DOI 10.15302/J-SSCAE-2018.03.017

An Urban Energy Strategy Development Index Evaluation System

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Abstract: Based on urban energy strategy development indexes, herein we put forward six principles for index design, and construct a two-grade index system for the evaluation of urban energy strategies, and their corresponding calculation models and methods. The two-grade index system introduces new methods of calculation, technologies, formats, and business models into the energy system. The index system covers eleven aspects: energy supply, energy consumption, electric power replacement, efficiency promotion, system flexibility, environmental and low carbon credentials, innovation and development, industry development, safety and reliability, economic benefits, and energy system. Furthermore, it can aid in the decision-making associated with development of urban energy strategies, in China. As an example, the system was applied to Zhangjiakou, as a verification tool for the evaluation of energy strategy in 2017, and to evaluate future progress achieved by 2020, and 2030. The results presented herein indicate that Zhangjiakou has a strong foundation of resources resulting in potential for development, and opens up avenues for technological breakthroughs. This paper also proposes energy development goals and strategic development advice, and provides guidance for future urban energy development.

Keywords: urban development; energy strategy; index evaluation

1 Introduction

Energy is an important basis for human survival and development, and is a driving force and foundation for social and economic progress. “The development of Energy Internet, characterized by the integration of renewable energy and Internet information technology, will be the key to the realization of clean energy and low carbon substitution and high efficiency and sustainable development.” [1]. In *The Thirteenth Five Year Program of National Economic and Social Development*, China proposes “to promote the deep integration of new technologies in energy and information, to co-ordinate the infrastructure network of energy and communications, traffic and other infrastructure, to build a coordinated development of ‘source-network-charge-storage’ and a complementary energy Internet”. On July 26, 2016, the National Energy Bureau issued *On Notice of the Implementation of Internet plus Wisdom Energy (Energy Internet) Demonstration Projects* to aid energy sector structural reform, which promoted the healthy development of the Energy Internet through developing different types and scales of energy pilot demonstrations.

In the 21st century, the development of energy technology has continuously progressed, and brought forth new ideas in various fields, such as politics, economy, and culture. It is changing the mode of operation and innovation of human society, and driving the transformation and upgrading of energy systems and the so-

Received date: June 10, 2018; **Revised date:** June 20, 2018

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Funding program: CAE Advisory Project “Strategic Research on the Technological Trend and System of the Energy Technology Revolution in China” (2015-ZD-09); management and technological project of State Grid Jibei Electric Power Company Limited “Research on Energy Strategy Development System in Zhangjiakou Area” (52018F17001S)

Chinese version: Strategic Study of CAE 2018, 20 (3): 117–124

Cited item: Li Shunxin et al. An Urban Energy Strategy Development Index Evaluation System. *Strategic Study of CAE*, https://doi.org/10.15302/J-SSCAE-2018.03.017

cial economy. On October 18, 2017, at the nineteenth National Congress of the Communist Party of China, President Xi Jinping pointed out that the major social contradictions in the country had been transformed into the contradiction between the growing needs for a good life of the people, and uneven and inadequate development. In the process of continuous development, and the evolution of energy development and supply systems, there is widespread general concern in government and industry on how to evaluate the level of development of energy strategy rationally, to summarize development needs and therefore, how to create a suitable development strategy. The evaluation of energy strategy development has guided implementation of the energy revolution significantly, and has reference value for energy policy making.

In 2008, Germany proposed the "E-Energy" plan, to build a new energy network, to achieve digital interconnection, and computer control and monitoring, of the entire energy supply system. In addition, the German government put forward the development strategy of "Industry 4.0" in its 2020 high technology strategy [2]. Along similar lines, the Swiss Confederation Polytechnic Institute is devoted to the study of a concept model of an Energy Hub, which is applied to intelligent energy. It collects and integrates real-time load forecasting and monitoring data on the distribution network power flow, and optimizes power generation and load. The National Science Foundation's FREEDM system innovation platform, in North Carolina State University, is committed to introducing electronic and information technologies into the power supply system, emulating the concept of a router in the communication network, and has put forward the concept of "energy routers", as part of the concept's initial development. The National Renewable Energy Laboratory has been engaged in research on intelligent energy, which considers the future energy network to be in the form of "power, heat / cold, fuel + data". The German International Cooperation Agency (GIZ), and the Chinese National Renewable Energy Center jointly issued the China Germany New Energy Demonstration City Energy plan, to achieve a zero emission target for Dunhuang, in Gansu province, China. [3] Accenture published the 2015 global energy architecture performance index (EAPI), to determine performance benchmarks for the current national energy system, and to provide information for decision-making in the context of changing global energy patterns.

2 The development of urban energy strategy

The Energy Internet is a new type of energy system which deeply integrates the concept of the Internet, technology and energy production, transmission, storage, consumption, and the energy market. It is an important element in constructing intelligent, low-carbon cities, which have the goals of energy saving, high efficiency, and environmental protection. It uses various advancements in energy and information technology, and uses intelligent means to improve the efficiency of energy utilization, promoting sustainable civilization. It has the potential to play an important role in intelligent city energy and environmental protection systems. [4]

The framework of an urban energy strategy is divided into three layers. The first layer is the infrastructure layer: electricity, oil, gas, water, communications, environmental protection, transportation, and thermal networks, which are the indispensable infrastructure of the urban architecture system. The interconnection and efficient utilization of these facilities is the guarantee of intelligent city. The second is the information application layer. The energy information is collected, analyzed and controlled by the Energy Internet. The energy status, energy characteristics and energy use prediction of the city are further analyzed, and the new and renewable energy sources are optimized according to various energy use conditions This is done to analyze and evaluate the energy efficiency of the equipment, to collect and analyze energy use information of electric vehicles, to provide energy use suggestions to guide the low-carbon lifestyle, to identify key emission sources, to collect and monitor urban environmental quality data, and indicate environmental risks. Solutions to key problems are also suggested. The third layer is the decision-making transaction layer, which uses the information on energy, transportation and the environment, in the Energy Internet, analyzes the energy structure, ecological conditions, the characteristics of municipal and resident life, and provides support for urban decision-making. At the same time, it provides value mining, innovative business model energy operation, and Internet thinking, to the energy supply chain.

In the field of index evaluation, the National Laboratory of New Energy Power system, of the North China Electric Power University, has constructed the energy efficiency index system for distribution networks, based on an Analytic Hierarchy Process (AHP) [5]. The weight of each single index is determined by the AHP, and the stated values of the single indexes are combined. A comprehensive energy efficiency score for the distribution network is thus obtained, and any weak link in the efficiency of the energy distribution network is identified. Based on analysis of the new index of energy utilization efficiency, the College of Petroleum and Natural Gas Engineering, of the China University of Petroleum, proposed a reduction in the coal structure, an increase in the proportion of clean energy, management of development of secondary industry, improvements in energy use efficiency, and an increase in the proportion of tertiary industry [6]. The key Laboratory of Smart Grid Technology and Equipment, in Jiangsu province, has carried out evaluation and optimization of technical energy conservation, based on an energy efficiency assessment of the power supply system [7]. The calculation method and influencing factors of the Distributed Energy System (DES), the Combined Cooling, Heating and Power (CCHP) System, and the regional energy use efficiency analysis, of the South China University of Science and Technology have been reviewed, and an evaluation index and energy efficiency calculation method for the region have been presented [8].

The evaluation system of the urban energy strategic development index, constructed by the Energy Internet Innovation Institute, of Tsinghua University, combined with the practice of urban energy transformation and developments at home and abroad, seeks to reflect the true level of energy strategy development in China, from multiple levels and perspectives. The evaluation system of the urban energy strategy development (UESD) index is established, and lays a foundation for formulating a scientific energy policy. The indexes of energy supply, energy consumption, energy efficiency improvement, re-electrification, and low carbon emission are designed to ensure that the index evaluation system keeps pace with the aspirations of society. The urban energy system achieves optimal allocation of the flow of material, energy, information, business, and capital, through multi-energy, supply and consumption, centralized, and distribution cooperation, and with broad participation of the public, to promote higher quality, efficiency, equitability, and the sustainable development of energy systems. Based on previous research, this paper reports on further studies and analyses carried out on the evaluation system of the urban energy strategic development index, based on different aspects of energy production, transmission, consumption, storage, and conversion.

