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Analysis of the Impact of Data Elements on the Low-Carbon Transformation of Bengbu Glass Industry

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Abstract: With the continuous development of the digital economy, low-carbon transformation has gradually become the inevitable choice for the transformation and upgrading of the glass industry. Based on the glass industry data (2020-2024) released by Bengbu Bureau of industry and information technology, bureau of statistics and national development and Reform Commission, this paper explores the impact of data elements ofthe analysis demonstrates that the low-carbon transformation of the glass industry. By analyzing the case of Bengbu Glass Industry, it is found that data elements have a significant role in promoting the low-carbon transformation of the glass industry, which is mainly reflected in monitoring production data to improve energy efficiency, data-driven clean energy substitution, data collaboration to optimize logistics carbon footprint, and optimizing resource allocation to reduce equipment idling. However, there are still some problems to be solved, such as the lack of data element industry chain coordination, the weak ability of data-driven technological innovation and application, and the lag of data security and standardization construction. In order to further deepen the role of data elements in the low-carbon transformation of the glass industry, this paper proposes actionable recommendations, including constructing an industrial chain data collaboration platform, strengthening the data-driven collaborative innovation mechanism of industry, University and research, and improving the data standards and security system.

Keywords: Data elements; Low carbon transformation; Glass industry.

1. Introduction

Relying on the rapid development of digital technology, digital economy has become the core engine of global economic growth [1]. The digital technology group represented by big data, artificial intelligence and industrial Internet is deeply reconstructing the manufacturing value chain, and its synergy with the green low-carbon goal has become the core proposition of global industrial transformation. As the largest manufacturing country, China urgently needs to build a new industrialization system driven by "digital intelligence + green" to solve the structural contradiction between energy consumption and emissions of traditional industries. Among them, the glass industry, as a typical process type manufacturing industry, ranks in the forefront of the building materials industry in terms of energy consumption intensity. However, unlike high-carbon industries like steel and cement that have a mature research system, existing academic research is evidently inadequate in elucidating the low-carbon transformation mechanism of the glass industry: it lacks systematic deconstruction of the industry specific process chain and carbon emission structure, and pays less attention to the practical constraints such as low technology penetration and transformation cost sensitivity in the industrial ecosystem dominated by small and medium-sized enterprises, which leads to significant limitations in the relevant theoretical models and transformation path design.

In recent years, the international academic community has carried out in-depth research on the interaction mechanism between data elements and low-carbon transformation of industry. Huang Ping's research shows that data element driven industrial change can indirectly improve green total factor productivity through AI algorithm optimization and other channels. When the data element penetration reaches the critical threshold, the industrial carbon emission intensity will show an exponential downward trend [2], which provides an important theoretical support for the digital transformation of the glass industry.

In this context, this study selected Bengbu Glass Industry with typical significance as the analysis sample. Relying on the national scientific and technological innovation platform, the city has taken the lead in building an industrial matrix covering high-end products such as photovoltaic glass and display glass. Its digital transformation practice presents three characteristic dimensions: first, optimizing the synthesis process parameters of silicon-based materials through intelligent algorithms to reduce unit emissions; second, building an industrial chain level carbon data monitoring system to drive clean energy substitution; third, building an industrial Internet platform to realize the full life cycle energy efficiency management of key equipment such as kilns. By deconstructing its technology integration path, this paper focuses on revealing the value release mechanism of data elements in process reengineering, energy system iteration and supply chain collaboration, and then provides a theoretical reference for the construction of "digital intelligence green" symbiotic system in the same type of industry, and provides a basis for local policy design.

2. Overview of Data Elements and Low Carbon Transformation of Glass Industry

Data elements usually refer to new production factors with data resources as the core, which not only promote the optimization and upgrading of economic structure, but also promote the fundamental change of industrial form and economic growth mode. Especially in the process of carbon neutralization, the real-time carbon emission monitoring system driven by data elements can accurately identify

emission reduction nodes, and machine learning algorithms can accelerate the research and development of new energy storage materials, carbon capture technology and other green innovations, forming a closed-loop mechanism of "Monitoring Optimization innovation". As the core engine of the digital economy era, data elements are reshaping the technological path and business model of low-carbon transformation of the industry, injecting sustainable momentum into high-quality development.

The low-carbon transformation of the glass industry is to significantly reduce the carbon emissions of the whole industry chain through technological innovation, energy structure optimization and production process reconstruction. At present, the transformation of this industry is imminent: first, China's total carbon emissions in 2024 will be about 12billion tons, accounting for 32% of the total global carbon emissions, of which the carbon emissions of manufacturing industry will account for about 40% of the total national carbon emissions [3]; Second, China's "double carbon" target requires the building materials industry to reach the peak carbon by 2030, while glass, as a key area, needs to be laid out in advance [4]; Third, the demand for photovoltaic glass, automotive glass and other emerging markets showed explosive growth, forcing enterprises to transform through low-carbon technology. Accelerating transformation is not only an environmental responsibility, but also a strategic choice to break through industrial bottlenecks and seize the green market. The addition of data elements can effectively solve the problems of information asymmetry and high cost in the low-carbon transformation of the traditional glass industry, and further promote the high-quality development of the glass industry.

3. The Role of Data Elements in Promoting the Low-Carbon Transformation of the Glass Industry

3.1. Production Data Detection to Improve Energy Efficiency

The low-carbon transformation of Bengbu's glass industry relies on the application of digital technology, which has significantly promoted the development of green glass industry projects, especially in the field of glass production. Taking CNBM Glass New Materials Research Institute Group Co., Ltd. as an example [5], the company realized the digital control of the whole process of glass production through the "Kaisheng AGM industrial Internet carbon footprint monitoring platform (The Capvision AGM Industrial Internet Carbon Footprint Monitoring Platform, based on a device - edge - cloud - collaborative architecture, performs carbon emission monitoring and supports low - carbon transformation of the glass industry in Bengbu via dynamic carbon modeling and AI - driven optimization)." The platform will deeply integrate digital technology and energy conservation and environmental protection business, and promote the transformation of glass enterprises from "dual control" of energy to "dual control" of total carbon emissions and intensity [6]. Through the real-time collection of key process parameters such as furnace temperature and raw material ratio, a dynamic assessment model of carbon emission intensity is established according to the industry standard of quantitative requirements and guidelines for carbon footprint of greenhouse gas products (Draft for approval), so as to realize the minute level automatic accounting and visual Kanban presentation of carbon emission intensity in the whole production process[7]. The model can automatically identify the influence trend of process fluctuation on carbon efficiency, and provide real-time data support for kiln temperature optimization and batching scheme adjustment. As Daniel pointed out in the life cycle assessment study, the strong nonlinear characteristics of the glass melting process make the traditional empirical model difficult to meet the needs of dynamic optimization. Through the coupling optimization of furnace temperature and raw material ratio, the comprehensive energy consumption per unit product decreased by 12% -15%, which not only confirmed the actual value of digital monitoring system in process optimization, but also highlighted the necessity of data-driven model in the low-carbon transformation of glass industry [8].

In addition, Bengbu is also actively building a "carbon peaking and carbon neutrality goals (‘dual carbon’ goals)" science and technology support system [The "dual carbon" technology support system refers to the systematic measures such as low-carbon technology research and development, industrial carrier construction (such as science and Technology Industrial Park) to promote the realization of carbon peaking and carbon neutralization goals. Typical practices include the cultivation of green industrial clusters such as photovoltaic glass], accelerating the construction of carriers such as China's new glass materials science and Technology Industrial Park, and building a "dual carbon" industrial cluster such as photovoltaic glass. Through these measures, Bengbu not only promoted the low-carbon transformation of the glass industry, but also provided experience for other high energy consuming industries.

3.2. Data Driven Clean Energy Alternatives

Relying on the production data detection technology, the ineffective energy consumption in the production and manufacturing process of Bengbu Glass industry has been significantly reduced, which has become the key factor to promote the green development of the glass industry. By leveraging industrial Internet platforms, Bengbu's glass manufacturers can monitor real-time key parameters—such as furnace temperature, raw material ratios, and energy consumption data—during production. The accurate collection and analysis of these data enable enterprises to identify and optimize high energy consumption links, so as to effectively reduce invalid energy consumption. For example, Bengbu Kaisheng glass has realized the full life cycle management of production equipment by introducing the lean production management system. The system can not only monitor the running status of the equipment in real time, but also automatically generate the maintenance plan through data analysis, reducing the unplanned downtime of the equipment. In addition, the built-in intelligent diagnosis function of the system can alarm in time when the equipment is abnormal, shorten the maintenance response time, and improve the availability of the equipment and the stability of the production line. In terms of energy management and environmental protection, Bengbu Kaisheng's lean production management system identifies high energy consumption links and energy waste in equipment operation through real-time monitoring of energy consumption data in the production process and comparative analysis combined

with historical data.

