Data-Driven Approaches to Energy Utilization Efficiency Enhancement in Intelligent Logistics

Xuan Long
School of International Trade Hainan College of Economics and Business, Hai'kou 571127, Haikou, China

***Abstract*—With the rapid development of intelligent logistics, new challenges and opportunities are presented for energy utilization efficiency improvement. This study explores the feasibility and effectiveness of using data-driven methods to improve energy utilization efficiency in an intelligent logistics environment and provides theoretical support and practical guidance for achieving the sustainable development of optimized logistics management procedures. First, a dataset was established by collecting relevant data in the optimized logistics management procedure, including transportation information and energy consumption data. Then, data analysis and mining techniques are used to conduct an in-depth dataset analysis to reveal the influencing factors of energy utilization efficiency and potential optimization directions. Then, strategies and methods for energy utilization efficiency improvement are designed by combining intelligent optimization algorithms. Finally, simulation experiments and case studies are utilized to verify the effectiveness and feasibility of the proposed methods. The results show that using data-driven methods can significantly improve the energy utilization efficiency of optimized logistics management procedures, reduce logistics costs, and enhance the sustainability and competitiveness of the system. Through in-depth analysis and empirical research, a series of actionable optimization strategies are proposed, providing new ideas and methods for optimizing energy and logistics management procedures. These results significantly promote the sustainable development of optimized logistics management procedures and enhance competitiveness.**

Keywords*—*Intelligent logistics; energy; utilization efficiency; data-driven

I. Introduction

As of 2021, China's digital economy is expected to reach $45.5 billion, according to a report by China's Ministry of Industry and Information Technology. With China's economy expected to grow by 4.5% in 2024, the digital economy is already playing an integral role in production and life [1]. Since the new Crown Pneumonia epidemic in 2019, the digital economy has contributed significantly to China's economic recovery and pushed various industries toward digital transformation. China's economy is developing coordinated and systematically, with the digital economy playing an increasingly prominent role in this process. China is in a critical period of industrial reform, and the digital economy will play a vital role in this process, driving the development of new industries and upgrading and transforming traditional ones. However, China faces many challenges to its long-term economic development, including colossal energy consumption and environmental concerns [2]. The international energy situation has recently been unstable, and China's dependence on imported resources is under pressure. It has therefore become particularly urgent to ensure national energy security, avoid new energy bottlenecks, utilize digital technologies to improve energy efficiency, develop new clean energy technologies, improve the environment, and promote the development of a sustainable green society [3]. China needs to deepen the reform of its energy system, strengthen the clean and efficient use of coal, and accelerate the design and construction of new energy systems while promoting the two main objectives of coal. The Global Digital Energy Conference, Carbon Summit, and Carbon Neutral Forum 2022 emphasized accelerating the convergence of digital energy and innovative energy technologies [4]. The Chinese government has emphasized promoting the development of digital transformation in the green energy industry, accelerating the development of the clean energy industry, and building a safe and efficient electrical system. Applying the digital economy in the energy sector is critical to China's digitalization and achieving its "dual-carbon" goals, improving new clean energy technologies and enhancing green energy efficiency [5]. These initiatives are crucial to promoting green transformation and realizing high-quality economic development in China. Therefore, studying the factors affecting green energy efficiency in the digital economy is essential. In-depth research in this area can help address China's challenges in sustainable development and green transformation while providing essential references and guidance for future policymaking.

The rapid rise of the digital economy has attracted widespread attention globally, as it changes production methods and daily life and profoundly impacts overall energy utilization. With the widespread use of digital technologies, concerns about energy efficiency are increasing [6]. Improving energy utilization efficiency is urgently needed to ensure high-quality economic development and a sustainable social environment. Research on the impact of the digital economy on green energy efficiency is of dual significance, not only to deepen theoretical understanding but also to provide valuable insights for practice [7]. Although research on the impact of the Internet or ICT on global energy efficiency has been relatively adequate, research on the specific impact of the digital economy on urban energy efficiency still needs to be developed. Therefore, it is necessary to combine theoretical and empirical analyses to explore specific ways to improve the energy efficiency of various elements of the digital economy [8]. This research results will not only enrich the theoretical foundation of the digital economy field in terms of improving the eco-efficiency of various energy elements but also provide essential references for the formulation of specific policy recommendations in various regions.

II. Background

In recent years, China has made some progress in restructuring its energy supply side. It has optimized its energy mix by strengthening its green policy and financial system [9]. Despite the gradual replacement of some of the use of coal by cleaner energy sources, total carbon emissions have continued to rise, resulting in China still needing to reach peak carbon emissions. This suggests that improving the efficiency of energy use remains an integral part of China's energy strategy. China faces an unbalanced energy mix, with shortages of traditional energy sources such as coal, oil, and natural gas, and coal dominates the energy consumption mix. Although China's energy mix has improved from 2011 to 2021, with coal's share of the energy mix decreasing, it has remained the dominant carbon in the overall energy mix [10]. With the restructuring of energy policies, CO2 emissions are expected to increase further by 2030, posing challenges for China's environment and sustainable development. China's energy infrastructure is unlikely to be effectively upgraded in the short term, resulting in lower than global average energy utilization efficiency. This situation may not only hinder business development but also exacerbate environmental concerns. While most modern countries globally rely on clean and renewable energy sources, China's energy mix relies heavily on traditional carbon-intensive sources [11]. This means China still has a long way to go in its energy transition. Therefore, China needs to intensify its efforts further to improve energy utilization efficiency and actively promote energy structure transformation to achieve sustainable economic development and environmental improvement. Through innovative science and technology, policy support, and international cooperation, China can achieve a more significant transformation of its energy mix and contribute to the goal of carbon neutrality.

