HUA ZHEN

China's solar energy scenarios and simulation analysis based on Bayesian methodology

This paper analyzes the driving forces and key uncertainties of solar development in China, and identifies prior and posterior probability of the key uncertain factors. Thenthree scenarios of China's solar energy development are established by using Bayesian approach: best, standard and worst scenarios thatwill provide the central government reference while making strategies on energy development in China.

Key words: solar; scenario; Bayesian; China;

1. Background& Introduction

By the end of 12th five-year plan, Chinese central government embarks on nuclear energy, wind energy, solar energy and biomass energy, which are considered as the main supported new energy industry. However, due to its security issue, the nuclear energy has been restricted its further development and wider use; and meantime, due to the regional disequilibrium factors, the development of the biomass and wind energy have been restricted as well. Thus, solar energy becomes the key segment at the nation level.

At present, China's new energy research and development are in a fledging period, the progress of the solar energy is exposed to the restricts of absent policy onfaulty techniques, excessively high cost and many other factors, so, analysis of identifying itspotential risks and uncertainties in solar energy development has its practical significance.

2. Analysis of the drivers and key uncertainties of the solar development

2.1 ANALYSIS OF THE DRIVERSOF SOLAR DEVELOPMENT

Deficit in energy. With the rapid development of China's economy, with the huge population base, China's craving for energy is more than ever, especially with the acceleration of urbanization process, the demand for energy exceeds its supply, and the deficit is becoming more outstanding, so, solar energy has been considered as one of most emblematic renewable resources in China's new energy strategies, which provides the alternative options for the government.

Mr. HuaZhen, School of Economics and Management, Harbin Engineering University, Harbin, 150001, China, e-mail: 17036587@qq.com

Necessity for improving quality of life in rural areas. China is known as a great agricultural country, 80% of the total population are living in rural areas, and ithas the great significance if boosting the solar extensive development and utilization.Tough there is an increase in the usage of coal relevant products in rural areas, due to its characters of vast territory and huge population, it determines that conventional energy is unlikely to meet the rapid growing demand in the countryside, solar energy still occupies an important position and plays its crucial role, solarenergy accounted for more than 1/3 of the total rural energy usage. Thus, research and development of the solar technology has been considered asone of the most crucial tasks which can help these areas to develop and improve thestandard of living.

Economic factors. Due to its non-renewability, and the conventional fossil energy is limited, and there is a strong need for new type of energy which is renewable and sustainable. The cost of developing solar energy is lower, comparing with biomass energy, nuclear energy and other clean energy, and that is why it is emphasized during the 12th five-year plan by the central government.

2.2 ANALYSIS OF THE KEY UNCERTAINTIES OF SOLARENERGY DEVELOPMENT

Solar energy is radiant light and heat from the sun harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture and artificial photosynthesis. [2,3] Though solar industry has made the great progress in China, many difficulties in terms of its storage, transportation, marketization operating and technology transfer are still remaining to tackle. The key uncertain factors of solar development can be summarized as followed:

(1) Unsound environmental policies. The problems existing in the current environment policiesare referring that the government policies supporting related industrial organization are imperfect and inadequate,and the holistic economic incentives policies and mechanism are insufficient. Solar energy industry has higher social benefits,higher ecological benefits, and higher environment benefits, however, relatively lower economic benefits. According to the foreign experience, we can see that, both in developedand

developing countries cannot depart from the support of the government, it needs the government'snecessary slant in terms of the taxation, subsidies, financing or marketing aspects.At present, Chinese central government has established the relevant package of laws, regulationsand policies which supporting solar development, however, the specific detailed enforcement regulation which has strong operability has been absent at times, so, it cannot form a long-term effective mechanism of supporting the steady and continuous development of solar energy, additionally, more attention has not been paid to the economic returns, and enthusiasm of investors might been debased in some extent if the governments did not take their appropriate actions.

