Quantitative Study of Post-Pandemic Electricity Productivity Fluctuations Based on LMDI

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Abstract. This study focuses on China’s electricity productivity post-pandemic, employing the Logarithmic Mean Divisia Index (LMDI) method and the Kaya identity. Despite the clarity of the electricity productivity indicator, factors like industrial structure, energy efficiency, and electrification rates contribute to fluctuations. Quantitative analysis reveals a decisive role of the terminal electrification rate in declining electricity productivity. The proposed analytical method provides a more accurate assessment of electricity’s contribution to economic growth, aiding informed policy decisions for sustainable energy development in China.

1. Introduction

China’s economic development efficiency is a crucial issue of widespread concern in various sectors of society. Due to the advantages of timeliness and authenticity, electricity data is often utilized to calculate electricity productivity, which involves directly dividing the GDP of a particular region by its electricity consumption. Electricity, as a clean, efficient, and convenient secondary energy source, is increasingly prevalent in economic production. Many studies focus on the relationship between electricity consumption and economic growth in China[1]. China’s proportion of electricity in final energy consumption and the share of electricity in primary energy consumption both exceed the levels seen in developed countries at similar stages of development. Furthermore, there is considerable room for increased electrification, indicating a growing role for electricity in the economy in the future[2]. In recent years, the global outbreak of the COVID-19 pandemic has significantly impacted China’s electricity usage and economic situation, attracting widespread attention in society. Studying the post-pandemic trends in China’s electricity productivity and conducting a thorough analysis of the reasons for fluctuations is essential for objectively understanding the relationship between the economy and electricity and guiding societal expectations appropriately.

The advantage of the electricity productivity indicator lies in its clear logic, ease of understanding, and simple calculation. It enables a quick assessment of the impact of electricity factors on economic growth and allows for comparative analysis between regions and over time. However, ongoing adjustments in industrial structure, energy transition, and the rapid promotion of green and low-carbon initiatives will influence the trajectory of electricity productivity from various perspectives. In terms of energy transition, there is a relationship of mutual substitution between electricity and other energy types, and changes in the electrification rate are a crucial factor affecting electricity productivity. Regarding economic structural adjustments, China continues to advance industrial restructuring, and the core content and direct results of initiatives such as “three reductions, one compensation,” “supply-side structural reform,” and “high-quality development” lead to changes in economic structure[3], resulting in objective differences in electricity consumption density among industries. In terms of new technologies and energy strategies, digitization and intelligence will significantly increase the dependence of various industries on electricity. Simultaneously, China has proposed an energy strategy prioritizing conservation, which will to some extent reduce the electricity demand. These changes ultimately manifest in industry energy utilization efficiency.

In summary, changes in electricity productivity do not directly reflect the efficiency of economic and social development. This paper will establish a quantitative decomposition model for the factors influencing electricity productivity, conducting an in-depth quantitative analysis of the post-pandemic trends in China’s electricity productivity. This approach aims to clarify the reasons for the indicator’s fluctuations, providing a more comprehensive and objective understanding of electricity productivity.

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2. Analysis of Changes in Electricity Productivity Post-Pandemic

The productivity of electricity in China exhibits an "M"-shaped trend within the year, influenced significantly by heating and cooling electricity demand during the winter and summer seasons. The first and third quarters show relatively smaller values of electricity productivity. It is noteworthy that China's electricity productivity has shown a continuous decline over the past five years (shown as Figure 1), dropping from 12.3 yuan/kilowatt-hour in 2019 to 11.0 yuan/kilowatt-hour in 2023. This decline may be attributed to various factors, including but not limited to technological advancements, energy structure adjustments, and improvements in energy utilization efficiency. This not only reflects the transformation and development of China's power system but may also be correlated with the national policy orientation towards clean energy and efforts to promote the sustainable development of the power industry.

To delve into the reasons behind the trend in electricity productivity, the next section of this paper establishes a decomposition model for electricity productivity. This model aims to comprehensively and systematically analyze the various factors influencing the changes in electricity productivity. The model will assist in gaining a profound understanding of the composition structure of electricity productivity and reveal the driving mechanisms behind it.

![Electricity productivity](image)

Figure 1. Quarterly trends in electricity productivity since 2019.