Improving energy efficiency involves reducing carbon dioxide emissions and addressing environmental and climate challenges. As China has gradually become one of the world's major CO_2 emitters, the international community's attention to reducing emissions has increased. In some developed countries, such as the EU member states, initiatives such as promoting CO_2 tariff programs and establishing green barriers have become essential strategies to combat climate change. These measures are expected to be further strengthened, and China, one of the world's largest greenhouse gas emitters, will be under even greater international pressure [12]. In addition, national economic issues are increasingly taking on an international dimension, such as trade wars and technological embargoes, and economic development is no longer confined to the domestic arena but is closely linked to the global economic landscape. Therefore, adapting to China's new economic development standards and realizing sustainable development has become a top priority [13]. Improving energy utilization efficiency reduces carbon emissions, solves the problems of unbalanced energy consumption and insufficient energy reserves in China, and promotes economic restructuring and upgrading. By adopting clean and efficient energy technologies, such as renewable and energy storage technologies, energy utilization can be maximized while reducing reliance on traditional fossil energy sources, providing solid support for China's sustainable economic development.

China's solemn commitment to achieving the "double coal" goal reflects its active role in global environmental governance and demonstrates its determination to build an ecological civilization. Achieving the "dual coal" goal is necessary for China's sustainable development and an essential contribution to the global ecological environment and climate stability [14]. The Chinese government has put forward a series of plans, including promoting the establishment of a zero-carbon energy sector, which will promote the optimization and transformation of the energy structure by encouraging enterprises to adopt advanced technologies, shift to cleaner energy sources, and significantly increase the use of renewable and cleaner energy sources [15]. However, despite a series of measures already taken, it will take time to realize the shift in energy consumption patterns, and there are several challenges to achieving the "double coal" goal. The Chinese government has implemented environmental protection documents on the agenda, but there still needs to be a gap in addressing the problem [16]. The inconsistent pace of market reforms is also a challenge, so the Chinese government is gradually exploring market-based environmental regulatory tools, including the introduction of a carbon planning system, an energy exchange system, and a carbon swap system, in order to adapt to market trends and facilitate the development and improvement of the carbon market. Despite the many challenges, improving energy efficiency remains one of the keys to realizing China's development goals in the new era. This will address China's energy consumption imbalance and reserve shortage, effectively respond to environmental and climate threats, and enhance the country's coping capacity [17]. Therefore, the Chinese government will continue to promote energy efficiency, realize the "double coal" goal, make more remarkable contributions to global sustainable development, and demonstrate the responsibility and commitment of a great country (Table I).

TABLE I. FACTORS AFFECTING ENERGY EFFICIENCY

Variant	Brochure	Average value	S.D	Minimum value	Maximum values
T	251	3.62	0	0.25	60.36
SO_2	251	555.36	0	43.21	68423
CO_2	251	0.516	0	0.0021	0.654
economic structure	251	47.62	0.36	12.36	651.52
GPD	251	983.36	0.54	44.636	66517
GNP	251	44.63	77.88	11.25	11158.32

Ensuring the proper functioning of the carbon dioxide trading system requires establishing a fair carbon dioxide allocation mechanism and effective carbon market regulation to ensure that enterprises comply with the relevant regulations. The fairness of such a mechanism directly affects the stability and sustainable development of the carbon trading market. In carbon markets set up abroad, the impact of the CO_2 quota method on company emissions and CO_2 intensity could be more precise, so further research and practice are needed to determine the most effective allocation method [18]. In addition, paying for CO_2 does not automatically change the transfer of costs to the energy sector, so regulatory mechanisms are needed to ensure that these costs are used correctly to promote the development and use of clean energy. Different carbon allocation methods impact innovation, operational viability, and product prices. For example, historical intensity increases carbon prices, while reference rules incentivize firms to promote innovation. Therefore, the most suitable carbon allocation method needs to be selected by considering the actual situation of enterprises and the development trend of the market. Recently, China's carbon allocation mechanism has been widely discussed. Some scholars have developed carbon trading decision-making models and studied the impact of different carbon allocation methods on the economic efficiency of the carbon market. These studies provide essential references for constructing China's carbon market and help promote the regular operation and development of the carbon trading system.

III. Methodology

A. Study Design

The main reasons for choosing data from 2011 to 2019 to assess the digital economy and environmental efficiency can be summarized in two ways. First, 2011 marked the launch of China's 12th Five-Year Plan, which promulgated energy-saving and emission-reduction policies and new environmental and energy requirements. Implementing these policies had a profound impact on the economic structure, industrial layout, and energy consumption patterns of cities, so the data from this period can more accurately reflect the effects of these policies. Second, 2019, as the last year of data collection, helps to avoid the interference of epidemics in the data and ensure the accuracy and comparability of the results.

The level of the digital economy is an essential criterion for assessing the degree of digitization of a city or region. It plays a crucial role in evaluating the degree of economic development of a city. China's digital economy development over the past timeframe has shown an average annual growth rate of 0.122. Although the overall level of development in the digital economy is relatively low, its potential is still enormous. Specifically, from 2011 to 2019, China's digital economy index grew from 0.07 to 0.162, indicating that the level of the digital economy has shown a steady improvement and that relevant policies have achieved significant results. Among the top 20 cities in Guangdong Province, six possess rich political, workforce, and resource advantages and excel in the digital economy. This phenomenon reflects the differences in the level of digital economy among cities and suggests the importance of factors such as politics, workforce, and resources in urban development. In order to promote sustainable economic development, innovative cooperation with high-level cities should be strengthened to enhance the digitalization level of cities, targeting low-level cities.

Intelligent logistics transportation process, as shown in Fig. 1.

