can be attributed to the relationship between loan interest and IRR. If loan interest is higher

Table 1

Price Ladder of Shaanxi Residential Electricity

Level	Annual Power Consumption/kWh	Electricity Price/($CNY \cdot kWh^{-1}$)
1st	Power consumption < 2,160	0.4983
2nd	2,160 ≤ Power consumption < 4,200	0.5483
3rd	Power consumption ≥ 4,200	0.7983

Table 2

Relationship between Shaanxi Distributed PV Financial Returns and Household Load

Annual Power Generation/kWh	Annual Power Consumption/kWh	Financial Returns/CNY
0–2,160	$\text{Consumption} < \text{Generation}$	$\text{Consumption} \times 0.4983 + (\text{Generation} - \text{Consumption}) \times 0.3974$
	$\text{Generation} \leqslant \text{Consumption} < 2{,}160$	$\text{Generation} \times 0.4983$
	$2{,}160 \leqslant \text{Consumption} < (2{,}160 + \text{Generation})$	$1{,}076.328 + (\text{Consumption} - 2{,}160) \times 0.5483 - (\text{Consumption} - \text{Generation}) \times 0.4983$
	$(2{,}160 + \text{Generation}) \leqslant \text{Consumption} < 4{,}200$	$\text{Generation} \times 0.5483$
	$4{,}200 \leqslant \text{Consumption} < (4{,}200 + \text{Generation})$	$1{,}118.53 + (\text{Consumption} - 4{,}200) \times 0.7983 - (\text{Consumption} - \text{Generation} - 2{,}160) \times 0.5483$
	$\text{Consumption} \geqslant (4{,}200 + \text{Generation})$	$\text{Generation} \times 0.7983$
2,040–2,160	$\text{Consumption} < \text{Generation}$	$\text{Consumption} \times 0.4983 + (\text{Generation} - \text{Consumption}) \times 0.3974$
	$\text{Generation} \leqslant \text{Consumption} < 2{,}160$	$\text{Generation} \times 0.4983$
	$2{,}160 \leqslant \text{Consumption} < 4{,}200$	$1{,}076.328 + (\text{Consumption} - 2{,}160) \times 0.5483 - (\text{Consumption} - \text{Generation}) \times 0.4983$
	$4{,}200 \leqslant \text{Consumption} < (2{,}160 + \text{Generation})$	$2{,}194.86 + (\text{Consumption} - 4{,}200) \times 0.7983 - (\text{Consumption} - \text{Generation}) \times 0.4983$
	$(2{,}160 + \text{Generation}) \leqslant \text{Consumption} < (4{,}200 + \text{Generation})$	$1{,}118.53 + (\text{Consumption} - 4{,}200) \times 0.7983 - (\text{Consumption} - \text{Generation} - 2{,}160) \times 0.5483$
	$\text{Consumption} \geqslant (4{,}200 + \text{Generation})$	$\text{Generation} \times 0.7983$
2,160–4,200	$\text{Consumption} < 2{,}160$	$\text{Consumption} \times 0.4983 + (\text{Generation} - \text{Consumption}) \times 0.3974$
	$2{,}160 \leqslant \text{Consumption} < \text{Generation}$	$1{,}076.328 + (\text{Consumption} - 2{,}160) \times 0.5483 + (\text{Generation} - \text{Consumption}) \times 0.3974$
	$\text{Generation} \leqslant \text{Consumption} < 4{,}200$	$1{,}076.328 + (\text{Consumption} - 2{,}160) \times 0.5483 - (\text{Consumption} - \text{Generation}) \times 0.4983$
	$4{,}200 \leqslant \text{Consumption} < (2{,}160 + \text{Generation})$	$2{,}194.86 + (\text{Consumption} - 4{,}200) \times 0.7983 - (\text{Consumption} - \text{Generation}) \times 0.4983$
	$(2{,}160 + \text{Generation}) \leqslant \text{Consumption} < (4{,}200 + \text{Generation})$	$1{,}118.53 + (\text{Consumption} - 4{,}200) \times 0.7983 - (\text{Consumption} - \text{Generation} - 2{,}160) \times 0.5483$
	$\text{Consumption} \geqslant (4{,}200 + \text{Generation})$	$\text{Generation} \times 0.7983$
Above 4,200	$\text{Consumption} < 2{,}160$	$\text{Consumption} \times 0.4983 + (\text{Generation} - \text{Consumption}) \times 0.3974$
	$2{,}160 \leqslant \text{Consumption} < 4{,}200$	$1{,}076.328 + (\text{Consumption} - 2{,}160) \times 0.5483 + (\text{Generation} - \text{Consumption}) \times 0.3974$
	$4{,}200 \leqslant \text{Consumption} < \text{Generation}$	$2{,}194.86 + (\text{Consumption} - 4{,}200) \times 0.7983 + (\text{Generation} - \text{Consumption}) \times 0.3974$
	$\text{Generation} \leqslant \text{Consumption} < (2{,}160 + \text{Generation})$	$2{,}194.86 + (\text{Consumption} - 4{,}200) \times 0.7983 - (\text{Consumption} - \text{Generation}) \times 0.4983$
	$(2{,}160 + \text{Generation}) \leqslant \text{Consumption} < (4{,}200 + \text{Generation})$	$1{,}118.53 + (\text{Consumption} - 4{,}200) \times 0.7983 - (\text{Consumption} - \text{Generation} - 2{,}160) \times 0.5483$
	$\text{Consumption} \geqslant (4{,}200 + \text{Generation})$	$\text{Generation} \times 0.\ 7983$

