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Decomposition and forecasting analysis of China's household electricity consumption using three-dimensional decomposition and hybrid trend extrapolation models

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ABSTRACT

In the present "new normal" economic mode, the household is a major driver of China's electricity consumption growth. To guide the development of the electric power industry in adapting to this situation, this study used the household electricity consumption and population data of 30 provinces during 2001–2014, a three-dimensional decomposition model, and a hybrid trend extrapolation model to explore the driving factors of China's household electricity consumption growth and forecast its future development trend before 2030. Empirical analysis drew the following conclusions: (1) China's household electricity consumption growth is mainly attributed to the improvement of its living standards and still has great potential. (2) Population increase and provincial population structure adjustment have little impact on household electricity consumption growth. (3) In 2030, China's household electricity consumption per capita will increase to 1.06 thousand kWh per capita. (4) China's household electricity consumption will increase to 1.57 trillion kWh in 2030, which is twice that in 2015. The implementation of the universal two-child population policy will have no significant impact on these forecasting results. (5) Raising household electric price level, setting cool and heat storage price, and developing the microgrid are the suggested policy directions.

1. Introduction

China is presently transforming to a "new normal" economic mode [1]. In this development pattern, China's electricity consumption growth comes primarily from households [2]. The purpose of this study is to decompose and forecast China's household electricity consumption growth to guide the development of its electric power industry in adapting to this new situation.

China's electricity consumption has grown rapidly in recent years, from 1.46 trillion kWh in 2001 to 6.12 trillion kWh in 2016, with an average annual growth rate of 10.03%. Since 2011, China has surpassed the USA to become the world's largest electricity consumer [3]. Given the abundance of coal resource and historical overdevelopment of coal-fired power plants, electricity generated by fossil energies accounted for the single largest part of the country's total; this share has never been less than 75% since the founding of the People's Republic in 1949 [2]. China's large-scale thermal power has been exerting a significant impact on the global climate and China's local environment. Energy-related CO_2 emissions are identified as the main driver of the global greenhouse effect aggravation, which is one of the most important issues in scientific and political agenda [4,5]. In 2015, the CO_2 emissions generated by China's thermal power plants were approximately 4212.68 million tons (45.95% of China's total) [3,6], which equaled to 80.79% of the country emissions of the USA, and far exceeded these of India (2218.43), Russian Federation (1483.18), Japan (1207.79), Germany (753.64), Canada (532.5), and many other major emitters [3]. China made a commitment in its Intended Nationally Determined Contributions (INDC) to the Paris Agreement that its CO_2 emissions will reach its peak before 2030 [7]. China's electric power industry will obviously take major responsibility for the realization of this goal. Furthermore, extremely severe and persistent haze has been occurring frequently in China in recent years. More than 99% of the 500 largest cities affected by the haze in

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China do not meet the air quality standards recommended by the World Health Organization, and seven of these cities are ranked among the 10 most polluted cities in the world [8]. Researches have proved that NO_X, SO_2, and particulate matter emitted from coal-fired power plants are some of the major causes of China's air pollution [9,10].

China has maintained fast expanding economic development for a long period of time. Vast natural resources were consumed to support the economic growth. To realize the sustainable development, China's economy is presently transforming to a "new normal," characterized by lowering economic growth, upgrading its industrial structures, and converting the motivating force of economic growth from key elements and investment to innovation [1]. This transformation of the development pattern made the household become the most potential electricity consumer in China. In 2016, households contributed to 27.85% of China's total electricity consumption growth, although its consumption share was only 13.61%. The heavy industry, as a major electricity consumer, consumed 58.05% of China's total electricity supply, but only contributed 30.89% for the consumption growth [11]. Predictably, with the promotion of this transformation, households will play a more important role in China's electricity consumption structure. Furthermore, compared with other electricity consumers, household electricity supply needs longer transmission line and lower voltage, and presents larger peak-valley difference [12]. The share increase of household electricity consumption will inevitably decrease the operation efficiency of the whole power system. As the goals of this research, exploring the driving factors of household electricity consumption growth and forecasting its future development trend are important for the Chinese government to adjust its development policy and plan for the electric power industry, mitigate its fossil energy consumption, fulfill the INDC promises, and improve the local environment.