3 Index system and evaluation methods

3.1 The principles of index design

Guiding, systematic, comparable, scientific, maneuverable, and dynamically optimized design principles should be built into the design of the evaluation index system.

3.1.1 Guiding principle

The design of the index system aims at promoting development of an energy strategy. It is guided by the national policy of the government, the law of economic development, and the demand for clean and low-carbon energy. It embodies the overall requirements of national energy strategy development. The index system as a whole can incorporate the main influencing factors and characteristics of the development of urban energy strategy. At the same time, in terms of index elements and weightings, the system should be oriented to reflect its guiding role.

3.1.2 Systematic principle

Energy development is an organic system, with close links between the main elements and various fields of the economy and society. The index system is not a simple pile of indicators, but a distinct entity. The indexes of various aspects are at different levels, forming a certain hierarchy between the individual indexes, and the index layers. There is a clear logical relationship. A single index in the system can reflect a certain aspect of the development of energy strategy, and the accumulation of indicators can reflect the overall situation. The Department of Electrical Engineering and Applied Electronic Technology, of Tsinghua University, has put forward a comprehensive energy utilization index [9], and an Energy Internet comprehensive energy efficiency evaluation method [10], which are suitable for energy efficiency assessment, in multi-energy cooperative parks.

3.1.3 Comparable principle

Evaluation results can be compared horizontally or vertically. We can find differences in regional resource endowments, energy systems, ecological conditions, technical levels, policy guarantees, and economic developments, in different areas, by comparing energy strategy development indicators from different regions, and the direction, level and speed of the development of energy strategy in the same areas, by comparing the index for the same area over time. The energy conversion coefficient (ecc/ECC) index was constructed by the Department of Architectural Technology Science, of Tsinghua University, and the energy efficiency of a series of energy use links have been compared and evaluated [11].

3.1.4 Scientific principle

The main scientific principle embodied in the choice of index, is to exclude the influence of subjective factors as much as possible. A quantitative index is the main component, with a qualitative index being supplemental. The index system tries to objectively and accurately reflect the reality and future potential of the development of energy strategy. This is the main guiding principle of the energy strategic development evaluation index design, thus ensuring that the results of the evaluation index can objectively reflect the trend of the development of energy strategy, its reality level, and the speed of change.

3.1.5 Maneuverable principle

Inconsistency between the rationality of the theoretical model, and the availability of data, is one design issue with the evaluation index for energy strategy development. A theoretically ideal measurement index is often difficult to obtain in reality, while data that is easily available may not be relevant to the requirements of the index. Therefore, the design of the evaluation index for energy strategy development aims to achieve a balance between theory and data availability. For example, at present, the specific algorithm for renewable energy efficiency has not been unified. The North China Electric Power University and the China Institute of Architectural Design and Research have defined renewable energy substitution and renewable energy utilization, and provided a renewable energy utilization algorithm [12]. In addition, it is difficult to compare different energy sources. In general, the calculation method of primary energy consumption is used to convert different kinds of energy sources, such as coal and natural gas, into standard coal equivalents, according to their calorific values. Using coal consumption and energy production from a coal-fired power plant to create a standard unit of energy production, electrical energy produced from any source can be converted into standard coal equivalents [13,14].

3.1.6 The dynamic optimization principle.

Energy development is a dynamic process. The upgrading of energy infrastructure, the change of energy technology and data availability, the emergence of new data sources, and the adjustment of evaluation targets will lead to the dynamic evolution of the evaluation index of the development of energy strategy. On the premise of maintaining the basic stability of the overall framework of the index system, a comprehensive balance between energy development stage, and the dynamic supplementary adjustment of the indicators, can be made, to reflect the state of energy development in a more comprehensive and objective way. The city index system has dynamic and flexible components, for different types of cities, and provides guidance to help these different cities make decisions during different periods of strategy development and implementation.

3.2 Construction of index evaluation system

The index evaluation system for the UESD is divided into two levels. There are 11 first-grade indexes: energy supply, energy consumption, energy efficiency, electric energy substitution, system flexibility, green and low-carbon, innovation and development, industry development, safety and reliability, economic benefit, and energy system. The first-grade index weight is 0.05−0.15. There are 14 second-grade indicators: renewable energy installed capacity ratio, clean energy consumption ratio, non-fossil fuels consumption ratio, new energy vehicle popularization, comprehensive energy utilization efficiency, electric power proportion in terminal energy utilization, capacity of cross-regional transmission channels, energy storage capacity, carbon dioxide emission reduction, research and development input, registered enterprise volume, power outages time in central cities, investment return rate, and the number of policies in the major cities. The weight of the index is 0.5−1 (Fig. 1).

3.3 Construction of the index evaluation model

Based on the work above, the evaluation model for the UESD index is basically constructed, and the quantitative analysis and calculation of the multilevel energy strategy proceeded, with four elements—index calculation, index weight, index value calculation method, and case analysis.

3.3.1 Index calculation

The construction of the basic index system was mainly done through literature review, application of databases, or through questionnaires targeting industry specialists. Thus, the values of the quantitative index, synchronized with the economic cycle at different times, were obtained, thresholds were set, values were standardized, and the base index calculated.

$$B_i(t) = d_i(t)/T_i(t) \tag{1}$$

In Equation (1), $B_i\ (t)$ is the unweighted basic index value of the i-th index, at the moment t, $d_i\ (t)$ is the value of i-th index value at the time t, and $T_i\ (t)$ is the threshold of the i-th index at moment t, as t = 1, 2, 3, and so on.

After obtaining the basic index of i different indices, the weight was set, and the exponential result of weighted time t was calculated.

$$I_i(t) = \sum_{i=1}^{N} B_i(t) W_i \tag{2}$$

In Equation (2), W_i is the weight of the i-th index, and N is the number of indicators. $B_i\ (t)$ is the unweighted basic exponent of the i-th index, at time t. $I_i\ (t)$ is the i-th exponent of t moment.

According to Equation (1), the basic index $B_i\ (t)$ was obtained, using 11 first-grade indices selected from index calculation. After equal weighting, the index calculation results, $I\ (t)$, for all the second-grade indexes were obtained, giving the total weight $I_i\ (t)$.

3.3.2 Index weight

The weight of the energy strategy development index system was determined by AHP, and the complete calculation process is as shown below. First, a hierarchical structure model was set up, according to the settings of the energy strategy development index evaluation system. The relationship between the indexes was settled, and then the judgment matrix was constructed. In determining the weight of each level and each index, pairwise comparisons were carried out, using the uniform matrix method, so as to reduce the comparison difficulty between different factors, and improve accuracy. Second, hierarchical single rankings were conducted. For a certain top level factor, the importance ranking for all the factors at this level was checked, to ensure consistency. Third, we carried out a general ranking of layers, and determined the ranking weights of each of the factors, in a certain level, in terms of relative importance to the total objectives. The first-grade index weight range was 0.05−0.15, and the second-grade index weight range was 0.5−1.

3.3.3 Comprehensive index

The comprehensive index score was calculated, by means of a linear weighting method, according to the index level, with the formula shown in equation (3).

$$D = \sum_{i=1}^{5} \alpha_i \sum_{i=1}^{n} \beta_j P_j \tag{3}$$

In equation (3), i is the number first-grade indices; j is the number of second-grade index corresponding to the i-th first-grade index; P_j is the j-th index value; α_i is the weight of the first-grade index; β_j is the weight of the j-th second-grade index

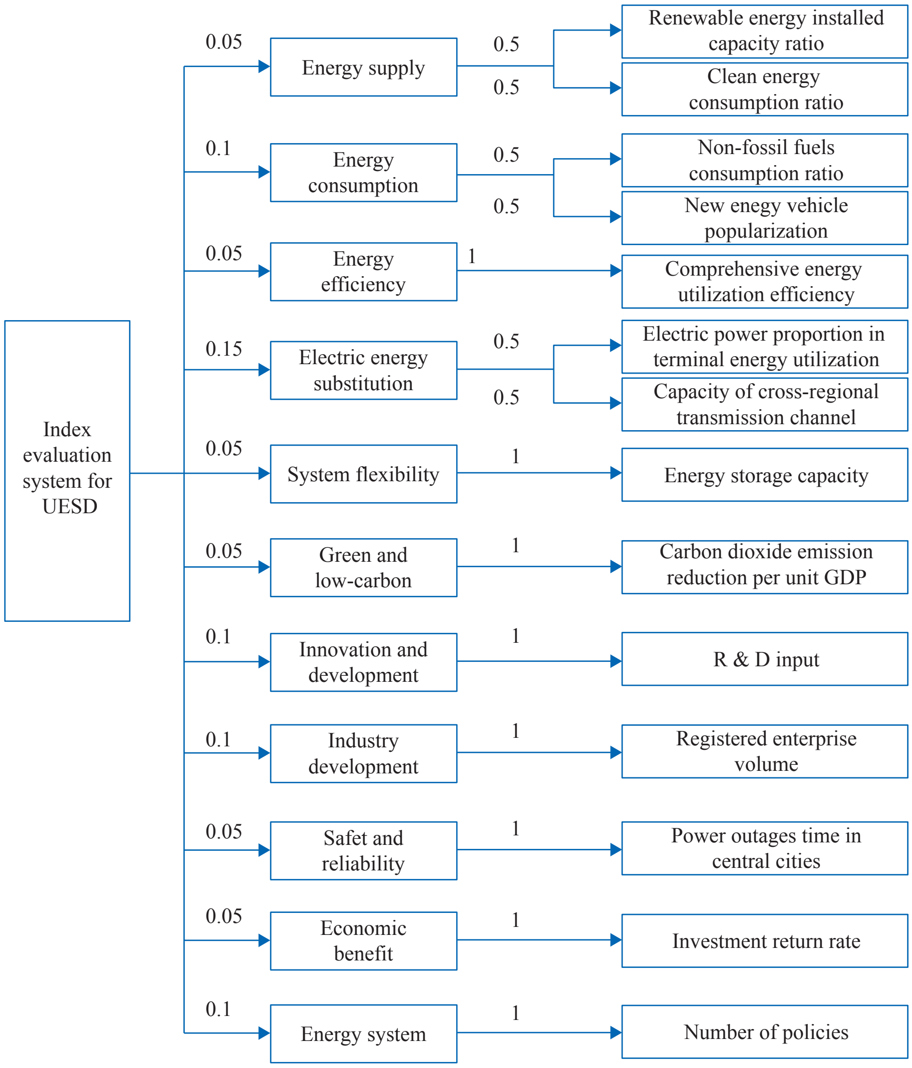

Fig. 1. Index evaluation system for UESD.

corresponding to the k-th first-grade index; and D is the UESD index.

3.3.4 Index evaluation analysis using Zhangjiakou as the test case

At present, authorities in Zhangjiakou, in Hebei province, China, are working to improve the city's innovation, coordination, environmental performance, openness, and information sharing, securing opportunities for three-way coordinated development between Beijing, Tianjin, and Hebei, as well as joint organization of the Winter Olympic Games with Beijing, and establishment of a national renewable energy demonstration area. Furthermore, authorities have actively cultivated leading major participants in the ecology, tourism, big data, health management, new energy, new technology, and high-end manufacturing industries. The city has also been focusing on presenting itself as a water conservation function area, green industry gathering area, renewable energy demonstration area, international leisure tourism city, and Olympic city. The UESD index for the city has been calculated using the inputs from the Zhangjiakou energy index for 2017, and the comprehensive index evaluation method described in this paper. The results are shown in Table 1.

By applying the "13th Five-Year" development plan, and medium and long-term planning in the national energy field, UESD results for 2020 and 2030 in Zhangjiakou, China have been simulated, and are presented in Table 2 and Table 3.

The evaluation results for the UESD index were calculated for Zhangjiakou, and have been illustrated in Fig. 2.

4 Conclusions and suggestions

This study takes into account different perspectives of energy supply, consumption, and energy efficiency, and proposes an evaluation system and calculation method for an urban energy strategic development index, which is intended to improve the comprehensive, scientific, and practical evaluation of the index

Table 1. UESD index in 2017.

No.	First-grade indexes	Second-grade indexes	2017	Second-grade score	Second-grade weighted score	First-grade score	First-grade weighted score
1	Energy supply	Renewable energy installed capacity ratio	1 280	43	17.2	42.9	2.1
		Clean heating rate	17	17	5.1		
		Wind power abandonment rate	7	50	7.5		
		Photovoltaic power abandonment rate	1.3	87	13.1		
2	Energy consumption	Non-fossil fuel consumption ratio	0.15	60	30	45	4.5
		New energy vehicle popularization	0.1	30	15		
3	Energy efficiency	Reduction of energy consumption per unit GDP	5.8	22	22	22	1.1
4	Electric energy substitution	Proportion of renewable energy in electricity consumption	20	40	20	30	4.5
		Renewable energy outbound transmission capacity	400	20	10		
5	System flexibility	Energy storage capacity	5	40	40	40	2
6	Green and low-carbon	Carbon dioxide emission reduction per unit GDP	18	56	14	50.8	2.5
		Carbon dioxide emission reduction	1 300	35	8.8		
		$PM_{2.5}$ yearly value	34	50	12.5		
		Air purification level	81	62	15.5		
7	Innovation and development	R & D input	0.6	24	24	24	2.4
8	Industry development	Registered energy enterprise volume	1 816	52	52	52	5.2
9	Safety and reliability	Power outages time in central cities	156	38	38	38	1.9
10	Economic benefit	Investment return rate	8	60	60	60	3
11	Energy system	Number of policies	60	60	60	60	6

Table 2. UESD index in 2020.

No.	First-grade indexes	Second-grade indexes	2020	Second-grade score	Second-grade weighted score	First-grade score	First-grade weighted score
1	Energy supply	Renewable energy installed capacity ratio	2 000	60	24	72	4
		Clean heating rate	60	60	18		
		Wind power abandonment rate	0	100	15		
		Photovoltaic power abandonment rate	0	100	15		
2	Energy consumption	Non-fossil fuel consumption ratio	0.3	80	40	80	8
		New energy vehicle popularization	0.3	80	40		
3	Energy efficiency	Reduction of energy consumption per unit GDP	0.19	78	78	78	3.9
4	Electric energy substitution	Proportion of renewable energy in electricity consumption	55	75	37.5	67.5	10.13
		Renewable energy outbound transmission capacity	1 500	60	30		

No.	First-grade indexes	Second-grade indexes	2020	Second-grade score	Second-grade weighted score	First-grade score	First-grade weighted score
5	System flexibility	Energy storage capacity	10	60	60	60	3
6	Green and low-carbon	Carbon dioxide emission reduction per unit GDP	0.21	62	15.5	70	3
		Carbon dioxide emission reduction	3 600	66	16.5		
		$PM_{2.5}$ yearly value	25	70	17.5		
		Air purification level	90	80	20		
7	Innovation and development	R & D input	0.01	40	40	40	4
8	Industry development	Registered energy enterprise volume	2 000	60	60	60	6
9	Safety and reliability	Power outages time in central cities	60	80	80	80	4
10	Economic benefit	Investment return rate	0.15	80	80	80	4
11	Energy system	Number of policies	80	80	80	80	8

Table 3. UESD index in 2030.

No.	First-grade indexes	Second-grade indexes	2030	Second-grade score	Second-grade weighted score	First-grade score	First-grade weighted score
1	Energy supply	Renewable energy installed capacity ratio	5 000	100	40	100	5
		Clean heating rate	100	100	30		
		Wind power abandonment rate	0	100	15		
		Photovoltaic power abandonment rate	0	100	15		
2	Energy consumption	Non-fossil fuel consumption ratio	0.5	100	50	100	10
		New energy vehicle popularization	0.5	100	50		
3	Energy efficiency	Reduction of energy consumption per unit GDP	0.3	100	100	100	5
4	Electric energy substitution	Proportion of renewable energy in electricity consumption	80	100	50	100	15
		Renewable energy outbound transmission capacity	3000	100	50		
5	System flexibility	Energy storage capacity	100	100	100	100	5
6	Green and low-carbon	Carbon dioxide emission reduction per unit GDP	0.25	100	25	96	4.8
		Carbon dioxide emission reduction	8 500	95	23.75		
		$PM_{2.5}$ yearly value	10	90	22.5		
		Air purification level	95	100	25		
7	Innovation and development	R & D input	0.018	78	78	78	7.8
8	Industry development	Registered energy enterprise volume	4 000	90	90	90	9
9	Safety and reliability	Power outages time in central cities	5	100	100	100	5
10	Economic benefit	Investment return rate	0.2	90	90	90	4.5
11	Energy system	Number of policies	120	100	100	100	10

of urban energy development strategy. According to this method, the test case city of Zhangjiakou has a strong foundation in energy consumption, re-electrification, energy systems, and other indicators. Our forward simulation also indicates that it has potential for innovation and industrial development, by 2030. The index indicates that the city needs technical breakthroughs in energy supply, needs to review and adopt environmentally-friendly and low-carbon emission technologies, and needs improved

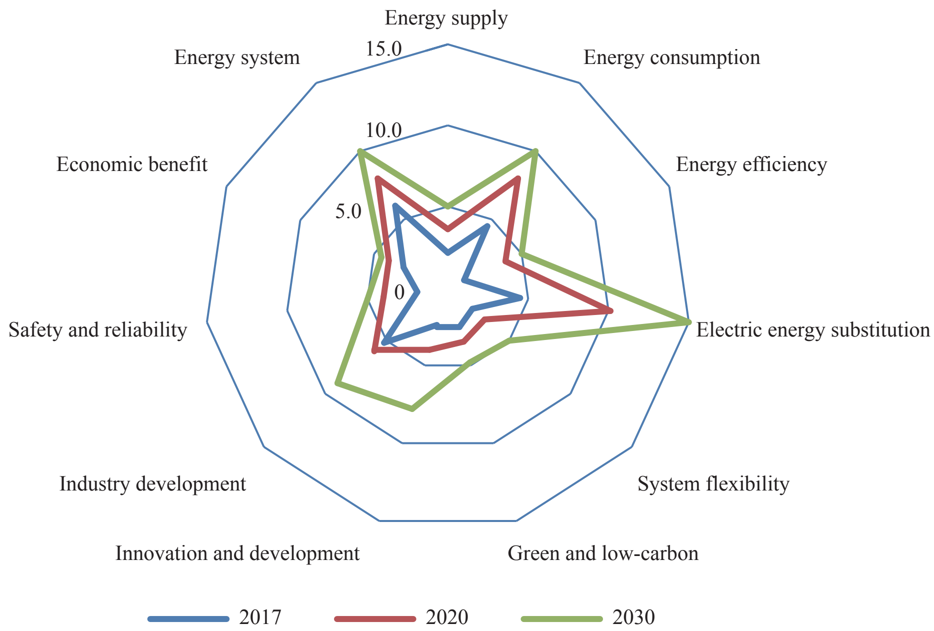

Fig. 2. UESD index evaluation results, for Zhangjiakou, China.

safety and reliability credentials, going forward to 2017−2020. The index also identifies that the city needs strong technical support and policy promotion, in energy efficiency, system flexibility, and ensuring economic benefits, from 2020−2030. To support this future direction, a future, "1 + 5" development goal for Zhangjiakou has been proposed: "to create a system−technology−industry innovative, clean energy demonstration area, with a pleasant living environment and an international leading demonstration effect." That is to say, Zhangjiakou will be the embodiment of a national core-area energy base, a green energy use city, a green intelligent valley, a low-carbon Winter Olympic zone, and a green Davos in Chongli. Power grid development goals are also proposed.

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