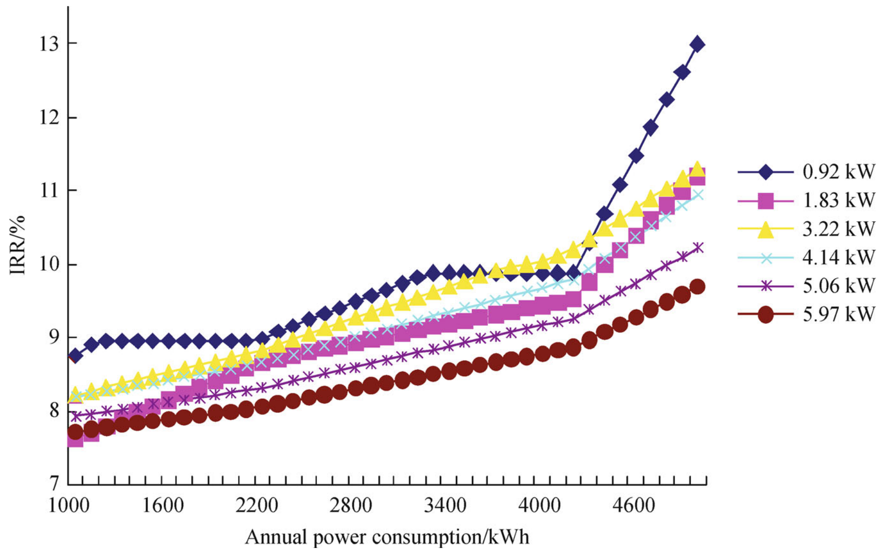


Figure 1. The variation between IRR of photovoltaic system and household load.

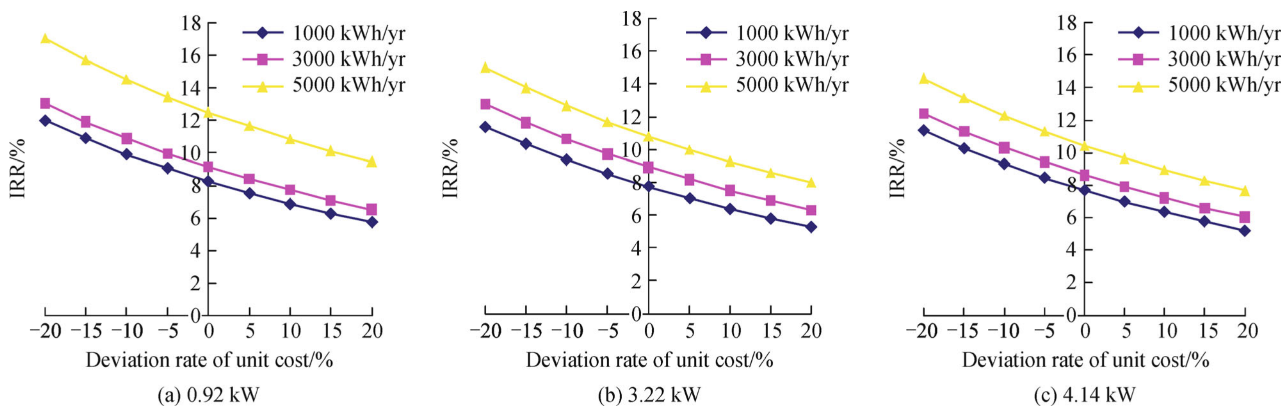
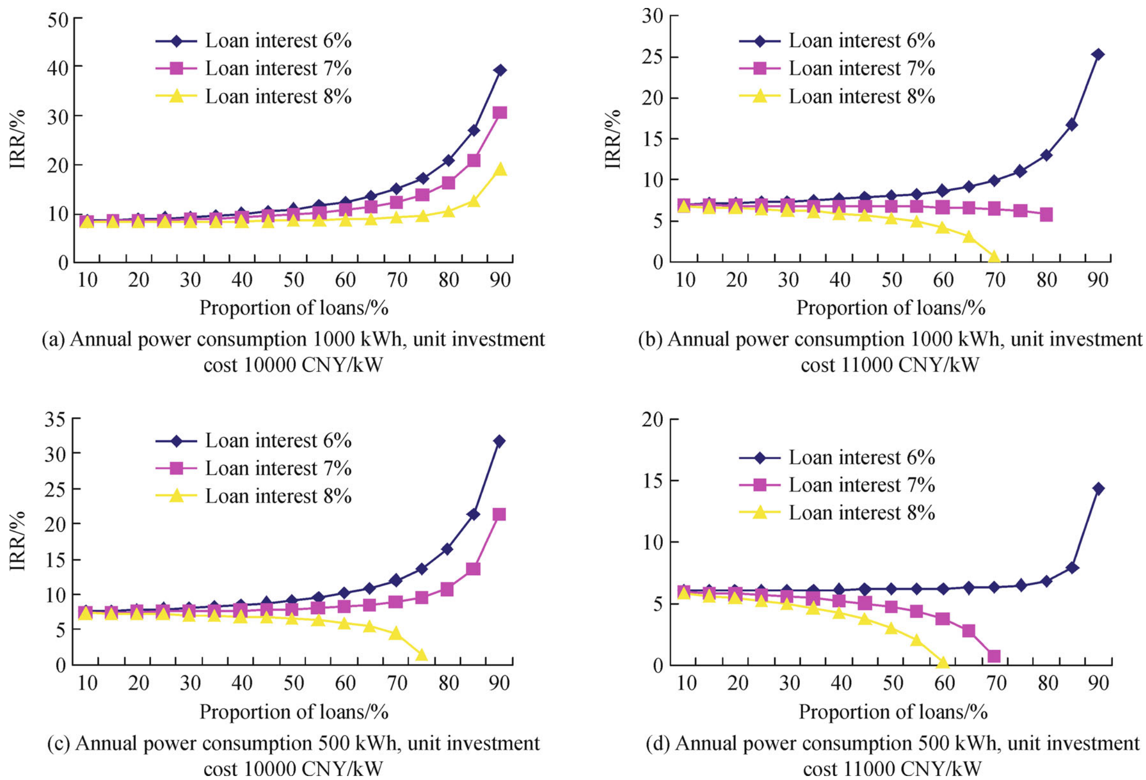


Figure 2. Sensibility analysis of unit investment cost of distributed solar photovoltaic system.

Table 3

The Influence of IRR Caused by Unit Investment Cost

System Size	Power Consumption/kWh	Deviation of Unit Investment Cost					Sensibility
		–20%	–10%	Basic	10%	20%	
0.92kW	1,000	11.9865	9.9216	8.2650	6.8962	5.7385	0.018899
	3,000	13.0498	10.8885	9.1591	7.7334	6.5303	0.017795
	5,000	17.0317	14.5028	12.4953	10.8528	9.4762	0.015117
3.22kW	1,000	11.3813	9.3568	7.7301	6.3840	5.2443	0.019848
	3,000	12.7679	10.6298	8.9174	7.5045	6.3113	0.018101
	5,000	15.0123	12.6701	10.8034	9.2703	7.9809	0.016271
4.14kW	1,000	11.3435	9.3211	7.6985	6.3508	5.2120	0.019911
	3,000	12.4284	10.3178	8.6261	7.2294	6.0491	0.018488
	5,000	14.5671	12.2708	10.4388	8.9326	7.6647	0.016531



(a) Annual power consumption 1000 kWh, unit investment cost 10000 CNY/kW

(b) Annual power consumption 1000 kWh, unit investment cost 11000 CNY/kW

(c) Annual power consumption 500 kWh, unit investment cost 10000 CNY/kW

(d) Annual power consumption 500 kWh, unit investment cost 11000 CNY/kW

Figure 3. The influence of IRR caused by interest and proportion of loans.

than IRR of whole project, which means project earnings are not sufficient to pay the interest, the greater the proportion of loans leads to lower IRR of own capital; on the contrary, if loan interest is lower than IRR of whole project, which means financial cost is lower than project earnings, this creates the positive leverage that provides the incentive for investors to borrow money; therefore, the greater the proportion of loans leads to higher IRR of own capital.

4 Government subsidies

Financial subsidy is an important method in dealing with the problem of high-cost of solar photovoltaic system. The rapid development of photovoltaic industry in China is largely attributed to government incentive; however, "The Notice on Leveraging the Healthy Development of Photovoltaic Industry by Tariff Policy" also points out that government may gradually reduce feed-in tariff and lower the subsidy standards of solar photovoltaic in accordance with the development of the industry (National Development and Reform Commission, 2013), which brings uncertainty to solar photovoltaic incentive policies and greatly influences the confidence of investors. In order to study the role government incentive is playing, the authors use 0.92kW, 3.22kW, and 4.14kW systems to do the economic analysis. Results are shown in *Figure 4*.

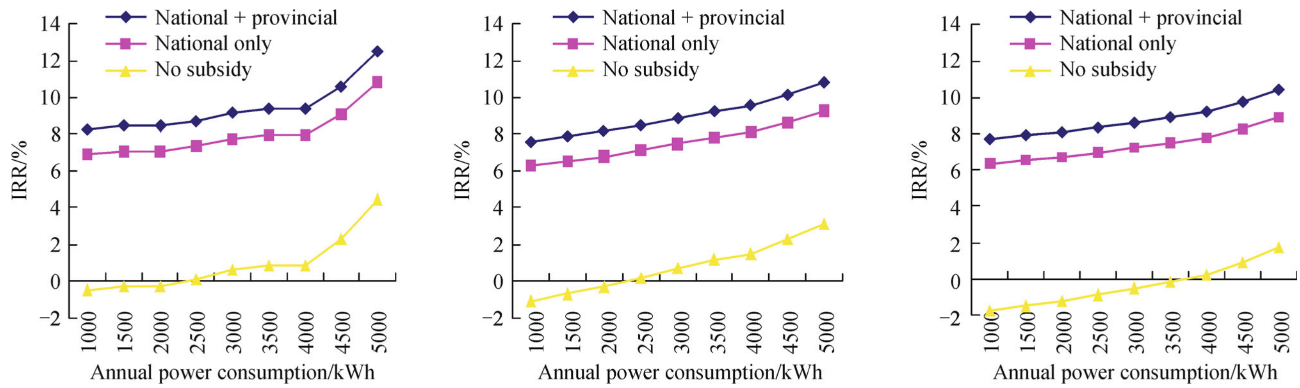
For each system, four kinds of loads are observed to quantitatively analyze impact on IRR coming from government incentives. A complete summary of assumption is provided in Table 4.