3. Establishment of the Decomposition Model for Electricity Productivity

The Logarithmic Mean Divisia Index (LMDI) decomposition method is a technique based on decomposing the target variable. Its advantage lies in the absence of unexplained residuals after the decomposition, and it allows for relatively straightforward expressions using both additive and multiplicative decomposition. This method is widely applied in analyzing trends in factors affecting energy or environmental impacts to gain in-depth insights into the contributions of individual factors to overall changes[4]. In the field of electricity, the LMDI method is employed to decompose electricity flows data or electricity consumption for conducting analyses of the development of the electric power sector[5], [6]. Therefore, in this paper, to analyze the reasons for changes in electricity productivity, the LMDI method is employed to decompose the electricity productivity. The foundation of the LMDI model is the Kaya Identity, a commonly used international method for examining the sources of carbon dioxide emissions, breaking down the target function of carbon dioxide emissions into factors such as energy use, economic output, and population[7]. Drawing inspiration from the Kaya Identity, this paper extends the concept to decompose the factors influencing electricity productivity into four elements: industry structure, industry energy utilization efficiency, energy structure, and end-use electrification rate. Logarithmic averaging is then utilized to analyze these influencing factors. While the decomposition model delves into the trends of electricity productivity, it comprehensively enhances the understanding of the main factors affecting electricity productivity and reveals their interrelationships.

Firstly, industry structure, as a crucial factor in electricity productivity, reflects the demand characteristics for electricity across different industries. Through decomposing industry structure, we can understand the extent of electricity consumption in different sectors, thereby clarifying the contributions of different industries to electricity productivity. Secondly, the role of industry energy utilization efficiency in electricity productivity is paramount. This factor considers the efficiency of energy use in different industries, subsequently influencing the fluctuations in electricity productivity. By decomposing industry energy utilization efficiency, a deeper understanding of the energy utilization status in different sectors can be
obtained, providing targeted recommendations for improving electricity production efficiency. Energy structure is another indispensable factor directly related to the types of energy used in electricity production. Decomposing energy structure enables the assessment of the contributions of different energy sources to electricity productivity, thereby revealing the proportion of clean and traditional energy in power output. Lastly, the end-use electrification rate considers the proportion of electricity traditional energy in power output. Lastly, the end-use electrification rate considers the proportion of electricity production efficiency. Decomposing the end-use electrification rate reflects the losses and benefits in the conversion process from electricity generation to end-user terminals, offering crucial information for enhancing power utilization efficiency.

Establish the Kaya Identity, whose expression is given by Equation (1).

\[
\frac{\Delta GDP}{GDP_{EC}} = \frac{\Delta GDP}{GDP_{EC}} \times \frac{\Delta GDP_{industry}}{GDP_{industry}} \times \frac{\Delta GDP_{industry}}{GDP_{industry}} \times \frac{\Delta GDP_{industry}}{GDP_{industry}} = (industry\ structure)^{-1} \times (industry\ energy\ use\ efficiency)^{-1} \times energy\ consumption\ structure^{-1}\times (terminal\ electrification\ rate)^{-1}
\]

(1)

Where EC, EN, denote electricity and energy consumption respectively, and the subscript of industry denotes an industry. The inverse of the industry structure, the inverse of the industry energy use efficiency, the energy consumption structure, and the inverse of the terminal electrification rate are denoted as

\[
Str = \frac{GDP}{GDP_{industry}}, \quad Eff = \frac{GDP_{industry}}{EN_{industry}},
\]

\[
EStr = \frac{EN_{industry}}{EN}, \quad ER = \frac{EN}{EC},
\]

and the expression (2) is obtained:

\[
\frac{GDP}{EC} = Str \times Eff \times EStr \times ER
\]

(2)

The change in value electricity productivity from year t to year t+j can be expressed as follows:

\[
\Delta \frac{GDP}{EC} = \Delta Str + \Delta Eff + \Delta EStr + \Delta ER
\]

(3)

Where, \(\Delta \frac{GDP}{EC}\) denotes the overall change in electricity productivity from year t to t+j degrees, this change can be decomposed into the change in the inverse of the industry structure \(\Delta Str\), the change in the inverse of the industry’s energy use efficiency \(\Delta Eff\), the change in the structure of energy consumption \(\Delta EStr\), and the change in the inverse of the terminal electrification rate \(\Delta ER\). The specific calculations are as follows:

\[
\Delta \frac{GDP}{EC} = \frac{GDP_{industry}}{GDP_{industry}}(t+j) \times \frac{GDP_{industry}}{GDP_{industry}}(t) \times \frac{EN_{industry}}{EN_{industry}}(t+j) \times \frac{EN_{industry}}{EN_{industry}}(t) \times \frac{Str_{industry}}{Str_{industry}}(t+j) \times \frac{Str_{industry}}{Str_{industry}}(t)
\]