(2) The shortage of the supporting materials and facilities are constraining the mass production of solar energy. China now, is in the start-up process in photovoltaic and thermal utilization, for instance, polycrystalline silicon research and production of independent intellectual property rights scaling, which are far behind the international advanced level in terms of production costs, products quality, and integrated utilization, meanwhile, silver paste, aluminum paste, TPT backing materials and EVA encapsulating materials mostly rely on imports. Due to its dispersity and inhomogeneous distribution, the solarenergy now has problems which cannot be solved appropriately in terms of transportation, storage and operation, thus, it limited the large-scale utilization of solar energy which is in order to constrain the booming development of solar industry.

(3) High cost (comparing with the current sizeable conventional fossil energy system) ofsolar is the crucial factor which constrains the solar energy development. Its high cost and high price are the key barriers which can constrain its technology commercialization, popularization and application.

(4) Lack of technology innovation ability, instability of technology industrialization. Firstly, the ability of solartechnology research and development is relatively weak. The research institutions distribute scattered, and there is no sufficient corresponding measures to attract talents, it hasn't formed the effective R&D echelons yet, so that it cannot adapt to the needs of the development of solar energy in China; secondly, the production crafts and equipments are old and backward, there are hurdles in technical generalization; lastly, the foundation of technology industrialization is unsubstantial, some technologies are still in research or trial stage, and there is noeffective underpinning of standard system and service system to the relative mature technologies whose level of industrialization is relatively low.

(5) Financing channel is always not expedite. Solar energy can be utilized in the projects, such as combustion electricity production, gasification power generation, large-scale livestock and poultry farms and large and medium-sized methane projects, the initial investments are relatively higher, and it needs the stable financing support from the long term effective financing channel which are mainly dominant by the local government in order to decrease the cost .Chinese government seldom constructively invest on other aspects of solar except methane and solar power generation. Meantime, due to the higher risk and low economic utility, enterprises

TABLE 1: PRIOR PROBABILITY OF THE DIFFERENT STATUS OF KEY UNCERTAIN FACTORS

Key uncertain factors (weight)	Different status of Key uncertainties factors	Prior probability	Posterior probability
1. Policies Environment (0.48)	A. better	0.35	
	B. remain the current status	0.35	
	C. worse	0.30	
2. Material Shortage (0.20)	A. surplus	0.30	
	B. shortage	0.40	
	C. serious shortage	0.30	
3. High Cost(0.18)	A. competitive comparing with fossil energy, competitive comparing with other renewable energy	0.35	
	B. not competitive comparing with fossil energy, competitive comparing with other renewable energy	0.35	
	C. not competitive comparing with fossil energy, not competitive comparing with other renewable energy	0.30	
4. Short of Technology Innovation	A. breakthrough progress	0.30	
	B. continuous innovation, but no breakthrough	0.40	
	C. serious shortage of innovation	0.30	
5. Un-smooth Channels in Financing	A. smooth financing channels	0.35	
	B. un-smooth financing channels	0.35	
	C. serious un-smooth financing channels	0.30	

TABLE 2: CROSS INTERACTION MATRIX

indicators	status	Prior probability	Policy environment			Material Shortage			High Cost			Short of Technology Innovation			Un-smooth Financing Channels		
			A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Policy environment	A substantial support	0.35				3	2	-3	3	2	-3	3	2	-3	3	2	-3
	B standard (support)	0.35				2	1	-2	2	1	-2	2	1	-2	2	1	-2
	C worse	0.30				-3	-2	3	-3	-2	3	-3	-2	3	-3	-2	3
Material	A surplus	0.30	-2	-1	3				3	2	-2	1	2	-2	2	-1	-2
	B standard	0.40	2	2	-2				2	1	-2	1	2	-2	2	1	-1
	C critical shortage	0.30	3	2	-2				-3	-2	2	-2	-1	1	-1	1	2
Cost competitiveness	A high competitiveness	0.35	3	2	-3	-3	-2	3				3	2	-2	3	-1	-2
	B general competitiveness	0.35	2	1	-2	-2	-1	2				2	1	-1	2	-1	-2
	C standard	0.30	2	1	-2	2	1	-3				-3	-2	2	-3	2	1
Capability of technology innovation	A radical innovation	030	3	2	-3	-3	1	2	3	2	-2				3	-2	-3
	B standard	0.40	2	1	-2	-2	2	1	2	3	-2				2	-1	-2
	C serious shortage of innovation	0.30	1	2	-1	-1	3	-2	-3	-2	2				-3	2	3
Investing and financing channels	A smooth	0.35	1	2	-2	-2	1	2	1	1	-1	3	2	-2			
	B un-smooth	0.35	2	1	-2	1	-1	-2	-1	-1	0	-2	-1	1			
	C serious un-smooth	0.30	3	2	-3	2		-1	-2	-2	-1	-3	-2	2			