From *Figure 4* and Table 4, it can be seen that if national and provincial subsidies are removed, IRR of distributed photovoltaic systems stays around 0%, or even negative. National subsidy of 0.42CNY/kW can significantly increase IRR and make project feasible, provincial subsidy of 1CNY/W can further increase IRR by 1.38%. As the capacity of the system increases, the impact from national subsidy on IRR gradually increases, and the impact from provincial subsidy reduces accordingly. It is because national subsidy is performance-based while provincial is capacity-based, when the installed capacity gets larger, power production increases faster, so its impact on IRR turns to be greater.

5 Conclusions

Based on the SAM software, the authors choose household load, unit investment, loan interest rate and loan fraction as influence factors to analyze the economical benefits of distributed solar photovoltaic in Baoji. Main conclusions are drawn as follows:

(1) Positive correlation exists between IRR and power consumption when capacity of photovoltaic system is



(a) 0.92 kW (b) 3.22 kW (c) 4.14 kW

Figure 4. The influence of IRR caused by government incentives.

Table 4

The Influence of IRR Caused by Government Incentives

System Size/kW	Annual Power Consumption/kWh	Averaged IRR/%		
		No Incentive	Only Federal	Federal + State
0.92	1,000	−0.4892	6.8962	8.2650
	2,000	−0.2914	7.0730	8.4579
	3,000	0.5902	7.7334	9.1591
	4,000	0.8459	7.9429	9.3845
3.22	1,000	−1.6752	6.3840	7.7301
	2,000	−1.0006	6.8551	8.2287
	3,000	−0.1025	7.5045	8.9174
	4,000	0.6071	8.0937	9.5533
4.14	1,000	−1.7768	6.3508	7.6985
	2,000	−1.2445	6.7191	8.0845
	3,000	−0.5276	7.2294	8.6261
	4,000	0.1893	7.7554	9.1846

fixed. Due to the ladder-type electricity price policy in Shaanxi province, the curve is of piecewise linear shape. Basically, IRR increase with the decrease of system capacity. The foreseeable prices decline of solar photovoltaic modules in the future will make solar photovoltaic systems more economically attractive.

(2) The comparison of project IRR and bank loan interest is the critical factor on funding source selection. When project IRR is higher than loan interest, IRR of own capital increases as proportion of loans increases; when project IRR is lower than loan interest, IRR of own capital increases as proportion of loans decreases.

(3) For now, the development of Chinese distributed photovoltaic industry is highly dependent on government incentives. Without stable investment environment and financial subsidies, there are still gaps between photovoltaic and other energy sources in regards to economic competitiveness.

References

International Renewable Energy Agency. (2015). *Renewable power generation costs in 2014*. Bonn: International Renewable Energy Agency (IRENA)

National Development and Reform Commission. (2013). *The notice on leveraging the healthy development of solar photovoltaic industry by tariff policy* (NDRC Price Issues, No.1638, 2013). Beijing: National Development and Reform Commission. Retrieved from http://www.sdpc.gov.cn/zwfwzx/zfdj/jggg/dian/201308/t20130830_556127.html

National Renewable Energy Laboratory. (2014). System advisor model (version 2014.11.24)[Computer software]. Golden, Colorado: Alliance for Renewable Energy, LLC

The People's Government of Shaanxi Province. (2014). *Policy on promoting demonstration program of distributed solar photovoltaic* (Shaanxi Government Issues, No. 37, 2014). Xi'an: The People's Government of Shaanxi Province. Retrieved from http://www.shaanxi.gov.cn/0/103/10703.htm