Given that China's past electricity consumption share of households is not prominent, there are not many related researches available, and most of these studies focus on two issues. The first issue is the impacts of different price strategies. Du et al. [13], He and Reiner [14], Khanna et al. [15], and Zhang et al. [16] investigated the responses of household electricity consumption to tiered price. Their researches proved that the impacts of tiered price to the household electricity consumption are very limited, although basic electricity needs differ between the rural and urban areas. Sun [17] and Wang and Zhang [18] evaluated the effects of household electric price subsidies. They found that subsidy policies can improve the electricity consumption efficiency and prompt the development of green electricity to some extent. However, to maintain the living level of the people, China has set low household electric prices for a long time. Thus, household electricity consumption is insensitive to the price, as discussed in Refs. [13–16]. Moreover, the household electric prices of China are set by the government [19] and seldom adjusted. As a result, prices are not a major driver of household electricity consumption and do not contribute enormously to the consumption growth. The second issue is the saving potential of household electricity consumption. Grottera et al. [20], Tao and Yu [21], Broadstock et al. [22], and Yu and Guo [23] evaluated the electricity-saving potentials of household behavior, major household appliances, wealthy households, and rural households, respectively. These studies failed to describe the general status of household electricity consumption in terms of scale, growth rate, and key policy directions. As a result, the existing literature cannot be used to guide the overall development of China's electric power industry.

To realize the goals of the current research, a decomposition algorithm and a trend extrapolation method were employed. Given its unique "family planning" policies, China's population has kept a slow and steady growth since the beginning of the 1980s [24]. From 2001 to 2016, China's population increased only from 1.28 billion to 1.38 billion, with an annual growth rate of 0.50%. During the same period, the household electricity consumption of China increased from 160.92 billion kWh to 842.06 billion kWh. The annual growth rate was as high as11.66% [2]. That is, the rapid growth of China's household electricity consumption mainly came from the increase of household electricity consumption per capita, not population (also verified by the empirical results of this research). The household electricity consumption per capita was hence selected as the decomposition target of this research. Data envelopment analysis and Malmquist productivity index (DEA-MPI) [25,26], structural decomposition [27], and logarithmic mean Divisia index (LMDI) decomposition [28] are widely used decomposition algorithms. DEA-MPI is usually used to decompose the changes of relative efficiency of the same objects (e.g., companies in the same industry [25] or states in a country [26]). It is hence not suitable for this research. Structural decomposition and LMDI decomposition methods have similar functions in most cases, but the latter is usually recommended to be the first choice in decomposition analysis because of its superiority in theoretical foundation, adaptability, ease of use and result interpretation, and some other desirable properties in the context [29]. Considering that the macroeconomic policies of China are commonly formulated by the central government but implemented mainly by the provincial governments [30], this research adopted an LMDI-based three-dimensional decomposition model [31], which has the ability to decompose the changes of household electricity consumption per capita into the quantitative impacts of three dimensions: time, factor, and province. As to the trend extrapolation method, because the annual data used in this research were very limited, time series algorithms [32], artificial neural network [33], and other large sample methods [34] were not used. Given that linear and exponential trends commonly appear for annual social economic indicators, this research adopted a hybrid trend extrapolation model. This model has the ability to use small samples to fit and forecast the above two trends at the same time [35]. Compared with the single-trend extrapolation methods [36,37], it has better adaptability and forecasting results.

The rest of the paper is structured as follows. Section 2 introduces the models and data used in this research. Section 3 describes the modeling results, which are discussed in Section 4. Section 5 concludes the study with some policy recommendations.

2. Methods and data

2.1. Three-dimensional decomposition model

The household electricity consumption per capita (H) is defined as follows:

$$H = \frac{E}{P} = \sum_{j=1}^{n} \frac{E_j}{P_j} \cdot \frac{P_j}{P} \quad (1)$$

where E is the household electricity consumption, P is population, j refers to the jth province, and n is the number of considered provinces.

Given H changes with time (t), the H derivative of time (t) is as follows: