Digital Energy Management Systems for Energy Conservation and Carbon Emission Reduction in Industry: Analysis and Recommendations (Postprint)

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Abstract

Industrial production constitutes the primary source of carbon emissions. Reducing energy waste and achieving energy conservation in production are essential for attaining China's "dual carbon" objectives. With advancements in digital technology, digital energy management systems can facilitate enterprise energy conservation by visualizing previously invisible energy consumption. This paper analyzes the current application status of energy management systems in the United Kingdom, United States, Germany, Japan, and Sweden, summarizes their characteristics and application prerequisites, compares these with China's development in this domain, and examines the challenges encountered during the deployment of energy management systems in China. The paper further proposes a methodological framework for analyzing energy consumption from the perspective of "factory, production line, and equipment" to "product", constructing an "energy consumption label per unit product based on production steps". It explores the roles of stakeholders, including government and enterprises, within this methodology, and puts forward strategies for government support in developing digital energy management systems, encompassing promoting system construction, fostering collaboration, establishing energy consumption benchmarks, and guiding enterprises to benchmark against industry best practices.

Full Text

Preamble

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Analysis and Recommendations for Energy Conservation and Carbon Emission Reduction in Industry Boosted by Digital Energy Management Systems

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Abstract

Industrial production constitutes a primary source of carbon emissions. Reducing energy waste and achieving energy-efficient production are crucial for realizing China' s "dual-carbon" goals. With advances in digital technology, digital energy management systems can promote enterprise energy conservation by visualizing previously invisible energy consumption. This paper analyzes the current status of energy management system applications in the United Kingdom, United States, Germany, Japan, and Sweden, summarizing their characteristics and application conditions. It compares these international experiences with China' s development in this domain and explores the challenges China faces in deploying energy management systems. The paper also proposes a methodological framework for analyzing energy consumption from a "product" perspective rather than from "factories, production lines, and equipment," constructing a framework for "unit product energy consumption labels based on production steps." The roles of stakeholders, including governments and enterprises, within this methodology are discussed, and policy recommendations are proposed to support the development of digital energy management systems. These include promoting system construction, supporting collaboration, establishing energy consumption benchmarks, and guiding enterprises to benchmark against industry best practices.

Keywords: digital technology, energy waste, energy management, energy system, carbon neutrality
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As climate change intensifies, carbon emission reduction has garnered global attention. The Paris Agreement, adopted in 2015, aims to limit global average temperature increase to within 1.5°C [1]. To achieve this target, Western countries have implemented Nationally Determined Contributions, regularly reviewing and enhancing their emission reduction commitments [2]. China has also responded actively. In September 2020, President Xi Jinping announced at the 75th United Nations General Assembly that China would strengthen its Nationally Determined Contributions and adopt more robust policies and measures to peak carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060.

Industry represents a significant source of carbon emissions. In 2022, global industrial carbon emissions reached 9.2 Gt, accounting for 25% of total emissions [2]. As the world' s largest industrial nation, China' s industrial carbon emissions totaled approximately 2,888 Mt, representing over 28% of national emissions. The primary pathways for reducing industrial carbon emissions include: adopting clean energy, carbon capture, utilization and storage (CCUS), and energy conservation. China's energy structure remains in the early stages of transitioning to clean energy, and CCUS technologies are not yet mature. