Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 104 (2016) 233 – 238
Energy Procedia

CUE2016-Applied Energy Symposium and Forum 2016: Low carbon cities & urban energy systems

The Selection and Promotion of Core Technology to China's Energy Goals

Mei Sun[a,*], Cuixia Gao[a], Changsheng Jia[a], Faye D.F.Ni[b], Jijian Zhang[a]

[a]*Center for Energy Development and Environmental Protection, Jiangsu University, Zhenjiang 212013, China*
[b]*Department of Building and Real Estate, Hong Kong Polytechnic University, Kowloon, Hong Kong SAR, China*

Abstract

Energy technology is perceived as the most powerful means to improve energy efficiency and reduce emissions. However, some technologies will not achieve the expected goals due to uncertainties. It is necessary to identify the most effective ones. After that, another issue is how to promote and apply them successfully. This paper uses Kaya equation to identify the core technologies for achieving China's energy goals: energy security and emission reduction. Then, the external and internal environments for the promotion of China's core energy technologies are analyzed using technology diffusion model. Lastly, conclusions and certain policy suggestions are put forward.

Peer-review under responsibility of the scientific committee of the Applied Energy Symposium and Forum, CUE2016: Low carbon cities and urban energy systems.

Keywords: Energy technology; China's energy goals; Kaya equation; Technology diffusion model

Nomenclature

AFL	Advanced fossil fuel liquids	TRAN	Energy-efficient transportation
BIO	Biomass energy	HYD	Hydrogen energy
CCS	Carbon capture and sequestration	BLDG	Energy-efficient buildings
DG	Deep geothermal engineering technology	NUC	Nuclear energy
ELEC	Efficient electricity generation and power safety	OCE	Ocean energy
TNFF	Non-fossil fuels ground transportation technology	SOL	Solar energy
IND	Energy-efficient industrial processes	WIND	Wind energy

* Corresponding author. Tel.: +86 13775366657.
E-mail address: sunm@ujs.edu.cn.

Peer-review under responsibility of the scientific committee of the Applied Energy Symposium and Forum, CUE2016: Low carbon cities and urban energy systems.
doi:10.1016/j.egypro.2016.12.040

1. Introduction

Energy and environmental problem has become one of the hottest issues attracting worldwide attention today. Developing energy technology is the most effective means to achieve energy conservation and emission reduction [1,2]. As a major energy consumer in the world, China faces great challenges in balancing its goal of economic growth with environmental sustainability. One of the most important tasks is to develop renewables on a large scale and focus on emission control to ensure China's energy security [3,4]. Much effort has been devoted to innovate energy technologies. Additionally, successful emission reduction can encourage more involvement in innovative energy technologies [5]. Therefore, energy technology should become the first priority in China. With an accurate estimation of technologies' development level, we can ensure the achievement of the country's energy goals.

This paper identifies the importance of the selected 14 key energy technologies that can reduce CO_2 emissions and oil consumption in different combinations using Kaya equation. To understand the development of energy technology in different countries, we compare the influence of energy technology on national energy goals in China and the US. After identifying the core energy technology, another important issue is the promotion of the technology's application. Therefore, we use wind and solar energy as examples for an empirical study of the influencing factors on technology development. Lastly, conclusions, and policy implications are summarized.

2. China's energy goals and potential core technologies

2.1. China's energy goals

Both energy security and conservation with low emissions should be considered simultaneously when establishing national energy goals. China's energy goals can be set as: (1) reducing the consumption of imported oil within 1% of GDP in 2050; and (2) reducing China's CO_2 emissions to 30-50% of the level in 2005 by 2050.

2.2. Selection of key energy technologies and basic principles

Although each technology contains many specific sub-technologies for achievement, we only consider the ultimate energy effect that each technology can achieve. After considerable discussion and debate, a team of 30 scientists at Chinese Academy of Sciences with expertise spanning a wide range of energy science and technology decided in a list of energy technology categories for mitigating emissions and reducing oil dependence. According to the future technologies development introduced in China energy technology development roadmap to 2050 [6,7], the main 14 key technologies and their influences are summarized.

Five basic principles are followed in the selection of 14 key technologies. For technologies that independent R&D but have been unable to keep up with demand on time, the introduction, digestion, absorption route is selected; For technologies that have a good prospect but no large-scale application, a key breakthrough route is selected; For forward-looking technologies but still in the stage of scientific research and exploration, a completely independent innovation route is followed; For technologies that have been mature or large-scale industrial application, such as hydropower, are not consider; For various factors, the priority rule of "Resource features-Contribution-Environmental resistance-Technicality-Achievable level-Economy" is implemented. As for uncertainties including technological outcome of R&D, market acceptance of a new technology, and the future state of the world, probability of technology success is the most uncertain and different to analyse. The premise of this analysis is that valuable insights can be gained by asking the question in reverse: What must the probabilities of success for each technology be in order to be reasonably certain that society's energy goals will be achieved? Posing the question in this way turns the goals into constraints rather than objectives.

3. Methodology

The Kaya equation provides a framework to integrate impacts across sectors and energy forms while avoiding double counting. In general, CO_2 emissions can be calculated by Eq. (1).

$$E=\sum_{u=1}^{U}\sum_{f=1}^{F}\left[\prod_{i=1}^{N}(1+\delta_i\Delta_{iufC})C_f\prod_{i=1}^{N}(1+\delta_i\Delta_{iufS})S_{uf}\prod_{i=1}^{N}(1+\delta_i\Delta_{iufI})I_{uf}(Q_{uf})\right] \tag{1}$$

where E is the total CO_2 emissions in 2050. $U=\{$agriculture, buildings, industry, transportation and electricity generation$\}$ is the set of sectors. $F=\{$coal, natural gas, oil, nuclear/renewable energy and electricity$\}$ represents energy forms. i represents different technologies. C_f is the carbon intensity in energy form f, and S_{uf} is the share of f in sector u. I_{uf} is the corresponding energy intensity, and Q_{uf} is the relative energy consumption. Δ_{iufC} represents the relative change of carbon intensity in u of f by applying technology i. Δ_{iufS} represents the application percentage of f in u by using i. Δ_{iufI} is the impact on energy intensity.

The Kaya equation is also applicable to the calculation of energy demand, but limited by liquid fuel type, such as oil. Let $F=\{$Oil$\}$, and the equation for oil consumption to 2050 can be calculated by Eq. (2).

$$O=\sum_{u=1}^{U}\left[\prod_{i=1}^{N}(1+\delta_i\Delta_{iuOS})S_{uO}\prod_{i=1}^{N}(1+\delta_i\Delta_{iuOI})I_{uO}(Q_{uO}GDP_u)\right] \tag{2}$$

To measure the importance of various energy technologies, we assume that if an energy technology fails in each scenario, the remaining technologies will be recombined. Consequently, the number of sets that can achieve China's energy goals will decline dramatically. Therefore, the more the sets decline, the more important the failed technology is to achieve the energy goals. The importance of technology i to realize China's energy goals, represented by p_i, can be expressed by Eq. (3).

$$P_i=\frac{\text{All sets which meet China's energy goals}_{\text{except technology } i}}{\text{All sets which meet China's energy goals}_{\text{all technologies}}} \tag{3}$$

4. Results: identification of China's core energy technologies

Two assumptions: China's economy retains its current growth rate (approximately 7%), and the structure of industry and energy consumption are invariant. According to the two goals in section 2.1, we perform statistical analysis on whether the goals can be achieved by all possible energy technology sets. Of the 16384 possible sets, 367 meet both the goals of -30% CO_2 and 150 million tons oil, in which no sets that include fewer than 8 successful technologies can achieve both energy objectives (see Fig. 1). Similarly, there are 126 types of energy technology sets that can meet the goals of -50% CO_2 and 200 million tons oil. In this case, no set that includes fewer than 9 successful technologies can achieve both China's energy goals. After deleting one of the 14 energy technologies in each scenario, we recombine the remaining technologies and calculate the technology sets that can achieve China's energy goals, as shown in Fig. 2.

According to Fig. 2, if BIO, CCS, NUC, SOL or WIND failed, the probability to meet the second type of energy goal is zero; this means that in the remaining technologies, the goals to reduce carbon emissions by 50% and oil consumption by 200 million tons by 2050 cannot be achieved. Thus, we must ensure the usage level of the above five technologies to achieve the intended goals. If China does not develop AFL, TRAN and TNFF, the possibility of achieving the energy goals will decrease to 7%, 13%

and 19%, respectively. The influences of BLDG, ELFC and IND range from 40% to 60%. HYD, DG and OCE have smaller influences on achieving the energy goals because they are immature and constitute a small portion of China's energy supply. Relaxing the energy goals to -50% for CO_2 and 200 million tons oil makes it impossible to achieve both energy goals without CCS. AFL, TRAN and TNFF are also important energy technologies for achieving the higher energy targets. In this paper, the five technologies including BIO, CCS, NUC, SOL and WIND are defined as China's core energy technologies to achieve the energy goals. Currently, solar and wind energy are the most promising technologies in China. Thus, we will analyse their internal and external factors using the technology diffusion model. And, the development situations, problems and technical barriers for BIO, CCS, and NUC are also discussed.

Besides, the differences and gaps in core energy technologies in China and the US are compared based on the results in Ref. [8]. The failures of NUC, SOL, and WIND are less influential on the success of the energy goals in the US. China needs to raise the overall developed level of energy technologies and reduce the risk that a single technology's failure makes the energy goals unattainable.

