Theoretical and Empirical Analysis on the Transformation of Energy Consumption New Mode

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Abstract. The innovation of energy consumption modes plays an important role in solving energy development problems of China. This paper proposes a theoretical system for the transformation of energy consumption modes. Through the analysis of four elements of energy consumption mode, and their internal and external influence factors, four types of energy consumption new mode are derived, namely, integrated, sharing, intelligent and green patterns. These new modes present the features of digitalization, marketization, high efficiency, electrification and cleaning in the future. Finally, a transformation analysis index system is built to evaluate and prospect the future energy consumption modes. The new energy consumption modes in the future show the features of ‘technology before the market’. The main features of energy consumption modes are digital and efficient in the early stage. In the later period, the characteristics of cleaning, marketization and electrification are obvious.

1. Introduction

After decades of rapid development, China has become the largest energy producer and consumer in the world. A complete energy supply system has been formed which includes coal, oil, natural gas, new energy and renewable energy, and the energy consumption conditions for people's production and life have been improved significantly. However, energy development in China still faces some problems such as energy demand pressure, environmental damage, imperfect mechanisms, and extensive energy consumption. Among them, the energy consumption mode is the crux of many problems, so the energy consumption mode innovation will become one of the key factors to solve the challenges of energy development in China. At present, the new energy consumption modes have been emerging and showing a booming trend. In the future, it may form the next market of over 10 trillion after the Internet economy. The innovation of energy consumption mode will become an important breakthrough point for strengthening our country's international competitiveness.

As a commodity, energy is able to meet the needs of residents or enterprise for energy consumption products. Many researchers focus on the energy consumption modes. Jianliang Gao² proposed two corresponding energy consumption modes based on different economic development modes. One is the traditional consumption mode of ‘resources (energy)-products-waste’ based on linear economics. The other is the feedback-type circular consumption mode of ‘resources (energy)-products-renewable resources’ based on the circular economy development modes. Yanyan Lu³ proposed that social production and consumption is a feedback cycle process of ‘resources (energy)-products-renewable resources’. The circular economy advocates a kind of economic development pattern that develops in harmony with nature. The establishment and development of circular economy require the transformation of consumption patterns from traditional patterns to sustainable patterns.
This paper first gives the following definition of energy consumption mode: Energy consumption mode is that under the promotion of certain technology, economy and policies, energy consumers consume energy products and related services through multiple channels or ways in the energy system to achieve the digitalization, high efficiency, cleaning, marketization and electrification. The energy consumption mode consists of four elements: energy consumers refer to the people, groups or end energy demand sector that consume energy; energy consumption products and services refer to products such as cold, heat, heating, gas, electricity and extended value-added services; energy consumption channels refer to the ways in which energy consumers consume energy products and services, including platforms, networks, centralized, distributed, etc.; energy consumption prices have evolved from fixed electricity, water, and gas prices to a diversified and market-oriented price system. The interaction of these four elements determines a new mode of energy consumption. Based on the Chinese and Western consumption theory, Marxist theory of practice, and the new energy strategy of ‘four revolutions, one cooperation’, we propose an energy consumption mode transformation theory, later the future energy consumption mode is forecasted and analyzed. The rest of paper is organized as follows: Section 2 introduces the energy consumption mode transformation theory which is proposed in this paper, Section 3 builds an analysis indicator system for energy consumption mode transformation, and describes the outlook analysis for future energy consumption pattern, and Section 4 gives the conclusions of this paper.

2. Theoretical Research on Energy Consumption Mode Transformation

2.1. Theoretical System of Energy Consumption New Mode Transformation

The Marxist theory of practice emphasizes that the practice activity is to realize the unity of human being and nature, subject and object, thinking and existence, purposiveness and regularity. This provides a theoretical basis for studying energy consumption transformation and analyzing the relationship between the subject and object of the energy consumption. The classic theory of consumption modes in China and the West explain the process of consumers' purchase decision behaviours and post-consumption evaluation behaviours under the marketing strategies of merchants, which provides theoretical support for the four elements of energy consumption mode transformation. President Xi proposed the new energy security strategy of ‘four revolutions, one cooperation’, which further promote the transformation of energy consumption to the direction of clean and low-carbon, intelligent interaction. The three complement each other and jointly promote the formation of the theoretical system of energy consumption mode transformation.

