Connotation and Benefit Evaluation on Integrated Energy System of Urban Agglomeration

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Abstract. With the development of ecological civilization construction and regional coordinated development strategy in China, to adapt to the development trend of urban agglomeration, the energy structure will be adjusted and upgraded accordingly. The energy structure has gradually changed from fossil energy to diversified supply mode. The integrated energy system of urban agglomeration will coordinate with energy planning, operation, management and other links, and realize the linkage and complementarity of multiple energy sources. In this context, it is necessary to carry out a systematic analysis of the comprehensive energy system of urban agglomerations. This paper analyzes the connotation, characteristics and function mechanism of comprehensive energy system of urban agglomeration, and constructs a set of evaluation index system. These research ideas and methods can be applied to the scenarios of energy development, utilization and management that adapt to the development of urban agglomeration, and provide scientific analysis tools for energy system management and evaluation.

1. Introduction

Based on ecological civilization construction and the regional development strategy, China's cities are showing a tendency of agglomeration and polarization at the same time of diversified development, gradually forming the urban agglomeration, represented by Jing-Jin-Ji area and Yangtze River Delta. The formation of urban agglomeration, on the one hand, expands the scope of resource allocation between cities, on the other hand, it needs to coordinate urban space and resources. These also pose greater challenges to the energy system, which need to solve the problems such as the lack of effective coordination, local imbalance and low energy efficiency among the energy supply subsystems. The comprehensive energy system of urban agglomeration plays an important role in improving the comprehensive efficiency of energy and infrastructure and promoting the development and utilization of renewable energy through the complementary coupling of electricity, heat, cooling and gas systems. However, because the integrated energy system is still in the primary stage of development, there is little research on the energy system of urban agglomerations. The research on its benefit evaluation technology is of great significance to the medium and long-term development of regional integrated energy system.

The present study of synergetic evolution mainly concentrates on the bioscience sector and gradually extends to the sectors of communications, industry and energy[1-3]. The existing study of coordinated
energy development mainly includes three aspects: firstly the study of supply and demand relations of different energy types and energy system coordination and optimization from the perspective of technology, secondly the study of energy system simulation from the perspective of planning[4-6], and thirdly the establishment of indicator system to evaluate the synergetic development from the perspective of performance[7-9]. However, few of them have probed into the comprehensive energy system or analyzed the impact mechanism of energy relations, and most of the evaluation indicators are qualitative instead of quantitative[10]. Therefore, the thesis conducts mechanism analysis of energy system relations and builds up the indicator system evaluating the extent of synergy that offers scientific methodology and tool to the development of integrated energy system.

2. Green development of integrated energy system of urban agglomeration

2.1. Green development of integrated energy system of urban agglomeration

Green development of energy is to play the role of the energy hub of electric power, promote the green transformation and clean production of energy, provide high-quality and diversified energy services, so as to promote the green transformation and sustainable development of society, and finally realize the ecological civilization of society. The integrated energy system refers to the multi-energy, full-chain integrated system formed after organic coordination and optimization of energy production, transmission and distribution, conversion, storage in the process of planning, construction, operation, etc. The integrated energy system of urban agglomeration is a energy system based on the difference of urban resources and load characteristics and adapted to the development trend of different cities. It is the geographical and functional manifestation of comprehensive energy system that integrates multiple types of energy within the region such as coal, petroleum, natural gas, electricity, heat energy, etc., and realizes coordinated planning, optimized operation, synergized management and mutual complementation of different energy subsystems, shown as Figure 1.

Figure 1. Frame diagram of integrated energy system of urban agglomeration
2.2. Characteristics of multi-energy complementation among cities

Based on the networking integration of energy systems of different forms, the integrated energy system has multiple functions of energy production, transmission, conversion, storage, use, etc. and the integrated physical system realizes the in-depth integration between sectors and users.

In terms of space, the integrated energy system breaks the barrier of conventional model and regional restriction of separate energy supply. Various energy systems are mutually convertible and supportive via transformation equipment that offers additional energy supply approach and improves system reliability and cost efficiency.

In terms of time, the integrated energy system realizes peak shaving and valley filling by coordinated energy utilization. The joint energy supply changes the over-reliance on single energy in peak load period and thus increases the utilization rate of energy equipment.

In terms of method, the integrated energy system achieves distributed, flexible, economical and diversified co-supply of energy.

In terms of price, by comprehensive utilization of multiple energy, the integrated energy system provides opportunity of conversion to and utilization of cleaner, cheaper and more efficient energy and effectively reduces total cost of system by optimized regulation and control.

3. Synergetic evolution of green development of integrated energy system of urban agglomeration

3.1. Mechanism of synergetic development of integrated energy system

The integrated energy system breaks the physical barrier of different energy systems like electricity, heating, cooling, gas, traffic, etc., realizes mutual complementation and integration of various energy and introduces plenty of renewable energy such as wind energy, solar energy, tidal energy, geothermal energy, bio-energy, etc. It combines "source-grid-load-storage" vertically and "multi-energy complementation" horizontally, coordinates centralized grid and distributed energy network and realizes synergetic development in and between energy subsystems.

3.1.1. Vertical coordination of "source-grid-load-storage".

The synergy of internal subsystems of regional integrated energy system is the vertical coordination of "source-grid-load-storage" where the each link follows the same evolution direction of the whole subsystem. This process does not occur separately but interacts with its structure and environment.

"Source-load" balance is demonstrated by the synergy of energy supply and demand. At the "source" end of energy supply, the resource reserve decides the exploitable volume of resource while the exploitation capability further decides the scale of energy supply; the resource distribution decides the distribution of energy supply capacity. The energy supply capacity is influenced by all these supply conditions.