(4)

4. Analysis of the Reasons for the Change in the Electricity Productivity

Considering the accessibility of data, the calculation time interval was selected from 2019 to 2021, taking the industrial sector as an example. During this period, the proportion of industrial value added to GDP rose from 30.8% to 31.4%, contributing 51.3% to the decrease in electricity productivity. The energy efficiency of the industrial sector improved, with energy consumption reducing from 0.75 tons of standard coal per 10,000 yuan to 0.71 tons of standard coal per 10,000 yuan, which, paradoxically, contributed negatively at -130.1% to the decrease in electricity productivity. The proportion of industrial energy consumption to total energy consumption increased from 51.0% to 51.3%, contributing -16.2% to the decrease in electricity productivity. Finally, the rate of electrification in end-use increased from 7.8% to 8.5%, with a positive contribution rate of 195% to the decrease in electricity productivity.

In the premise of data accessibility, the temporal scope for the analysis was set from the year 2019 to 2021, focusing on the industrial sector. Throughout this designated interval, the share of industrial value added to the Gross Domestic Product (GDP) exhibited an upward trend from 30.8% to 31.4%. Decomposing the impact of the changes in electricity productivity reveals that the
industrial sector plays a pivotal role, contributing 51.3% to the decline in this metric.

Initially, there was a shift in the energy efficiency utilized by the industry, decreasing from 0.75 tons of standard coal per 10,000 yuan to 0.71 tons of standard coal per 10,000 yuan. The slight decrease in energy efficiency in industrial production reflected a negative contribution rate of -130.1% when calculating the changes in electricity productivity, indicating an adverse effect of declining energy efficiency on the economic productivity of electricity within the industrial processes. Subsequently, the proportion of industrial energy consumption within the total energy consumption rose from 51.0% to 51.3%. This change manifested a contribution rate of -16.2% to the decline in electricity productivity. This might be associated with the higher demand for energy within the industrial sector and a relatively lower energy utilization efficiency, resulting in a reduction in the economic productivity of electricity. Lastly, the electrification rate in end-use applications experienced an increase from 7.8% to 8.5%. This elevation yielded a contribution rate of 195% to the decrease in electricity productivity, signifying that the heightened rate of electrification in the industrial sector has exercised a positive impact on the value productivity of electricity, possibly reflecting the adoption of advanced technologies in the utilization of power.

5. Conclusion

Based on a comprehensive evaluation of multiple influencing factors, this study provides a more practical and comprehensive analysis method for electricity productivity, assisting policymakers in better understanding the relationship between power and the economy. In our research, we decomposed the electricity productivity using the Logarithmic Mean Divisia Index (LMDI) method and established a decomposition model based on the Kaya identity, conducting an in-depth analysis of fluctuations in electricity productivity from aspects such as industrial structure, energy utilization efficiency, energy mix, and the rate of terminal electrification. The enhanced practicality and operability of our electricity productivity analysis method is a significant advancement. The findings indicate that increases in the rate of terminal electrification and changes in industrial structure are causes for the decline in electricity productivity, while improvements in industry-specific energy efficiency and shifts in the energy consumption structure are reasons for an increase in electricity productivity. The rise in terminal electrification played a decisive role, ultimately leading to a decrease in electricity productivity.

Looking ahead, as the rate of terminal electrification continues to climb, electricity productivity may further decline. Thus, it is necessary to have a more comprehensive and objective understanding; changes in electricity productivity do not directly reflect the efficiency of economic and social development, and a comprehensive judgment based on multiple influencing factors is required. Our study enhances the accuracy and scientific rigor of electricity productivity analysis, dissecting the indicator with greater precision through technical means. From an economic impact perspective, our research more accurately assesses the actual contribution of electricity to economic growth, offering robust support for the scientific formulation of economic policies and power planning. The comprehensive analysis of industrial structure and energy utilization efficiency provides targeted energy optimization recommendations for different regions, further promoting the sustainable development of the energy industry.

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