Fig.1 shows the framework of the theoretical system of energy consumption mode transformation. The influence factors for energy consumption include external environmental factors such as economy, technology, market, policies, and endogenous power factors such as energy structure transformation, energy system interconnection. The combined effect of these factors has a profound impact and
changes on energy consumers, energy products and services, energy consumption channels, and energy consumption price, and jointly promote the transformation of energy consumption modes. Through the analysis the characteristics and transformation paths of the energy consumption new mode, it lays the foundation for the development of the energy consumption new pattern.

2.2. External Factors for Energy Consumption New Modes
The external environmental factors for energy consumption new mode include economic and social development, scientific and technological progress, market mechanism improvement, policy and strategy guidance. Economic and social development is traction. As industrialization and urbanization enter the middle and late stages, the energy development of China is entering a new stage from total expansion to improvement of quality and efficiency. The optimization of the economic structure has promoted the shift of energy service entities from industry to commerce and residents, and the main energy consumption is shifted from coal and oil to cleaner, more efficient low-carbon energy. In 2019, urban permanent population accounted for 60.6% in China. In the future, the population will continue to be concentrated in cities, and the economy and population agglomeration effects of cities will continue to show a central trend of energy demand.

The progress of science and technology is the driving force. In terms of the clean utilization of fossil energy, the application of technologies such as clean utilization of coal, fuel economy of motor vehicles, ultra-low emission of coal-fired power generator units have been accelerated. In terms of clean energy substitution, coal-to-electricity and coal-to-gas conversions are actively promoted according to local conditions. Electric boilers and electric furnaces are gradually popularized. New energy vehicles are developing rapidly and electrified railways are fully popularized. Information technologies such as ‘Big data, Cloud computing, Internet of Things and AI’, are able to realize real-time and intelligent response to energy supply and demand, improve the overall operating efficiency of the energy system, and promote the derivation of more energy consumption modes.

Perfecting the market mechanism is the pathway. Market-oriented reforms in the energy sector have been comprehensively deepened. While oil and gas companies are gradually improving their prices, they will increase internal resource integration and reorganization. The upstream sector of oil and gas will be opened to private companies. The electricity market reform focuses on electricity price, and innovate a variety of incremental power distribution and electricity sales business patterns. By improving the market investment and financing environment, private investment will be further activated, market diversified competition will be promoted. This provides space for consumption mode innovation. China is gradually establishing a market trading system covering coal, oil, natural gas, electricity, various ancillary services, green certificates, carbon emission rights and so on, which provides a platform for a new mode of energy consumption.

Policy and strategic guidance are boosts. As the changes of the principal contradiction of energy development, it is necessary to improve the quality of supply and meet effective demand for energy industry development. The optimization of energy supply structure will directly affect the change of energy consumption pattern. The new urbanization centered on the urbanization of people will make people’s lives more comfortable, form a greener way of development and life, it also brings about changes in energy consumption patterns. In recent years, the government has established a policy support mechanism for new modes in the energy sector, which has promoted the development of the entire industry chain of wind and solar, and enabled China to lead the world in the scale of installed clean energy power generation.

2.3. Endogenous Driving Factors for Energy Consumption New Modes
The transformation of energy structure is accelerated. The world energy is developing in the direction of high efficiency, cleaning and low carbon. It is estimated that the global energy intensity will drop from 2.8 tons of standard coal per 10,000 $ in 2015 to 2.0 tons of standard coal per 10,000 $ in 2030 (2010 price). From 2015 to 2035, the proportion of non-fossil energy in the global primary energy consumption will rise from 22.8% to one-third. Two-thirds of the world's new energy will be used for power generation by 2035, and the proportion of power generation energy will rise from 42% in 2015
to 47% in 2035 according to the BP data. It is necessary to complete the transition from coal-led to clean energy-led for China which follows the overall development trend of world energy. The growth rate of energy demand in China will slow down, and primary energy demand will reach its peak around 2035. In 2030, electric power will replace coal’s dominant position in the final energy, and the proportion of electricity in the terminal energy structure will increase to about 30%.

Energy interconnection is an inevitable trend. With the progress of science and technology and industry barriers are broken, the energy system has shown a significant improvement in the informatization level, centralized and distributed coordination of clean energy development, interconnection and complementary coordination of different energy varieties, and coordination of vertical ‘source-network-load-storage’. The network form of energy system is becoming increasingly obvious. Interconnection will become the basis of the new energy consumption mode in the future, and the energy consumption mode will change from a passive acceptance type to an active selection type. The energy internet has promoted the transformation of the energy system from producer-led to consumer-led, and energy consumers will become the core of the future energy consumption system.

2.4. The Change of Energy Consumption Subject, Object and Relationship between Them

Energy consumers have the characteristic of diversification. Consumers can be divided into residential users, industrial and commercial users, agricultural users, government users and other public institutions according to the departments of energy consumption.

Energy products and services are diversified and personalized. First, there are more types of products and services, such as power supply services, heating supply services, combined heat and power (CHP) generation services, etc. Second, products and services have cross-border integration characteristics, such as ‘energy + e-business’, ‘energy + big data’, ‘energy + finance’ and others.

Energy consumption channel is more flexible. One is a combination of online and offline consumption methods, such as platform-based consumption mode. The other is a combination of virtual and real consumption methods, such as carbon emissions trading and so on.

Energy consumption prices are characterized by marketization. Restore the attributes of energy commodities, play the leading role of the market, and form a pricing mechanism that reflects factors such as market supply and demand, resource scarcity, and environmental governance costs. On the other hand, the natural monopoly should be more regulated and form the pricing system of ‘permitted cost + reasonable income’.

2.5. The Formation of Energy Consumption New Modes

In the previous the transformation theory of energy consumption mode, we studied the external environmental and endogenous driving factors of energy consumption. Based on the changes of energy consumers, energy consumption products and services, consumption channels and prices, this

![Figure 2. The corresponding relationship of new modes and new characteristics.](image)
section derives four energy consumption modes, which are integrated mode, sharing mode, intelligent mode and green mode. As shown in Fig.2, the four modes combine with each other, and the energy consumption new mode in the future has the characteristics of digitalization, high efficiency, cleanliness, marketization, and electrification.

Integrated mode. This mode integrates different types of energy consumers or energy consumption products and services by market-oriented ways, which produces scale effect integration. Consumers can be prosumers, such as the comprehensive utilization of waste heat, pressure and gas. Consumers consume energy and generate waste heat, pressure and gas. In addition, consumers can use these waste heat, pressure and residual gas to achieve cascade utilization and efficient utilization of energy.

Sharing mode. It refers to real-time response or interaction between energy consumers and energy products and services, which improves and enhances the quality of existing energy products and services. Energy big data has become a new kind of energy products and services. The operation and service data information generated by consumers will become new products. The existing service experience can be greatly improved based on these new data products.

Intelligent mode. This mode connects energy consumers and various energy products and services based on a virtual platform with advanced internet technology. It is able to meet the needs of all kinds of consumers and achieve profitability through the digital management and analysis. The energy supplier and demanders can trade on the energy trading service platform, which breaks the information barrier and realizes the free choice and flexible combination of energy products and services.

Green mode. It refers to the energy consumption mode with clean and low-carbon, and meeting the requirements of large-scale renewable energy access. This mode includes green power trading, distributed wind power, photovoltaic, and other renewable energy products and services.