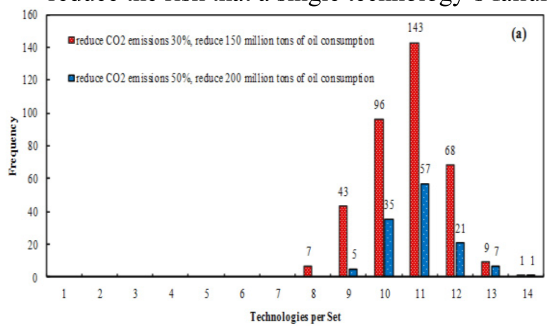

Fig. 1. Frequency distribution of technology combination.

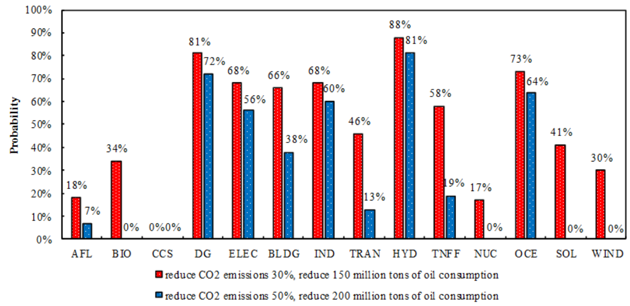

Fig.2. Effects of losses of individual technology on achieving the goals.

5. Promotion of China's core energy technologies

5.1. Promotion of WIND and SOL

In this section, we conduct a macro-evaluation of the external (*such as media, policy, and investment environment*) and internal environment (*such as feedback from technology applications*) of energy technology promotion. China's wind energy and solar energy are developing rapidly; however, certain bottlenecks remain, such as wind curtailment and photovoltaic products mainly for exportation. It is significant to study how to promote them effectively. Therefore, we analyse solar and wind energy technology diffusion as an example. Similar analysis can be conducted in the same manner for other core technologies when data is available. The diffusion model is in the form of a differential equation, as shown in Eq. (4).

$$\frac{dA(t)}{dt} = p[m - A(t)] + \frac{q}{m} A(t)[m - A(t)] \cdot \qquad (4)$$

where $A(t)$ represents the total installed capacity, and $dA(t)/dt$ is the new added installed capacity in each year, whereas m is the potential capacity. According to wind and solar energy data (Table 1) of China, we identify the parameters by the least square method; the results are shown in Table 2 and Figs. 3-4.

First, Table 2 shows that both parameters p and q for wind and solar are significantly positive. This finding means that the effects of the external policy environments and internal benefit of wind and solar energy technologies are positive. Second, in the development of wind energy, q is greater than p, which means that the effects of technology use feedback and the market demand are greater than the policy incentive for wind energy development. This is because climatic conditions and equipment constrain the scale of wind energy generation. In this circumstance, large-scale development is more affected by market factors. China's wind energy technology is progressing rapidly in the positive conditions of a large market with large demand and an excellent policy. As for solar, *q* remains greater than *p*. It is worth noting that China's solar energy is exploited by the centralized grid-connected mode, which is similar to wind energy generation. China is currently the third largest country in producing PV cells, after Japan and Germany. However, the domestic solar technology development lags because of the lack of core technology, the lack of policy support and the exportation of most of the products.

Table 1. Solar and wind energy resources in China.

Energy	Potential capacity
Wind	Total storage of wind energy resources is 23.80×10^5MW, in which, about 10×10^5MW can be developed by technology.
Solar	Potential resource is about 10^8 MW.

Table 2. Parameter estimation results of wind and solar energy.

Energy	Parameters	Standardized Coefficients	Standard Deviation	Sig.	Adjust R Square
Wind	p	6.760	0.315	0.000	0.994
	q	7.510	0.338	0.000	
Solar	p	3.299	0.280	0.000	0.999
	q	4.295	0.304	0.000	

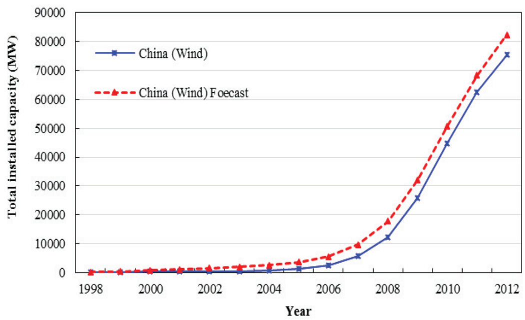

Fig.3. Wind power installed capacity predicting outcomes.

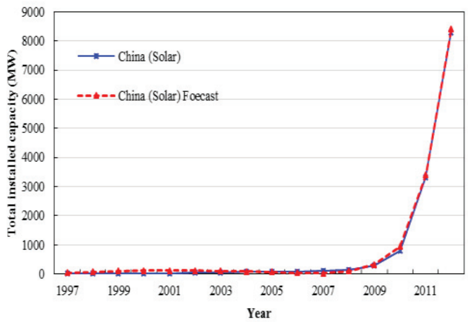

Fig.4. Solar power installed capacity predicting outcomes.

5.2. Promotion of CCS, NUL and BIO

CCS. CCS is an essential energy technology for realizing China's energy goals. Meanwhile, the situation of China's energy development and geographical conditions for carbon sequestration also illustrates that CCS may become the largest single response in China's climate mitigation portfolio. The chief barriers to implement CCS are poor economic feasibility (cost) and lack of capital source, as well as the policy environment. Therefore, development of CCS technology in China should seize the opportunity. For example, enhancing the technology of compression and purification, improving the social public acceptance of CCS, and promoting the technology transfer and communication.

NUL. Nuclear is the most important decarbonisation electricity supply second only to CCS during the 14 key energy technologies. However, the development of NUL has special industry disciplines. Technologies barriers include new nuclear technology and nuclear waste treatment technology. Furthermore, other factors including continuous training of skilled technical staff, and influences caused by low flow rate are also should be take into consideration.

BIO. Regional distribution feature of biomass power generation is obvious significantly which resulting in the dependency on resources and production characteristics for different areas. Technological barriers include the development of distributed generation based on direct-fired biomass power plant; the need for new, specialized energy crops; and biomass collection and transportation.

6. Conclusions and policy implications

This paper applies the enumeration method to analyse the importance of 14 different key energy technologies for achieving China's energy goals. We can provide priority development to core technologies that were identified as greatly influencing China's economy. Of course, other technologies with weak profits should also be invested in. The results show that CCS, NUC, BIO, SOL and WIND are significant to guaranteeing the success of China's energy goals. Simultaneously, AFL, TRAN and TNFF also have important impacts. By comparing with the situation in the US, we conclude that the level of China's energy technology development is less mature than the US's, and overall technology development continues to lag. The lag is reflected in the critical impact of a single technology failure on the energy goals. Moreover, CCS technology is indispensable to achieve the energy goals. However, CCS is costly and creates a high energy consumption, which needs to be addressed. The exploration of clean energy, such as NUC, BIO, SOL and WIND, is the main tendency.

For the successful promotion of core energy technologies, we study their internal and external factors, and analyse the development of WIND and SOL in China under the influence of external policy, market environment and internal technique factors based on the technology diffusion model. The current development of WIND and SOL greatly relies on government commitments because of their higher costs in comparison to conventional fuels. Although policy support, promotion and related external factors are important at the early stage, the market should gradually begin to regulate the development of technology, depending on the internal factors and ultimately achieving marketization. If the parameter p is relatively large, the government can gradually reduce the policy subsidy.

Acknowledgments

This research was supported by the National Nature Science Foundations of China (No. 71273119 and No. 71473108) and the Graduate Innovative Foundation of Jiangsu Province KYLX15_1076.

References

[1] Y.M. Liu, X. Guo, F.L. Hu. Cost-benefit analysis on green building energy efficiency technology application: A case in China. *ENERG BUILDINGS* 2014;82:37-46.

[2] Omar Ellabban, Haitham Abu-Rub, Frede Blaabjerg. Renewable energy resources: Current status, future prospects and their enabling technology. *Renew Sustain Energy Rev*. 2014;39:748-64.

[3] J. Byrne, B. Shen. The challenge of sustainability: Balancing China's energy, economic and environmental goals. *Energy Policy* 1996;24(5):455-62.

[4] L. Yao,Y. Chang. Energy security in China:A quantitative analysis and policy implications. *Energy Policy* 2014;67:595-604.

[5] J.A. Edmonds, M.A. Wise, J.J. Dooley, S.H. Kim, S.J. Smith, L.E. Clarke, et al. *Global energy technology strategy: Addressing climate change joint global change research institute.* College Park, Maryland. 2007.

[6] The energy strategy of the Chinese academy of sciences research group, *China to 2050 energy technology development roadmap*. Science press, Beijing, China. 2009.

[7] China's energy medium and long-term development strategy research project, *China's energy medium and long-term research on development strategy (2030, 2050)*. Science press, Beijing, China. 2011.

[8] Greene D.L.. Measuring energy security: can the U.S. achieve oil independence? *Energy Policy* 2010;38(4):1614-21.

Biography

Mei Sun is a Professor at Center for Energy Development and Environmental Protection, Jiangsu University. Her research interests are energy economy system modeling, and complex system analysis. She has published more than 40 papers in SCI/EI indexed peer-reviewed English journals.