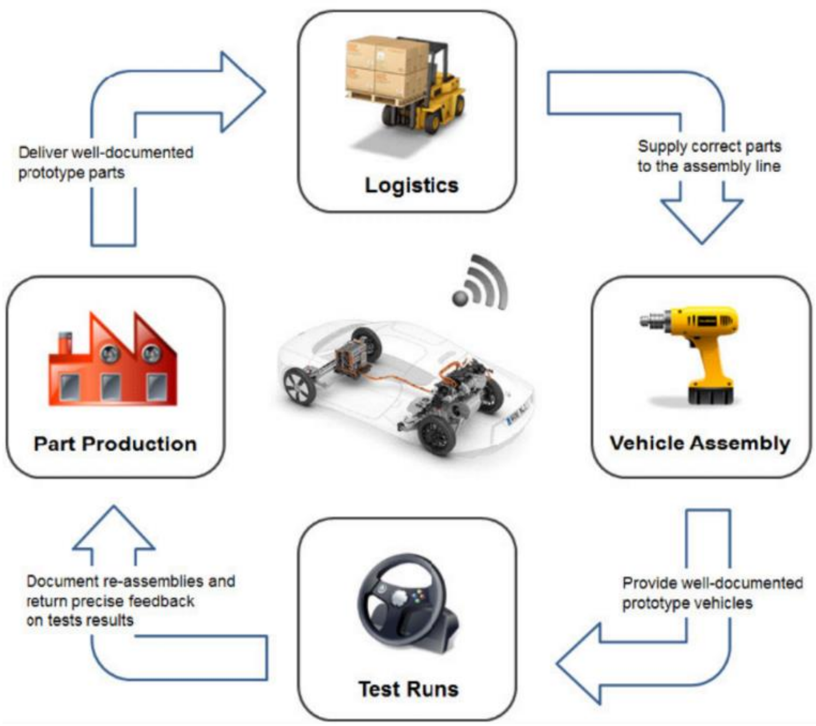

Fig. 1. Intelligent logistics transportation.

B. Indicators and Input-Output Ratios

In conducting the energy use efficiency assessment, the results of previous research were taken into account, and a system of assessment indicators was developed to analyze energy use in Chinese cities. These assessment indicators cover three main input variables: labor, capital, and energy. When selecting the type of energy, the current energy structure of the cities was fully considered, with particular attention paid to the total amount of natural gas, gas, and liquefied natural gas (LNG) delivered, as well as the electricity consumption of the whole society. In order to accurately estimate the total energy consumption, the standard carbon dioxide conversion rates of various energy sources were used as reference standards. In order to eliminate the influence of price distortions on the results, the real GDP of each city was adjusted to match its expected economic output, thus ensuring a more objective and accurate assessment.

Industrial waste and greenhouse gas emissions have also been introduced as indicators of adverse impacts to enhance the reliability and accuracy of the assessment results. These indicators include industrial waste emissions such as sulfur dioxide, water, and soot and greenhouse gas emissions such as carbon dioxide. These data were mainly obtained from the Annual Statistical Reports of Chinese Cities, and the vacuum coefficients were estimated using linear interpolation. In calculating carbon dioxide emissions, reference was made to the calculation methods of other countries, specifically, the carbon dioxide emission coefficients published by the Natural Gas Commission in 2006 and the emission coefficients of the power grids of six regions in China, which were used. These comprehensive data and methods enable a more comprehensive assessment of the energy utilization efficiency of Chinese cities and provide valuable references for policymaking and urban development. The flow of the open and closed logistics system is shown in Fig. 2.

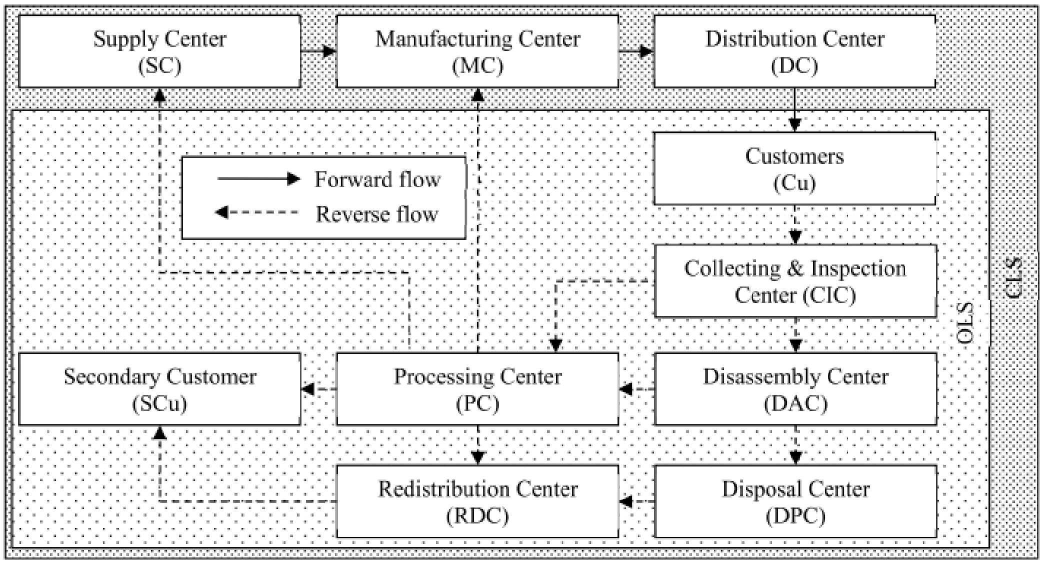

Fig. 2. Flow of open and closed logistics system.

A data-driven methodology model for energy use efficiency:

$$\pi = p(q_0 + \eta_1 e_1 + \eta_2 e_2) - \alpha e_1^2 - \frac{\beta}{e_1} e_2^2 \qquad (1)$$

π in Eq. (1) is the unknown variable for efficiency improvement;

$$e_1^{1*} = \frac{1}{2\alpha} p\eta_1 + K(1-D) \qquad (2)$$

(1-D) in Eq. (2) is to get the actual distance of TOPSIS.

$$e_2^{1*} = e_1^{1*} \frac{p\eta_2 + KD + \theta(1+g)}{2\beta} \qquad (3)$$

$(1+g)$ Eq. (3) is the coefficient of θ.

Analyzing the diversity of urban agglomerations is critical to understanding urban energy use. In this study, we consider different city sizes and delve into the impact of the digital economy on green energy utilization. The results show that the level of digital economy in medium and large cities contributes significantly to green energy utilization, being able to increase green energy utilization by 1%. However, differences in energy efficiency between different groups of cities were also identified. This triggered a further examination of energy efficiency between groups to assess its impact on environmental performance more fully. Although the model's p-value of 0.0681 fails at all levels of statistical significance, it passes the 10% group rate test, suggesting some unevenness in the impact of direct investment on environmental protection across different city sizes. We conducted a heterogeneity test to compare the regressors and obtained a high clustering value (0.594). This indicates significant differences between city groups, especially regarding battery eco-efficiency. Small city clusters have a higher impact on battery eco-efficiency in large cities (0.274), while small and medium-sized cities have a lower impact. This phenomenon can be explained by the fact that large cities have more developmental advantages, including geographic location, transportation infrastructure, technological innovation, and human resources, and are therefore more likely to achieve high efficiency in energy use.

Multiple dimensions characterize the indirect impact of the digital economy on urban green energy efficiency. First, the dynamic development of the digital economy promotes the rapid advancement and broad application of technological innovation, improving the efficiency of green energy utilization. Second, the rise of the digital economy has changed the industrial structure, promoted the rise and development of green industries, and indirectly improved the green energy efficiency of cities. The theoretical analysis identifies technological innovation, industrial structure, and rational industrial structure as the primary mechanisms by which the digital economy affects urban green energy efficiency. Recent studies have shown that technological innovation is critical in improving energy efficiency and creating more favorable conditions for the innovation and application of low-carbon energy technologies. Therefore, the impact of the digital economy on urban green energy efficiency involves technological innovation, adjustment and optimization of industrial structure, and inherent economic mechanisms. Empirical evidence of energy utilization efficiency improvement in intelligent logistics is shown in Table II.

TABLE II. EMPIRICAL EVIDENCE OF ENERGY UTILIZATION EFFICIENCY IMPROVEMENT IN THE CONTEXT OF INTELLIGENT LOGISTICS

	(1)*Ee*	(2)*Tfee*	(3)*Ee*	(4)*Tfee*
Treat×post	0.5817***	0.0514***	0.517***	0.0514**
Cons	0.871***	1.214***	11.214***	1.251***
Year	Y	Y	Y	Y
Province	Y	Y	Y	Y
Control	Y	Y	Y	Y
N	251	251	251	251
R^2	0.627	0.817	0.817	0.985

IV. RESULTS AND DISCUSSION

A. Discussion of Empirical Results on Green Total Factor Energy Efficiency (GTFE)

China faces energy and environmental challenges, including lower energy efficiency and environmental quality. In the context of green development, accelerating the development of the digital economy is critical to China's modernization and improvement of green energy efficiency. The rise of the digital economy provides new opportunities and impetus for China to realize its green transformation. On the energy front, China is developing traditional green energy production technologies, such as solar and wind power, and promoting low-carbon oil extraction technologies to reduce emissions from traditional energy use. The development of intelligent transportation is also vital, with digital technologies enabling the intelligent management and optimization of transportation systems, reducing traffic congestion and pollution, and improving the efficiency of urban energy use [19].

Regarding the environment, China uses digital technology to build a digital environmental management platform to monitor environmental conditions in real-time and provide accurate early warning and rapid response to environmental problems, thereby controlling the behavior of high-energy-consuming and high-emission enterprises and promoting sustainable environmental development. Digital means can realize comprehensive monitoring and analysis of environmental data, providing a scientific basis and technical support for environmental governance. China also needs to actively promote the development of the digital economy, accelerate the integration of digital technology with traditional industries, and especially promote the digital transformation of traditional industries. This process requires focusing on developing advanced industries, such as the modern service industry, and accelerating the intelligent development of traditional industries. Integrating digital technologies with traditional industries can help promote the digital transformation of industrial structures, improve the green energy efficiency of cities, realize the green and low-carbon transformation of cities, and inject new vitality into China's sustainable development.

Cities rich in natural resources, although endowed with abundant natural resources, have a relatively low level of economic development, a unique industrial structure, and a high degree of dependence on natural resources. Over-exploitation of resources may not only lead to resource depletion but also cause damage to the environment, thus affecting the sustainable development of society. Therefore, there is an urgent need to promote the digital transformation of these resource-based cities into resource-saving cities and actively explore helpful regional resources. These resource-centric cities are improving resource efficiency and driving the digital revolution. In general, the industrial structure of resource-intensive cities is dominated by resource-saving industries. However, these resource-centric cities should seize the significant opportunity to develop a digital economy and promote the upgrading and transformation of traditional industries into new digital industries to unleash the potential of the digital economy while reducing energy consumption. Realizing the digital transformation of cities requires an overall improvement in green energy efficiency. Some cities have steel as their primary industry, while others have wood as their primary industry. These resources could be used to establish innovative partnerships with other cities, which would not only help to promote economic development but also change the integrated industrial structure and facilitate the digital transformation of resource-efficient cities. Strengthening collaboration with resource-efficient cities to support their digital transformation is crucial. Resourceful cities often depend solely on natural resources and need more geographic and economic advantages, leading to a widespread brain drain. Technical cooperation is critical. Cities without natural resources are rich in technical resources and can provide technical support and guidance to accelerate the digital transformation of resource-saving cities. At the same time, resource-saving cities can also learn from the experience of non-resource-saving cities to find the most suitable path of digital transformation. The second is talent cooperation. Resource-poor cities have sufficient human resources to support the recruitment and training of resource-saving cities. At the same time, resource-saving cities can attract and train high-quality digital change experts to improve the efficiency and quality of digital change. Energy use efficiency data map.

Modernizing the energy mix and strengthening technological innovation are critical. Although China currently relies on traditional energy sources, such as coal, its reserves must be increased to meet demand. At the same time, more oil and natural gas inventories are required to meet market demand, and it relies heavily on imports, leading to an imbalance between supply and demand. The use of traditional energy sources generates large amounts of harmful gases, causing severe damage to the environment. Under the guidance of the green development concept, strengthening technological innovation and promoting energy conversion and modernization are vital ways to achieve the goals of dual-carbon and high-quality economic development. To this end, it is necessary to strengthen energy technology innovation, optimize energy structure, reduce traditional energy consumption, and improve energy efficiency. In particular, it should focus on developing traditional innovative energy exploration technologies, new energy technologies, clean energy technologies, and digital energy system technologies, as well as the construction of digital energy systems to gradually promote energy structure transformation. In addition to technological innovation, policy support and financial investment are equally crucial. The government should increase investment in R&D in the energy sector and provide sufficient funds for technicians to enhance the vigor of technological innovation in enterprises and promote the transition to clean and low-carbon energy, as shown in Fig. 3.

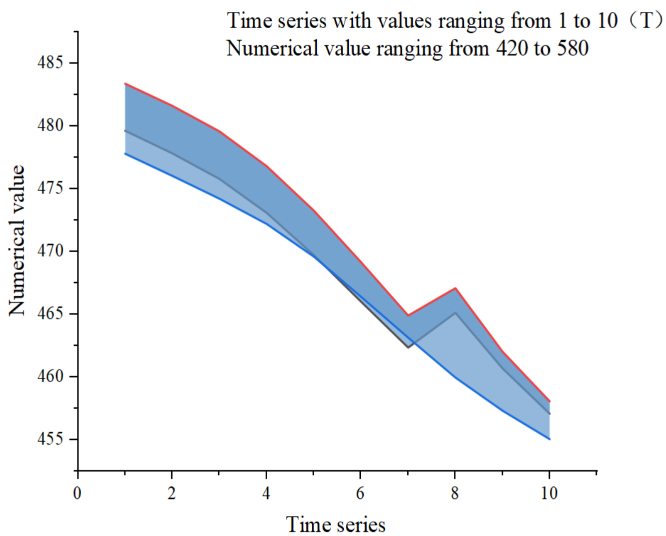

Fig. 3. Energy use efficiency data.

On the other hand, the government should pay attention to regions with high carbon consumption and provide appropriate policy incentives to promote the promotion and application of clean energy and new energy technologies to promote the green energy transition. Accelerating the modernization of the industrial structure and optimizing energy consumption is also crucial. Currently, the secondary industry occupies a larger share of China's economy, and its energy consumption per unit of GDP is much higher than that of the service sector, which means that industrial energy consumption is relatively high. However, the industry is the foundation of the real economy and the cornerstone of modernization, and reducing the proportion of the industry is not realistic. Improving industrial infrastructure and optimizing industrial energy use is the only way to improve environmental energy efficiency and promote sustainable urban development. In addition, according to relevant national laws and regulations, it is necessary to eliminate high-energy-consuming and high-polluting projects, eliminate excess capacity, rationally allocate social resources, and promote the green transformation of steel and other industries. Promoting the modernization of the energy structure reduces dependence on traditional energy sources, reduces environmental pollution, improves energy use efficiency, and lays a solid foundation for the sustainable development of China's economy and the realization of the dual-carbon goal [20].

B. *Time-Space Evolution of Energy Use Efficiency*

Based on the SBM super-efficiency model and MaxDE7 super software, the green energy efficiency of cities was calculated from 2011 to 2019. The study aims to explore the regional differences in the overall eco-energy efficiency of cities by analyzing them from a temporal and spatial perspective. During the study period, China's average energy efficiency was 0.508, indicating that China still has the potential to improve energy efficiency. Much work remains to be done to realize the goal of "dual-carbon" and sustainable green development of society. The temporal characteristics of the development of the national green energy efficiency coefficient show an increasing volatility trend. 2011-2016 is considered a period of energy efficiency improvement, 2016-2017 a period of energy efficiency decline, and 2016-2019 a period of energy efficiency improvement. 2016 marks the beginning of the 13th Five-Year Plan, which aims to reduce individual energy consumption and manage overall energy consumption. Although there is a time lag between policy liberalization and implementation, it will take time for regional industrial reforms and modernization to become established, which will reduce overall environmental impacts in the short term. As policies are implemented and local development adapts, the Green TFE will gradually improve its energy efficiency after 2017. To further improve China's energy efficiency, attention needs to be paid to the research, development, and application of green energy technologies, increasing the utilization rate of renewable energy and reducing dependence on traditional energy sources; optimizing the energy structure, encouraging clean energy to replace traditional energy sources, and improving the efficiency of energy use; and strengthening energy management, setting up a comprehensive energy monitoring and evaluation system, promoting changes in energy consumption patterns, and promoting green and low-carbon development. The government should introduce more robust policy measures to guide and support enterprises and residents in saving energy and reducing emissions and jointly promote improving China's energy efficiency level. Energy improvement efficiency data map, as shown in Fig. 4.

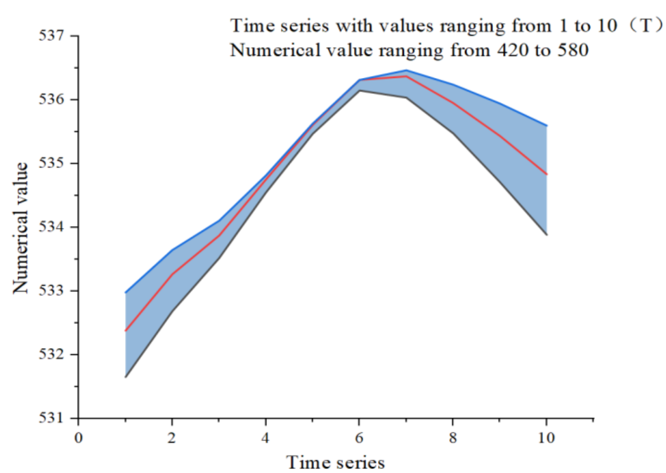

Fig. 4. Energy improvement efficiency data.

Analyzed from the perspective of control variables, the level of economic growth has a significant positive impact on all aspects of environmental effects at a significance level of 1%. Further, economic growth also attracts more investment, which increases enterprises' production capacity and competitiveness and promotes technological innovation and the application of environmental management technologies. The capital mobilization of enterprises can be used not only to promote technological innovation but also to improve the production process and enhance resource utilization efficiency. On the other hand, population density (POP) significantly negatively impacted the overall ecological efficiency (significance level of 1%), indicating that high population density may lead to higher energy consumption and more severe pollution problems, thus hindering the improvement of ecological efficiency. Therefore, densely populated areas must adopt more effective environmental management and resource utilization measures to reduce environmental pressure and improve ecological performance. This finding underscores the positive impact of economic growth on environmental and energy efficiency, as economic progress helps to provide more resources for technological upgrading and industrial modernization, which in turn leads to the adoption of cleaner sources of energy, reduced use of traditional energy sources and pollution, and effective improvement of infrastructure. This further highlights the positive correlation between economic development and environmental protection and the mutually reinforcing relationship between economic prosperity and environmental sustainability. Infrastructure quality has a significant positive impact on the overall energy efficiency of green energy, with better quality infrastructure reducing transportation costs, improving energy use efficiency, and promoting technological advances that increase energy efficiency. Therefore, building high-quality infrastructure is one of the most important ways to improve environmental energy efficiency, which is of positive significance for promoting economic growth, improving the quality of life, and environmental protection.

Intelligent logistics construction principles and processes:

$$\pi_m = p_1(q_0 + \eta_1 e_1 + \eta_2 e_2) + K - \alpha e_1^2 \tag{4}$$

Thein Eq. (4) is a free variable introduced to guarantee the error value.

$$\pi_m^{2*} = p_2 q_0 + \frac{(p_2\eta_2 + \theta(1+g))^2}{4\beta} e_1^{2*} \tag{5}$$

The $p_2 q_0$ in Eq. (5) is the residual term of the least squares method.

Excellent infrastructure plays a significant role in reducing the transport coefficient, which helps optimize resource allocation and improve overall productivity and environmental sustainability. The entropy method was used to explain the potential regressors of economic levels, enabling the most influential variables to be extracted from many economic indicators, thus validating the stability of the model. The results show that PCADI significantly impacts green energy efficiency, with 0.00335 units per increase, which is significant for low-level regression, indicating the model's reliability. In addition, the study introduced foreign direct investment (FDI) as a new control variable to avoid the possible impact of omitted variables on the empirical results. The analysis results show that the level of the digital economy significantly negatively impacts overall eco-efficiency, implying that technological development is only sometimes beneficial to eco-efficiency.

Meanwhile, FDI negatively impacts overall energy efficiency, especially when developed countries transfer highly polluting and energy-intensive industries to developing countries. To validate these findings, static panel data were used to test the regression model's robustness and investigate possible endogeneity issues. Local government policies and interventions significantly impact environmental energy efficiency in a given developing urban setting, suggesting that small changes in government policies may significantly impact overall energy efficiency. The p-value of 0.0092 for the two direct investments suggests that they may significantly impact energy efficiency. The analysis of the differences between the different factors shows that direct investment's impact on the urban environment varies between developed and developing countries.

Regarding recovery factors, developed cities have a significant positive impact on energy efficiency because they have advantageous resources such as high levels of digitalization, economic development, and technological innovation. Therefore, implementing environmental management strategies and the increased use of clean energy will help improve these cities' energy efficiency and promote their sustainable development. The weight of each type of energy is shown in Fig. 5.

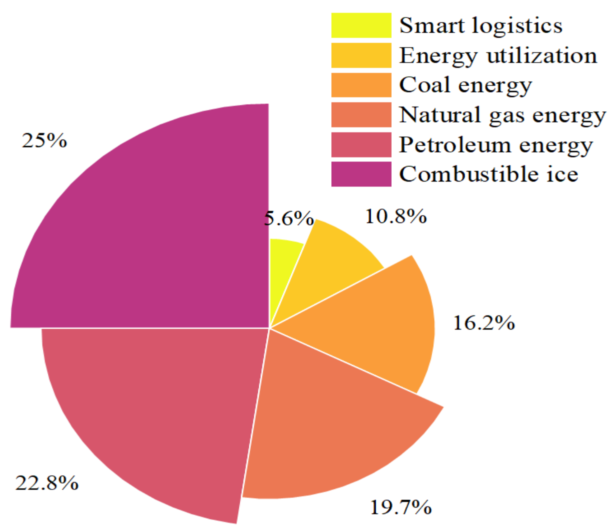

Fig. 5. Share of various energy sources.

In this study, 272 heterogeneous samples were grouped. Although the effect of the inhaler on the energy efficiency of the green factor was insignificant, there was a significant difference between the two groups. In order to ensure the reliability of the results of the different studies, the researchers delved into the factors that differed between the two groups. This showed that the model had passed the 5% group gap test, again validating the inconsistency of the impact of non-resource direct investment on green energy efficiency. The diversity recession factor reveals that direct investment significantly impacts the overall environmental energy efficiency of cities that do not consume large amounts of resources. This is because resource-efficient cities, despite having significant resources, are mainly made up of less developed cities with less digitization—global energy consumption shares, as shown in Fig. 6.

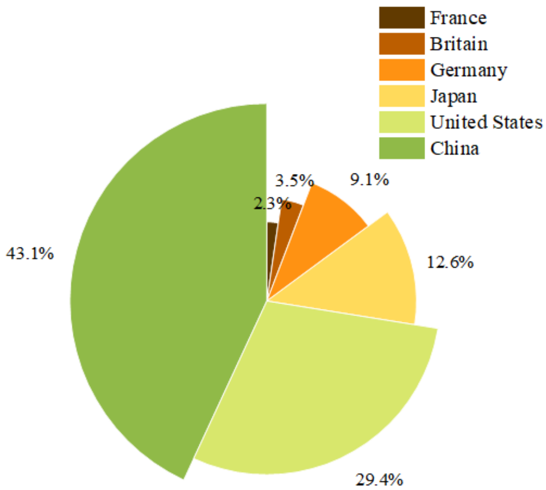

Fig. 6. Global energy consumption shares.

Over time, the industry has become the engine of economic development in resource-intensive cities; in the process of industrialization, although their economies are booming, these cities consume large amounts of national resources and bear environmental costs that do not contribute to sustainable development and more efficient use of society's resources. Resource-efficient cities are inherently less affluent than non-resource-efficient cities that rely on energy supplies or imports for economic development and daily life. However, in resource-scarce cities, industries change relatively quickly. While other cities rely on primary and secondary industries to drive GDP growth, some, such as Beijing, Shanghai, and Shenzhen, have shifted from primary and secondary industries to more environmentally friendly ones. These high-industry-consuming cities consume less energy, produce less waste and CO2 emissions, and have reduced energy waste and emissions in their cities. At the same time, the high degree of digitization, digitalization, and rapid digitization of natural resource-based cities has improved the eco-energy efficiency of various factors.

A comparison of domestic energy efficiency is shown in Fig. 7.

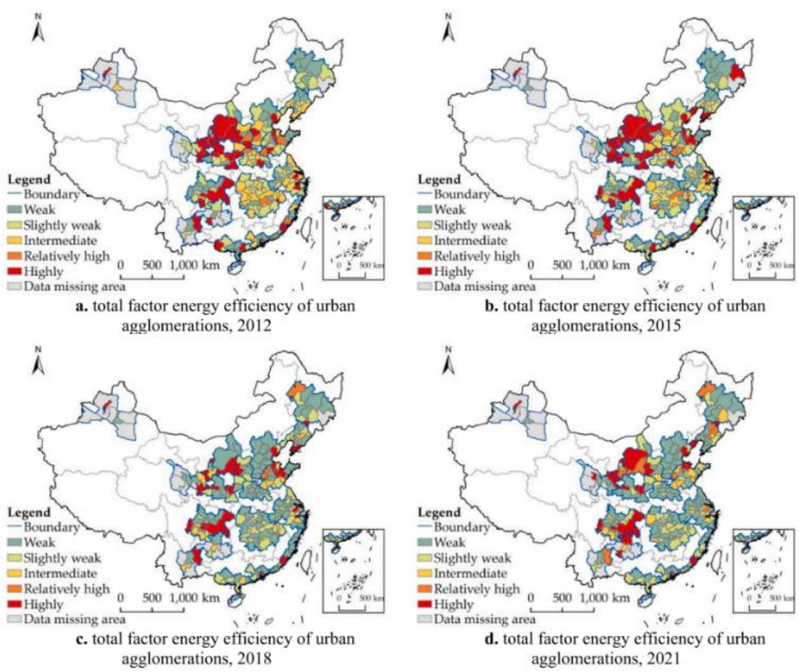

Fig. 7. Comparison of domestic energy efficiency.

V. Conclusion

Intelligent logistics is a current trend in the logistics industry, and one of its core objectives is to enhance energy utilization efficiency to reduce costs, minimize resource consumption, and improve the environment. This study systematically explores the feasibility and effectiveness of improving energy utilization efficiency through a data-driven approach in the context of global intelligence in various industries. The following conclusions are drawn from the introduction, purpose, methodology, and results: First, the large amount of accumulated data in the intelligent logistics environment becomes a valuable resource for improving energy utilization efficiency. Through the collection and analysis of logistics transportation information, energy consumption data, and other data, the operational status and energy utilization of the optimized logistics management procedures are deeply understood, providing a solid foundation for subsequent optimization. Secondly, key factors affecting energy utilization efficiency and potential optimization directions are revealed through data analysis and mining techniques. For example, optimizing transportation routes and improving vehicle load factors are essential in improving energy utilization efficiency. These findings provide theoretical guidance for the development of targeted optimization strategies. A series of data-driven optimization strategies and methods were designed at the methodological level by incorporating intelligent optimization algorithms. These methods not only consider the actual situation of optimizing logistics management procedures but also make full use of the advantages of big data and artificial intelligence technology to improve the precision and operability of the optimization effect. The effectiveness and feasibility of the proposed methods are verified through simulation experiments and case studies. The experimental results show that adopting the data-driven approach can significantly improve the energy utilization efficiency of the optimized logistics management procedure, reduce logistics costs, and improve the sustainability and competitiveness of the system.

In summary, through in-depth analysis and empirical research, this study demonstrates the feasibility and effectiveness of using data-driven methods to improve energy utilization efficiency in the context of global intelligence in various industries. The proposed series of optimization strategies provides new ideas and methods for energy management and optimization of optimized logistics management processes. These results significantly promote the sustainable development of optimized logistics management procedures and enhance overall competitiveness. In future research, optimizing other aspects of optimized logistics management procedures, such as environmental impact assessment and supply chain visualization, can be further explored to achieve the overall optimization and sustainable development of optimized logistics management procedures.

REFERENCES

[1] Sarker, I. H. (2022). Smart City Data Science: Towards data-driven smart cities with open research issues. Internet of Things, 19, 100528. https://doi.org/10.1016/j.iot.2022.100528

[2] Ahmad, T., Zhang, D., Huang, C., Zhang, H., Dai, N., Song, Y., & Chen, H. (2021). Artificial intelligence in the sustainable energy industry: Status Quo, challenges, and opportunities. Journal of Cleaner Production, p. 289, 125834. https://doi.org/10.1016/j.jclepro.2021.125834

[3] Tambare, P., Meshram, C., Lee, C.-C., Ramteke, R. J., & Imoize, A. L. (2021). Performance measurement system and quality management in data-driven Industry 4.0: A review. Sensors, 22(1), 224. https://doi.org/10.3390/s22010224

[4] Sarmas, E., Marinakis, V., & Doukas, H. (2022). A data-driven multicriteria decision-making tool for assessing investments in energy efficiency. Operational Research, 22(5), 5597–5616. https://doi.org/10.1007/s12351-022-00727-9

[5] Ohalete, N. C., Aderibigbe, A. O., Ani, E. C., Ohenhen, P. E., Daraojimba, D. O., & Odulaja, B. A. (2023). AI-driven solutions in renewable energy: A review of data science applications in solar and wind energy optimization. World Journal of Advanced Research and Reviews, 20(3), 401–417. https://doi.org/10.30574/wjarr.2023.20.3.2433

[6] Tan, J., Xie, S., Wu, W., Qin, P., & Ouyang, T. (2022). Based on a data-driven approach, evaluating and optimizing the cold energy efficiency of power generation and wastewater treatment in LNG-fired power plants. Journal of Cleaner Production, 334, 130149. https://doi.org/10.1016/j.jclepro.2021.130149

[7] Mohapatra, S. K., Mishra, S., Tripathy, H. K., Bhoi, A. K., & Barsocchi, P. (2021). Using predictive intelligence approaches, a pragmatic investigation of energy consumption and utilization models in the urban sector. *Energies*, *14*(13), 3900. https://doi.org/10.3390/en14133900

[8] Akhtar, S., Sujod, M. Z. B., & Rizvi, S. S. H. (2022). An intelligent data-driven approach for electrical energy load management using machine learning algorithms. *Energies*, *15*(15), 5742. https://doi.org/10.3390/en15155742

[9] Majeed, A., & Hwang, S. O. (2021). Data-driven analytics leveraging artificial intelligence in the era of COVID-19: An insightful review of recent developments. *Symmetry*, *14*(1), 16. https://doi.org/10.3390/sym14010016

[10] Ala'raj, M., Radi, M., Abbod, M. F., Majdalawieh, M., & Parodi, M. (2022). Data-driven based HVAC optimization approaches A systematic literature review. *Journal of Building Engineering*, *46*, 103678. https://doi.org/10.1016/j.jobe.2021.103678

[11] Ma, S., Zhang, Y., Lv, J., Ren, S., Yang, H., & Wang, C. (2022). Data-driven cleaner production strategy for energy-intensive manufacturing industries: Southern and Northern China case studies. *Advanced Engineering Informatics*, p. *53*, 101684. https://doi.org/10.1016/j.aei.2022.101684

[12] Alrashidi, M., Alrashidi, M., & Rahman, S. (2021). Global solar radiation prediction: Application of novel hybrid data-driven model. *Applied Soft Computing*, *p. 112*, 107768. https://doi.org/10.1016/j.asoc.2021.107768

[13] Lazaroiu, G., Androniceanu, A., Grecu, I., Grecu, G., & Neguriță, O. (2022). Artificial intelligence-based decision-making algorithms, IoT sensing networks, and sustainable cyber-physical management systems in big data-driven cognitive manufacturing. *Oeconomia Copernicana*, *13*(4), 1047–1080. https://doi.org/10.24136/oc.2022.030

[14] Kahraman, A., Kantardzic, M., Kahraman, M. M., & Kotan, M. (2021). A data-driven multi-regime approach for predicting energy consumption. *Energies*, *14*(20), 6763. https://doi.org/10.3390/en14206763

[15] Zheng, Z., Wang, F., Gong, G., Yang, H., & Han, D. (2023). Intelligent technologies for construction machinery using data-driven methods. *Automation in Construction*, *147*, 104711. https://doi.org/10.1016/j.autcon.2022.104711

[16] Bachmann, N., Tripathi, S., Brunner, M., & Jodlbauer, H. (2022). The contribution of data-driven technologies in achieving sustainable development goals. *Sustainability*, *14*(5), 2497. https://doi.org/10.3390/su14052497

[17] Strielkowski, W., Vlasov, A., Selivanov, K., Muraviev, K., & Shakhnov, V. (2023). Prospects and challenges of the machine learning and data-driven methods for the predictive analysis of power systems: A review. *Energies*, *16*(10), 4025. https://doi.org/10.3390/en16104025

[18] Bousdekis, A., Lepenioti, K., Apostolou, D., & Mentzas, G. (2021). A review of data-driven decision-making methods for industry 4.0 maintenance applications. *Electronicsweek*, *10*(7), 828.

[19] Bahramian, M., Dereli, R. K., Zhao, W., Giberti, M., & Casey, E. (2023). Data to intelligence: The role of data-driven models in wastewater treatment. *Expert Systems with Applications*, *p. 217*, 119453. https://doi.org/10.1016/j.eswa.2022.119453

[20] Bibri, S. E. (2021). Data-driven smart, sustainable cities of the future: An evidence synthesis approach to a comprehensive state-of-the-art literature review. *Sustainable Futures*, p. *3*, 100047. https://doi.org/10.1016/j.sftr.2021.100047