3. Empirical Analysis on the Transformation of Energy Consumption Mode

3.1. Energy Consumption Mode Transformation Index System

The analysis and evaluation of the transformation of energy consumption modes is a systematic project involving a large scope and many influencing factors. It is necessary to comprehensively consider factor such as energy, technologies, market, policies from different angles and levels. In order to better describe the transformation and development of the new energy consumption mode, this paper analyzes the digitization, efficiency, cleaning, marketization, and electrification characteristics based on the four elements of energy consumption. Then by analyzing the affect factors, we construct an indicator system for the transformation of energy consumption modes, which includes 5 primary indicators and 17 secondary indicators.

Digitization. Energy digitization can help realize the two-way interaction between energy producers and consumers, energy flow and information flow. The level of smart energy consumption will be greatly improved. The energy storage technology indicator is mainly characterized by the installed capacity of electrochemical energy storage.

Efficiency. Based on the innovation and development of energy technology and the improvement of energy service levels, the energy utilization efficiency will be improved, and energy consumption will be more reasonable. Among subindicators, comprehensive energy efficiency refers to the ratio of total terminal energy consumption to total primary energy consumption.
Table 1. Energy consumption mode transformation analysis index system.

| Analysis of energy consumption mode transformation index | Indicators | Subindicators |
|---------------------------------------------------------|------------|---------------|
| digitization                                            | smart electric meter coverage (%) | information fusion technology (score) |
|                                                         |            | multi-energy conversion technology (score) |
|                                                         |            | energy storage technology (ten thousand kilowatts) |
| efficiency                                              | energy intensity per unit of GDP (tce/10000yuan) | integrated energy efficiency (%) |
|                                                         | demand response resource scale (100 million kilowatts) | integrated energy service level (score) |
| cleaning                                                | electric vehicle (million) | proportion of final renewable energy consumption (%) |
|                                                         | distributed energy installed capacity (100 gw) | carbon emissions per unit of GDP (ton/10000yuan) |
| marketization                                           | proportion of electricity market transaction volume (%) | integrated electricity cost |
|                                                         | energy and power policy impact level (score) | proportion of non-state-owned economy (%) |
| electrification                                         | electricity proportion of final energy consumption (%) |

Cleaning. The renewable energy is popularized and a circular energy system is built, which can effectively reduce carbon emissions and achieve green and sustainable development of energy consumption. This indicator mainly includes the number of electric vehicles, the proportion of renewable energy in final energy consumption, carbon emissions per unit of GDP and so on.

Marketization. The energy products and services are traded by energy producers and consumers according to market-oriented prices, guided by market demand, trade energy products and services at market prices, this will promote economic and social development and realize the rational allocation of resources. Energy-electricity policy subindicator is mainly assigned by expert scoring method.

Electrification. Energy security can be ensured through the electrification of end-use energy. Electrification is also able to promote low-carbon energy consumption, and improve energy efficiency. The proportion of electrical energy in final energy consumption refers to the percentage of electric energy in the final consumption of various energy sources.

3.2. Transformation Analysis

3.2.1. Computation.

- Indicators normalization. Based on the common min-max standardized normalization method, the interval length of the denominator is reasonably enlarged to avoid extreme results that are difficult to explain in the later weighting calculation. This is able to ensure the rationality and validity of the evaluation results.

- Subjective weighting and objective weighting. This paper builds an optimal combination weighting model based on the generalized consistency criterion and TOPSIS method. In the process of calculating the combination coefficient, the objective weighting-entropy method is determined with the highest degree of generalized consistency, the subjective weighting-analytic hierarchy process is determined with the lowest degree of generalized consistency. The weight coefficient is obtained according to distance between two weights.

$$\kappa = \frac{L^-_j}{L^-_j + L^+_j}$$  \hspace{1cm} (1)
Grey relational evaluation calculation. Grey relational analysis is an application of grey system theory. As a method, it is able to use the potential information of existing data to process and make predictions or decision-making in the case of few and unclear data. The correlation coefficient between the comparison series and the reference series on the mode transformation index is computed as:

$$\rho_j = \frac{\min_j \min_i |x_0(j) - x_j(i)| + \rho \max_i \max_j |x_0(j) - x_j(i)|}{\max_i \max_j |x_0(j) - x_j(i)|}$$

(2)

where $\rho = [0, 1]$ is the solution coefficient, and it is used to improve the significance of the difference between the correlation coefficients. Then the gray correlation is calculated as:

$$\gamma_j = \frac{1}{n} \sum_{j=1}^{n} \rho_j(i)$$

(3)

3.2.2. Result analysis. Energy consumption mode transformation index system provides quantitative analysis of key transformation conditions from political, economic, social, and technological, which can better characterize the development and evolution of new energy consumption patterns. The data in this section are mainly derived from related reports from the International Energy Agency\(^7\), Bloomberg New Energy Finance\(^8\), and State Grid Energy Institute\(^9\).

Figure 3. 2020-2050 energy consumption new modes.

(1) High-efficiency and digitalization of energy consumption (2020-2035)

The total final energy demand of China is expected to peak at 4.1 billion tons of standard coal in 2035. The proportion of coal in primary energy demand will drop to 35% in 2035. The proportion of non-fossil energy in primary energy demand will increase to 32%-37% in 2035. The demand for natural gas will increase to 14%-15% in primary energy demand by 2035.

From 2020 to 2035, with the development of artificial intelligence and the Internet, the digital transformation of energy enterprises will be accelerated. Energy digitization will improve industrial energy efficiency, enhance users’ energy experience, and greatly promote the optimization of energy consumption. The features of the energy consumption new mode are high efficiency and digitalization during the time. As shown in Fig.3, in 2035, the digital level of the energy consumption new mode will be 0.74, which is about 10% higher than that in 2025. Driven by digital technology and policies, the energy consumption efficiency level in 2035 will be 80%, increasing 23% from 2025.

(2) Marketization, cleaning and electrification of energy consumption (2035-2050)

The economic growth rate of China will further slow down after 2035. In 2050, the total population will be about 1.4 billion, and the driving effect of population on terminal energy demand will be weakened. With the advancement of energy technology and the improvement of energy structure, the
efficiency of transforming terminal energy into effective energy services continues to increase, and the total terminal energy demand will decline. It is estimated that the total final energy demand will be reduced to about 3.6 billion standard coal by 2050.

From 2035 to 2050, the development of digital technology and energy technology is relatively mature and stable, and a unified energy and power market will be established. Energy producers and consumers interact with each other in a market-based manner to form a clean, safe and sustainable energy utilization method. The characteristics of the energy consumption new mode are cleaning and marketization and electrification. As shown in Fig.3, it is estimated that in 2045, the cleaning level of the energy consumption new mode will be 0.95, which is about 12% higher than that in 2035. The market-oriented pricing mechanism of energy will be formed, and the energy marketization level is about 0.89. The electrification level is about 0.92, up 23% from 2035.

4. Conclusion
This paper constructs a theoretical system framework for the transformation of energy consumption modes. Based on the analysis of the constituent elements of energy consumption pattern, internal and external influence factors, we derive four energy consumption new modes which are green, intelligent, sharing, and integrated modes. These new modes of energy consumption present the characteristics of digitalization, marketization, high efficiency, electrification and cleanliness. Finally, the future energy consumption modes are evaluated and prospected through the transformation analysis index system. The new energy consumption modes in the future are steadily developed and mature, showing the features of ‘technology before the market’. The main features of energy consumption are digital and efficient in the early stage. The energy consumption new mode in the later period presents the characteristics of cleanliness, marketization and electrification.

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