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Overview of China's Electrification Transformation and The Upgrading of the Manufacturing Structure

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Abstract:

With the occurrence of extreme climate events and air quality gradually deteriorating, the negative effect of traditional energy consumption patterns on the ecological environment has become increasingly evident. As an important manufacturing and energy-consuming country, the electrification transformation of China is not only an important means to achieve the "dual-carbon" goals, but also has a profound impact on the upgrading of manufacturing structure. This paper reviews the process, characteristics and economic effects of China's electrification transformation in promoting the upgrading of manufacturing structure in sequence. The results show that electrification not only promotes the upgrading of industrial structure and regional economic spatial pattern, but also promotes the manufacturing industry towards low-carbon and high-efficiency development. However, existing literature still has problems such as insufficient treatment of endogeneity, lack of long-term dynamic data, and lack of cross-region and cross-industry analysis. Therefore, future research should focus on combining micro-enterprise level data and macro-regional differences to further explore the coordination mechanism between electrification and industry, and put forward differentiated policy recommendations. This study provides a theoretical basis for understanding the economic and environmental co-benefits of the process of electrification transformation, and provides theoretical support and practical references for regional collaborative development and industrial policy formulation.

Keywords: Electrification transformation, manufacturing structure upgrading, regional differences, policy-driven, emission reduction effects.

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1. Introduction

As living standards improve and quality requirements increase, human development's impact on the natural environment cannot help but to become increasingly severe. For example, with the increase in greenhouse gas emission, the earth's warming speeded up and polar glacier melt, land desertification, drought and food shortage have followed. At the same time, the consumption of traditional energy sources and the economic benefits of manufacturing development cannot be abandoned. Taking China's steel industry as an example. The steel sector is not only energy-intensive but also a major source of carbon emissions. According to relevant data, carbon emissions from China's steel industry account for around 15% of the national total [11]. This heavy dependence on coal has, on the one hand, supported the industry's enormous output value and contributed significantly to China's economic growth; but on the other hand, it has also resulted in substantial environmental costs. According to the Green and Low-Carbon Transition Report of China's Steel Industry, the high proportion of coal consumption is a key reason for the sector's carbon-intensive nature [12]. In such a situation, scholars from different schools reached a wide consensus that further promotion of the transition from traditional energy sources to electrification is an inevitable new path. As electrification is an inevitable trend, it is particularly important to conduct in-depth research on the process of China's electrification development. China's development of electrification is rapidly advancing in an irreversible way. Its development is characterized by focusing on both leading total volume and structural optimization, and combining green and low carbon with innovation-driven development. This paper studies these issues and explains the practical significance and strategic value of this theme.

To solve these problems, scholars from different schools found that further promotion of the transition from traditional energy sources to electrification is an inevitable new path.

In view of the fact that China is the largest consumer of energy and the world's largest manufacturing power, the process of China's transition to electrification not only relates to China's energy security and realization of its "Dual Carbon" targets, but also plays a vital role in global climate governance.

Based on the above background, this paper first reviews the process, characteristics and research progress of China's process of transition to electrification. Second, it explains the economic effects of electrification on manufacturing structural upgrading. Third, it identifies the deficiencies and criticisms in the research, and finally puts forward suggestions and possible development directions for the impact of electrification on manufacturing structure. Therefore, this paper has theoretical and practical significance − it explains how electrification affects the economic benefits and optimizes the production methods of manufacturing through electrification.

2. The Process, Characteristics, and Research Progress of China's Electrification Transformation

2.1 The Connotation and Measurement of Electrification

Electrification is not only the replacement of energy types, but also a comprehensive process of transformation of energy system, industrial structure and consumption pattern. According to the *Annual Report on China's Electrification Development (2022)*, electrification plays a crucial role in China's low-carbon transition process [1]. People can calculate electrification by converting standard coal and calculating the ratio of electricity consumption to total end-use energy.

2.2 Overall Progress and Phase Characteristics of Electrification in Chinese Cities

China's electrification journey can be divided into four stages. The initial stage dominated by fuel-powered vehicles, roughly from 2000 to 2010, was characterized by a market in which traditional fuel cars prevailed, with electrification policies still in early pilot exploration, such as the 2009 "Ten Cities, Thousands of Vehicles" program. The start-up stage, from 2011 to 2015, marked the gradual entry of electric vehicles into the market as supportive national policies were introduced. The promotion and deepening stage, from 2016 to 2020, saw a rapid rise in the market share of electric vehicles driven by strengthened subsidies and industrial regulations. Since 2021, China has entered the maturity stage, in which low-carbon development and widespread electrification have continued to advance across the transportation sector [13].

2.3 Regional Differences in China's Electrification

China's level of electrification shows significant regional imbalances, mainly reflected in geographical and climatic conditions, stages of economic development, energy structure characteristics, and demographic and social structures. A deep analysis of these regional differences is essential for formulating differentiated transition policies and promoting coordinated electrification development nationwide.

Zhenhua Sun, Lingjun Du and Houxin Long partitioned China into 285 research units using significant geographic demarcation lines such as the Qinling–Huaihe Line, the Hu Line and the Shanhai Pass Line and presented a comprehensive picture of spatial variation in China's electrification level [2]. In areas north of Shanhai Pass and east of the Hu Line, which are cold in winter and therefore heavily dependent on coal for heating, low electrification levels and slow economic development, together with an aging population, keep per capita electricity use in these regions relatively low. However, more hot days is still associated with an increase in electricity demand.

Furthermore, in the area south of Shanhai Pass, east of the Hu Line, and north of the Qinling–Huaihe Line, the electrification situation is similar to that in the north. Based on the 2019 data, the per capita electricity consumption in this region was the lowest in the whole country, which shows that the process of adjustment in energy structure and the level of electricity consumption capacity are relatively weak.

By contrast, regions south of the Qinling–Huaihe Line and east of the Hu Line are economically developed and have hot climates, leading to strong demand for cooling and significantly higher electrification levels. Per capita electricity consumption is positively correlated with the number of hot days. However, increasing household size exerts a negative moderating effect on per capita electricity use, suggesting that smaller household sizes may further increase electricity intensity.

But what is worth noting is that, although the overall electricity base is low in areas to the west of the Hu Line, the speed of growth of per capita electricity consumption is the fastest in the country. This shows that, with economic development and people's growing demands, the process of electrification is accelerating and the region has strong transformation potential and growth space.

2.4 Policy Drivers and Institutional Environment

Electrification transformation is crucial for promoting global sustainable development in both economic development and environmental protection aspects. Therefore, China issued the Guiding Opinions on Vigorously Implementing Renewable Energy Substitution Transformation, Guiding Opinions on Promoting Transportation and Energy Integration Development, and Guiding Opinions on Promoting Electric Energy Substitution Transformation based on this. These opinions focus on strengthening infrastructure construction and renovation, promoting the integration of market and policy, and prioritizing high-electricity-consumption industries like transportation, industry, and construction.

In terms of the institutional environment, Liang Jing and Liu Peizhong emphasized that China must strengthen technological R&D, accelerate infrastructure construction, and promote the joint participation of multiple stakeholders to guarantee the application and implementation of electrification technologies and policies [3].

3. Economic Effects of Electrification Transformation on Manufacturing Structure Upgrading

3.1 Effect on Industrial Structure Advancement

Li Suxiu, Liu Lin, Zhang Ning, Dai Hongcai, and Lu Jing pointed out that electrification promotes industrial structure upgrading in several ways [4]. First, it improves energy-saving capacity across industries and eliminates outdated production capacity, thereby driving the entire industrial system toward higher efficiency and lower carbon emissions. Taking China's steel industry as an example, the electrification transition has achieved significant energy savings through the promotion of electric furnace short-process steelmaking. According to the "Research Report on the Development of Electric Furnace Short-Process Steelmaking in China (Part II)," the average energy consumption per unit of electric furnace short-process steelmaking is approximately 54.1 kilograms of standard coal equivalent per ton of steel, far lower than that of the traditional blast furnace converter process. This energy-saving advantage reduces energy consumption and carbon emissions in steel production, driving capacity optimization and industrial structure upgrading within the steel sector [14].

Second, electrification gives rise to collaborative low-carbon development among industries. For instance, electrification of vehicles generates synergy effects among related industries such as metal mining and non-metallic materials, battery and motor cores, power generation, and even insurance, forming a network of collaborative development that drives the industrial structure toward low energy consumption, low pollution and high added value.

3.2 Regional Economic and Spatial Effects

Gong Jia and Wu Zhenlei highlighted that ultra-high-voltage (UHV) transmission projects facilitate pollution reduction, substitute coal and thermal power generation, and improve the spatial allocation of energy resources [5]. These projects also have spatial spillover effects that stimulate urban economic growth.

The research reflects significant differences in electrification, particularly between eastern and central-western regions. The eastern region, with a strong economic base and well-developed power infrastructure, is more capable of promoting industrial structure upgrades toward low-carbon and high-efficiency development, forming a positive feedback loop.

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By contrast, the central and western regions are still experiencing electricity shortages and are more concerned about power supply than consumption. The power shortage in the central and western regions is partly due to the single structure of local power supply, and partly due to the lagging construction of ultra-high voltage transmission channels. Industrial upgrading in these regions is relatively weak.

Empirical results based on industrial chain and urban cluster levels demonstrate that developing and optimizing electrification infrastructure can promote industrial upgrading of chains and coordinated development of urban clusters and help achieve a greener development path.

4. Review and Limitations of Current Research

4.1 Consensus and Contributions in Existing Studies

First, electrification exerts a driving effect on the upgrading of industrial structure. Generally, an upgraded industrial structure should be characterized by an increasing proportion of technology-intensive and knowledge-intensive industries. Only energy supplied by electrification can provide strong support for these industrial sectors with high value-added. According to China Electrification Development Report, the proportion of electrification in high-tech and equipment manufacturing achieved is higher than the industrial average, which is above 64.7% and shows a strong positive correlation between electrification and industrial upgrading [6]. Existing research indicates a close interactive relationship between electrification and industrial upgrading. For instance, Song M et al.'s empirical study found that China's economic development and industrial structure upgrading are key drivers of electricity consumption growth. Conversely, the rise in electricity consumption also provides the essential energy foundation for industrial upgrading and urbanization, forming a long-term dynamic interconnection among these factors [7].

Second, variations in electrification results and infrastructure development in different regions exist due to their varying power situations and natural conditions. According to *Observations on Smart Grid Development in China*, smart grid rollout shows a pretty stark regional split: the richer southeast is moving much faster than large parts of central and western China.These gaps mainly come down to differences in economic strength, grid capacity, and how much money goes into infrastructure [15]. In the eastern coastal provinces, high power demand and stronger government and institutional support have helped push forward things like advanced distribution networks and intelligent energy management systems. Many central and western areas, by contrast, still struggle to secure funding and upgrade old power lines. A lot of them are still busy improving basic grid access and keeping the lights on reliably before they can seriously think about "smart" upgrades. It becomes crucial for policymakers to direct investment and design region-specific policies that both expand electrification and help lagging regions catch up in grid modernization.

Electrification in high-value-added industries contributes to emissions reduction. However, economically developing regions will generally focus on energy production because they lack power infrastructure. For example, base on the Chinese electric power industry annual report, economically advanced regions such as the eastern coastal areas have industrial structures with high-value-added technology and service [8]. These areas have initially completed the construction of ultra-high voltage transmission networks and smart distribution grids, and electrification will mainly be driven by the two goals of emission reduction and energy security. As indicated in The Comparative Analysis of Electrification Pathways in Different Regions: "Based on its electric grid and clean power investment, the Guangdong-Hong Kong-Macao Greater Bay Area has achieved an electrification rate of 41.7%. Its electrification pathway is closely aligned with the low-carbon requirements of high-end manufacturing and modern services, forming a virtuous cycle [9].

4.2 Several Issues Remain in Current Research

Causal inferences are biased due to endogeneity problems and reverse causality problems. Forinstance, green development may promote electrification, but it could also be that electrification can enhance green development. Most of the methods are used in static context and cannot reflect dynamic changes in markets and technologies. Long-term data are missing and most of the studies use short-term data or cross-sectional data which makes long-term long-run development path prediction less feasible. There is less research using static comparisons which makes it hard to have long-run long-term development path prediction. Most existing research has focused on the manufacturing sector itself, lacking comparative analysis across industries and regions. This makes it difficult to determine whether the electrification upgrade process in manufacturing is unique or whether the electrification upgrade of the entire industry follows universal patterns [10]. Therefore, the next research must adopt more rigorous causal inference methodologies, use long-term dynamic data and have more systematic cross-region and cross-industry comparison to find out the true drivers and long-term development path of electrification transition.

4.3 Future Research Directions

4.3.1 At the micro level

Future research should focus on electrification differences across enterprises and industry chains, targeting industries with different scales and economic bases, using firm-level data to develop tailored plans.

Research should expand beyond economic and emission-reduction effects to explore impacts on international competitiveness and employment structures, helping firms invest more effectively in electrification and maintain stability in competition.

4.3.2 At the macro level

Systematic analysis of regional energy conditions and industrial demands is needed to distinguish electricity input and output areas and compare their industrial upgrading status to propose suitable cooperative strategies.

More long-term dynamic data should be tracked to generate region-specific, dynamic policy recommendations.

4.4 Literature Summary, Conclusions, and Policy Implications

Its conclusion is that electrification is the driving force behind industrial structure upgrading, though the degree of phase, method and region upgrading differs. The current state of research is hampered by its inability to overcome endogeneity problems and by its reliance on static, short-run data; hence, the true drivers of structural upgrading are yet to be identified in terms of cross-industry and cross-regional studies.

Policy implications include focusing on precise coordination between electrification and industrial chains, establishing interregional collaboration mechanisms, and implementing large-scale west-to-east electricity transmission.

5. Conclusion

This paper reviews the process, characteristics and impact mechanisms of China's electrification transformation in the upgrading of manufacturing structure as follows.

First it was China's electrification transformation has distinct characteristics of phasing, regional differences and policy guidance. The process of electrification can be divided into three stages: Electrification has evolved from the traditional energy-oriented stage, over an initial transformation stage and a deepening stage, to the current large-scale development stage with persistent regional differences.

Electrification drives industrial upgrading and improves the regional energy allocation, and strongly promotes green transformation. The green transformation effect of electrification is more pronounced in industries with strong synergy effects, such as high-end equipment manufacturing and new energy vehicles.

Secondly, current regional electrification gaps stem from regional imbalance, uneven industry coverage, and policy alignment, caused by differences in regional resource endowment, infrastructure, technological standard, and lack of long-term mechanism. Recommendations are made to strengthen cross-region grid planning, power substitution incentive mechanism, differentiated transition path design, central and western region infrastructure development, and high-end manufacturing and energy internet integration in east region. This study presents an integrated analytical framework linking electrification and manufacturing upgrading process and offers empirical evidence to design integrated electrification mechanism under China's "dual-carbon" goal.

This paper mainly uses literature review method, there is no first-hand data, and it is not quantitative verification of models. The analysis of micro-level mechanisms are lacking, and the conclusions are based on short-term observation. In the future, this area of research should base on enterprise-level panel data, establish dynamic evaluation models, analyse its impacts on employment and international competitiveness, and conduct comparative studies with other developing countries following an electrification pathway.

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