"Source-grid" coordination is in essence the coordinating and matching between energy supply capacity and energy transmission and distribution capacity. At the "source" end, the progress of resource exploration capability, exploitation capability and energy production technology can gradually enlarge the capacity of energy supply; at the "grid" end, the grid construction input and technology progress can expand the capacity of transmission channel and uplift the transmission and distribution efficiency; the improvement of peak regulating capacity will also expand the transmission and distribution capacity of energy grid.

The dynamic interaction of "source-grid-load-storage" makes use of the flexible regulating feature of energy storage at the transmission/distribution end and load end and better matches energy supply, transmission/distribution and demand for synergized development. When energy supply exceeds the grid transmission capacity or consumption demand, the energy storage system may temporarily store the surplus; then it releases energy to meet demand in case of inadequate energy supply or huge upsurge of demand.
3.1.2. "Multi-energy complementation" horizontal coordination.
The subsystems within the regional integrated energy system are interactive with mutual impact where different types of energy are coupled by CCHP for mutual complementation. Their synergized development can realize large-scale utilization and sharing of renewable energy and tighten the connection between electric power system and heat production system and fuel gas network. Multi-energy complementation refers to the relations of mutual conversion, complementation and substitution of different types of energy. The multi-energy complementation in the regional integrated energy system means the coordination and complementation of different energy types including electricity, coal, heat and gas supply. It is flexibly applied in accordance with different resource conditions and energy consumers that can reasonably utilize natural resources and gain better economic, social and environmental benefits. Such mode covers the source-side comprehensive energy system, user-side comprehensive energy system and energy transmission network.

4. Evaluation of integrated energy system of urban agglomeration

4.1. Evaluation concept
The synergetic development level of integrated energy system of urban agglomeration refers to the status and level of regional integrated energy system within a specific period. The indicator system that describes its development level includes not only the indicators for each link but a few comprehensive indicators showing the development level of entire energy system.

It should be noted that the functioning of regional energy supply system is the result of joint efforts of all subsystems and their elements where some relations definitely exist between subsystems and elements. Therefore, some indicators describing the subsystem's development level may go beyond the status of single subsystem but describe the development status of several subsystems.

4.2. Evaluation indicator system and methodology
Following the mechanism analysis of impact of integrated energy system upon the energy system and the hierarchical, scientific and measurable principles, the evaluation indicators are set up in four aspects namely energy security, cites' functions, green development and energy efficiency as shown in Table 1. Meanwhile, given the different characteristics of dimensional indicators, the specific calculation method and variable note of each indicator are provided.

| Table 1. Energy Benefit Index System of integrated energy system of urban agglomeration |
|-----------------------------------------|------------------------------------------|---------------------------------|
| Dimensions | Indicator | Formulation | Variables |
|-----------------|-----------------|-----------------|-----------------|
| Energy security | Energy Self-Sufficiency | $ESS_i = \frac{\sum_{n} EP_i}{\sum_{n} EC_i}$ | $ESS_i$ is energy self-sufficiency rate. $\sum_{n} EP_i$ is total regional production of energy. |
| | Diversity of Energy | $ED_i = \sqrt{\frac{\sum_{n} QEI_i}{\sum_{n} EC_i}}$ | $ED_i$ is diversity index of energy input. $QEI_i$ is the quantity of type n energy input. |
| Cites' Function | Level of Power Supply Facilities | $LPF_i = \frac{\sum_{n} PC_i}{\sum_{n} EL_i}$ | $LPF_i$ is level of power supply facilities in regional i. $\sum_{n} PC_i$ is total capacity of regional power supply and substation. $\sum_{n} EL_i$ is total electric load. |
| | Per Capita Electricity Consumption | $Per_{EC_i} = TEC_i / Pop_i$ | $Per_{EC_i}$ is per capita electricity consumption. $TEC_i$ is total regional electricity consumption. $Pop_i$ is total regional population. |
| | Popularity Rate of Gas | $PRG_i = PGC_i / Pop_i$ | $PRG_i$ is popularity rate of gas. $PGC_i$ is Regional Population Use of Natural Gas. $Pop_i$ is total regional population. |
The multi-indicator comprehensive evaluation is to turn several statistical indicators describing the different aspects and dimensions of target into the non-dimensionalized relative values, and summarize these values to figure out the overall evaluation of target. The prevailing evaluation methods at home and abroad include analytic hierarchy process, expert evaluation, multivariate statistical analysis, fuzzy comprehensive evaluation, etc.

The general evaluation process usually includes three steps: firstly to select evaluation indicators and set up an indicator system as per the type of subsystem; secondly to collect indicator data for normalization; thirdly to evaluate the comprehensive development level of subsystem by the selected multi-indicator evaluation method.

### 5. CONCLUSIONS

This paper puts forward the connotation, characteristics and internal mechanism of integrated energy system of urban agglomeration. Based on the theory of correlation analysis, the collaborative development mechanism of energy processing, conversion, transportation and storage is studied.

Based on the analysis of the relationship between energy system and element, the thesis sets up the indicator system in four aspects of basic function, clean development, energy security and energy efficiency, and accordingly provides computing formula and evaluation steps. The result of study may be applied to the typical scenarios of future energy and electric power planning so as to provide a scientific tool for measuring the synergetic development level of regional integrated energy system. However, the thesis contains no profound analysis of specific characteristics of single energy type and its impact on the synergy of comprehensive energy system, which are the study orientations in the future.

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