have not got enough enthusiasm so that they are not tending to invest on these solar projects, solar energy productive enterprises and equipment manufacturing enterprises can hardly gain the direct investment from the capital market. It restricted development and utilization of solar energy due to the lack of effective investment financing mechanism.

3. Prior probability of the key uncertain factors

This part mainly is focused on using Bayesian scenario methodology for analytic hierarchy process and cross-impact analysis to identify the prior probability of the uncertain factors in different status. In Bayesian approach, prior probability, often simply called the prior, of an uncertain quantity is the probability distribution that would express one's beliefs about this quantity before some evidence is taken into account. It is the initial probability which is based on previous knowledge, intuition and expectation, it can cause a set of consequences which called “scenario”. And this analytical process can be divided into several parts: establishment of evaluation standard, identification of the weight of uncertain factors and the identification of prior probability of the different status of key uncertain factors.

3.1 EVALUATION STANDARD

Five key uncertain factors are picked up: environmental policies, material shortage, high cost, short of technology innovation and un-smooth channels in Financing. Each key factor has three different status, shown in Table 1.

3.2 IDENTIFICATION OF PRIOR PROBABILITY

There are two approaches of evaluating prior probability: one is pairwise comparison matrix, the other is estimate by experts based on empirical research. Generally, the results calculated though these two methods are homologous, and we adopt the latter one. The weights of prior probability are shown in Table 1.

4. Posterior probability of the key uncertain factors

In Bayesian approach, the posterior probability of a random event or an

TABLE 3: POSTERIOR PROBABILITY

indicators	Different status	prior probability	eigenvector	posterior probability I	posterior probability II	Scenario probability
Policy environment	A substantial support	0.35	0.091	0.0319	0.417	most likely
	B standard (support)	0.35	0.067	0.0235	0.308	Standard
	C worse	0.30	0.070	0.0210	0.275	most unlikely
Material	A surplus	0.30	0.086	0.0258	0.363	Middle probability
	B standard	0.40	0.065	0.0260	0.366	most likely
	C critical shortage	0.30	0.064	0.0192	0.271	most unlikely
Cost competitiveness	A high competitiveness	0.35	0.066	0.0231	0.376	most likely
	B general competitiveness	0.35	0.053	0.0186	0.302	most unlikely
	C standard	0.30	0.066	0.0198	0.322	Standard
Capability of technology innovation	A radical innovation	030	0.067	0.0202	0.297	most unlikely
	B standard	0.40	0.063	0.0253	0.372	most likely
	C serious shortage of innovation	0.30	0.075	0.0225	0.331	Middle probability
Investing and financing channels	A smooth	0.35	0.067	0.0235	0.430	most likely
	B un-smooth	0.35	0.041	0.0144	0.263	most unlikely
	C serious un-smooth	0.30	0.056	0.0168	0.307	standard

uncertain proposition is the conditional probability that is assigned after the relevant evidence or background is taken into account. Similarly, the posterior probability distribution is the probability distribution of an unknown quantity, treated as a random variable, conditional on the evidence obtained from an experiment or survey. "Posterior", in this context, means after taking into account the relevant evidence related to the particular case being examined. According to Bayes' theorem:

Posterior Probability = (Likelihood × Prior Probability)/ Normalized Constant

It can be seen that, posterior Probability is proportional to the product of prior probability and likelihood. And likelihood divided normalized constant gives out the standardized likelihood, so:

Posterior Probability = Standardized Likelihood × Prior Probability

4.1 CROSS INTERACTION MATRIX

The establishment of the cross interaction matrix is based on experts' estimate and discriminant. Three cross interaction matrixes are concluded: impeding effect, promoting effect and no effect. If A's occurrence increased the probability of B's occurrence, we consider that A has "promoting effect" to B; if A's occurrence decreased the probability of B's occurrence, we consider that A has "impeding effect" to B; If A's occurrence neither increased nor decreased the probability of B's occurrence, we consider that A has "no effect" to B. "-" stands for impeding effect, "+" stands for promoting effect, and "0" stands for no effect. The degree of the "impeding" or "promoting" is expressed in numbers, "+1" means it has the lower promoting effect, "-3" means greater impeding effect. Value of interaction (-3, -2, -1, 0, 1, 2, 3), shown as Table 2.

4.2 CALCULATION OF THE EIGENVECTOR

At first, calculating the cross interaction coefficient using formulas as followed:

CV = value of cross interaction + 1 (value of cross interaction ≥ 0)

CV=1/(1 - value of cross interaction) (value of cross interaction < 0)

Then, eigenvector is calculated using sum and product method. The values are shown in Table 3.

4.3 CALCULATION OF THE POSTERIOR PROBABILITY

At first, "prior probability X eigenvector" equals "posterior probability I"; then, calculate each index under three different status' percentage of the a posteriori probability which is "posterior probability II". It is shown in Table 3.

5. Scenarios establishment and conclusion

Three scenarios will be established according to the values of probabilities:

Scenario I: best scenario, which has the greatest probability indicator status.

Scenario II: standard scenario, which has the standard probability status.

Scenario III: worst scenario, which has the smallest

TABLE 4: SCENARIO ESTABLISHMENT ACCORDING TO PROBABILITY VALUES

indicators	Different status	Scenario I	Scenario II	Scenario III	posterior probability	Scenario probability
Policy environment	A substantial support	substantial support			0.417	most likely
	B standard (support)		standard (support)		0.308	Standard
	C worse			Getting worse	0.275	most unlikely
Material	A surplus				0.363	Middle probability
	B standard	Standard (general shortage)	Standard (general shortage)		0.366	most likely
	C critical shortage			critical shortage	0.271	most unlikely
Cost competitiveness	A high competitiveness	high competitiveness (cost sharply reduce)			0.376	most likely
	B general competitiveness			general competitiveness	0.302	most unlikely
	C standard		Standard (high price, no competitive)		0.322	Standard
Capability of technology innovation	A radical innovation			radical innovation	0.297	most unlikely
	B standard	Standard (continuous innovation, but not radical)	Standard (continuous innovation, but not radical)		0.372	most likely
	C serious shortage of innovation				0.331	Middle probability
Investing and financing channels	A smooth	smooth			0.430	most likely
	B un-smooth			un-smooth	0.263	most unlikely
	C serious un-smooth		serious un-smooth		0.307	standard

probability indicator status.

It is shown in Table 4.

Scenario I: best scenario. The solar energy development will gainstrong support from the series of relevant policies which are given by government, though the materials are in shortage, it is limpingly remaining sustainable, the cost will decline dramatically due to the technology innovation, solar products are very competitive. And meantime, the industrialization of solar is relatively effective.

Scenario II: standard scenario. China will continue supporting the development of solar, the materials are in shortage, and it is limpingly remaining sustainable. In spite of continuous technological innovation, it did not drive the cost greatly reduced, solar products have less competitiveness. Meantime, the industrialization of solar is facing many challenges due to the un-smooth Investing and financing channels.

Scenario III: worst scenario. Solarenergy development will gain less support from the local government, and the shortage of the materials is becoming more outstanding than ever. Meantime, the industrialization of solar is facing many challenges due to the un-smooth Investing and financing channels. However, the cost will be reduced to a certain extent though the technology innovation is not radical, so that the solar products have certain competitiveness.

Acknowledgements

The financial supports from National Social Science Foundation of China (16BJY078) and Heilongjiang Profince Social Science Foundation (14E081) for this study are gratefully acknowledged.

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