Cao et al. Further emphasized the complexity of the low-carbon transformation of the glass industry, and pointed out that both production process innovation and spatial design optimization must be considered. The "solar thermal conversion efficiency model of glass curtain wall" proposed in this study provides an interdisciplinary perspective for the "data element driven clean energy substitution" mechanism revealed in this study. The study also warns that relying solely on production side data optimization may lead to "carbon locking effect", that is, the system is difficult to achieve deep emission reduction due to excessive reliance on existing technology paths [9]. Therefore, the real low-carbon transformation must be realized through the collaborative optimization of the construction industry system. This view echoes the practice of Bengbu's glass industry and emphasizes the importance of multi-dimensional coordination in low-carbon transformation.

3.3. Data Collaboration to Optimize Logistics Carbon Footprint

Data collaboration not only plays an important role in reducing energy consumption, but also shortens the carbon footprint of logistics and transportation. By building a data sharing platform, Bengbu Glass production enterprises can realize data integration and Optimization in production, transportation and sales, thus significantly reducing carbon emissions in the process of logistics and transportation [10]. Wang's big data analysis research shows that data sharing in the logistics link can reduce the carbon emission intensity of the supply chain by 8% to 12%, which is mutually supported by the mechanism of "data collaboration to reduce vehicle idling rate" found in this paper. In particular, the study emphasized that among the emission reduction benefits brought by the optimization of transportation routes, the contribution of real-time traffic data reached 63% (IOT equipment data accounted for 27%), which provided a quantitative basis for the construction of the intelligent logistics system of the glass industry [11].

Bengbu CNBM glass new materials research institute optimized the logistics and distribution path of glass products through digital technology [12]. The platform uses big data analysis to monitor the driving status and energy consumption of transport vehicles in real time. Through the intelligent scheduling system, the empty driving rate and waiting time of vehicles are reduced. This data-driven logistics management mode not only improves the transportation efficiency, but also effectively reduces the energy consumption and carbon emissions in the transportation process [13]. At the same time, Bengbu has also achieved dynamic monitoring of energy consumption and carbon emissions of glass industry related buildings through the "photovoltaic building monitoring smart platform" [14]. This platform not only optimizes the energy efficiency of buildings, but also provides more accurate energy management solutions for logistics and transportation through the data sharing mechanism.

3.4. Predictive Maintenance and Resource Allocation

In addition to its significant advantages in improving transportation efficiency, the data elements also performed well in the low-carbon transformation of Bengbu's glass industry, especially in optimizing resource allocation and predictive maintenance. Through the internet of things devices, big data analysis and artificial intelligence technology, glass production enterprises can efficiently track the running state of equipment and predict potential faults, so as to reduce equipment idling and energy waste. Bengbu building materials and glass new materials research institute has realized the real-time monitoring and data analysis of production equipment by introducing the digital production management system. The system can predict the maintenance demand according to the operation data of the equipment, and arrange the maintenance in advance to avoid the production interruption caused by the sudden failure of the equipment [15]. This predictive maintenance strategy not only improves the operation efficiency of the equipment, but also significantly reduces the energy consumption and carbon emissions caused by equipment idling [16].

4. Challenges and Problems of Data Elements in the Low Carbon Transformation of Glass Industry

4.1. "Data Island" Restricts Element Chain Collaboration

Although the data elements have achieved remarkable results in the low-carbon transformation of the city's glass industry, the problem of insufficient industrial chain coordination is still prominent, and there is a "data island" phenomenon [17]. In the context of regional collaborative development, local government led construction of localized data platforms generally has a governance orientation of "focusing on local control and ignoring global collaboration". This administrative boundary oriented platform construction mode has derived three blocking effects: first, the isomerization technology framework leads to the lack of cross platform interface standards, forming "data capillary blockage", which hinders cross domain business collaboration such as supply chain carbon footprint tracking [18]; Second, there are regional differences in territorial data governance rules and division of rights and responsibilities, which aggravates the mutual recognition barriers of key indicators such as carbon emission accounting [19]; Third, the logic of performance competition generated by the administrative evaluation mechanism stimulates investment in the construction of repetitive platforms, resulting in waste of resources and overlapping functions.In the logistics transportation link, the lack of unified data standards and sharing mechanisms makes it impossible to monitor transport vehicles' operation status and energy consumption in real time, and also complicates the optimization of transportation routes and reduction of energy consumption.

4.2. Weak Ability of Data-Driven Technology Innovation and Application

Although the key enterprises in Bengbu have further promoted the digital transformation, the transformation efficiency of data elements to low-carbon technology is still an important bottleneck. The main reason lies in the lack of technology adaptability and the absence of innovation support system. Although the existing detection system is used to collect production data in real time, it lacks the ability of intelligent algorithm modeling, which leads to the energy consumption optimization scheme only staying at the threshold alarm level and fails to form a dynamic control mechanism.

In Bengbu Glass Industry Cluster, the industry university research collaboration platform has not yet established an effective joint research mechanism. Although CNBM glass new materials research institute has massive production data resources, it is difficult to build a dynamic environmental benefit model in the carbon emission monitoring database due to the lack of algorithm development cooperation with local universities. This technology transformation fault is also highlighted in the transformation of Anhui Fangxing technology's photovoltaic glass production line - although the enterprise has collected the energy consumption data of the whole process, it is unable to accurately predict the carbon emission reduction benefits of different process combinations due to the training ability of machine learning model, which directly affects the feasibility of obtaining digital technology support. At present, it is urgent to solve the "last mile" problem in the integration of data elements and low-carbon technologies by building an interdisciplinary innovation consortium.

4.3. Data Security and Standardization Construction Lag

The application of data elements is highly dependent on many data acquisition and sharing, which enables glass production enterprises to conduct glass product production and process management more effectively with the help of data analysis. However, in practice, although local enterprises have generally established energy consumption monitoring systems, there are significant security risks in data acquisition and transmission. For example, if the operation parameters and energy consumption data of kiln are lack of encrypted transmission protocol, the production data leakage event is likely to occur, resulting in the outflow of process optimization scheme.

The lack of standardization exacerbated the dilemma of industrial chain coordination. Bengbu Glass Industry Design and Research Institute and leading enterprises adopt different data interface standards, resulting in insufficient compatibility between the operation data of environmental protection equipment and the production system. The current dilemma stems from the lack of system: Bengbu has not yet established local implementation rules in line with the data security law of the people's Republic of China, especially the lack of data classification and grading standards for the characteristics of the glass industry. This lag in system supply directly causes some small and medium-sized enterprises to fall into a "prisoner's dilemma" between data security investment and standard implementation.

5. Suggestions on Promoting the Low-Carbon Transformation of Glass Industry Enabled by Data Elements

5.1. Build an Industrial Chain Data Collaboration Platform

To achieve a more comprehensive coverage of data elements to support the green development of the glass industry, Bengbu Municipal government should increase investment in digital infrastructure. First, we should rely on digital technology to build a vertical data sharing platform covering energy supply, manufacturing, storage and transportation, and realize real-time collection and dynamic analysis of energy consumption data of the whole industry chain by deploying intelligent sensors and edge computing nodes. Focus on establishing standardized data interfaces in high energy consuming industries such as steel and building materials, open up "information islands" among enterprises, and provide multi-dimensional data support for accurate identification of invalid energy consumption links. Secondly, it is necessary to introduce blockchain technology to build a reliable data traceability mechanism and establish a digital account of carbon emissions and energy consumption indicators. The contribution of upstream and downstream enterprises to emission reduction is automatically calculated through smart contracts to form a verifiable green integral system, which provides a credible basis for financial institutions to evaluate low-carbon projects. At the same time, AI energy efficiency optimization algorithm is developed to generate dynamic energy-saving scheme based on real-time production data, guide enterprises to adjust equipment operation parameters, and reduce idling rate and redundant capacity.

5.2. Strengthen the Data-Driven Mechanism of Industry University Research Collaborative Innovation

To solve the bottleneck problem of data-driven technology innovation in the field of glass production, we need to build a demand-oriented and multi-party collaborative innovation system. Firstly, we should build an industry - university - research joint innovation platform led by the government. This platform should integrate the algorithm research capabilities of colleges and universities, the operational data of glass enterprises, and the financial advantages of financial institutions. At the same time, establish a data sharing incentive mechanism, use federal learning technology to solve the problem of sensitive data circulation of enterprises, and form an industry-level environmental database to provide accurate support for the evaluation of emission reduction efficiency. Secondly, it is necessary to open up the channels of technology transformation and industrial application. Support glass enterprises and technology companies to jointly build a digital joint laboratory, focusing on breakthroughs in key technologies such as multi-source heterogeneous data fusion and intelligent adjustment of process parameters. For example, in the field of photovoltaic glass, a green card trading platform based on blockchain can be developed to dynamically link data such as power generation and carbon emission reduction with the financing quota, so as to achieve quantitative assessment of environmental benefits and accurate capital investment. In addition, we need to improve the training system of compound talents. Promote Bengbu colleges and universities to set up the interdisciplinary of "Materials Science + data science", and cultivate compound talents proficient in glass technology and data analysis. Establish a dual track system of enterprise mentors and academic mentors, and encourage graduate teams to participate in projects such as machine learning anti rolling plate and intelligent cutting system research and development, forming an innovation closed loop of "technology research - production line verification - commercial promotion".

5.3. Improve Data Standards and Security System

Data elements play a vital role in the low-carbon transformation of the glass industry. However, protecting data privacy while promoting data sharing is the key to the

sustainable development of the glass industry. Shenxiaobo et al. (2025) used the empirical analysis of China's urban panel data to point out that data elements can indirectly promote the optimization of energy structure by improving the efficiency of green innovation and promoting the agglomeration of high-tech industries, and the marginal effect of traditional green financial policies is gradually being replaced by new mechanisms driven by data elements [20]. This conclusion not only expands the interpretation boundary of the Resource Curse Theory in the context of digital transformation, but also provides a quantitative basis for policy makers in balancing data openness and energy security. In this context, the government and R&D institutions should jointly establish a sound data security protection system for industrial adaptation, focus on the differential protection of core production data such as furnace parameters and energy consumption curve, ensure the legality and compliance in the process of data circulation, and strictly regulate the scope and purpose of data use.

First of all, Bengbu should speed up the formulation and implementation of data security standards, requiring glass manufacturers to follow technical means such as data encryption and anonymization in the process of processing production data to ensure that sensitive information is not leaked. Secondly, Bengbu should establish a special class for data governance of glass industry led by the Municipal Bureau of industry and information technology, and build a public service platform for data governance covering safety monitoring, standard verification, risk assessment and other functions. We can learn from the "industrial data security laboratory" mode (The "industrial data security laboratory" mode refers to the innovative mechanism by which enterprises (CNBM) and universities (Anhui University of Finance and Economics) through industry university research collaboration, targeted research and development of high-temperature industrial scene data security technology and promote the transformation of achievements). jointly built by Bengbu China building materials Optoelectronic Materials Co., Ltd. and Anhui University of Finance and economics, and develop data encryption transmission technology suitable for high temperature environment of kiln through industry university research cooperation. This can not only form a situation of multi-party collaborative governance, but also solve the pain point of the lack of technical capacity of small and medium-sized enterprises, and finally form a glass industry data governance scheme system with Bengbu characteristics.

6. Conclusion

Data elements enable the low-carbon transformation of glass industry has become an important trend. Data elements have significantly promoted the low-carbon transformation of the glass industry by reducing energy consumption, driving clean energy substitution, shortening the carbon footprint of logistics and transportation, and optimizing resource allocation. However, at present, there are still problems such as insufficient industrial chain collaboration, weak technological innovation and application capabilities, and lagging data security and standardization construction, which restrict the further play of the role of data elements. It still needs to be continuously promoted by improving the efficiency of industrial chain collaboration, strengthening scientific and technological innovation, and improving data standards. By further deepening the combination of data elements and glass production, Bengbu is expected to further deepen the role of data elements in the low-carbon transformation of the glass industry, help the glass industry achieve green, efficient and sustainable development, and contribute to the goal of "carbon peaking and carbon neutralization" in Bengbu and even the country.

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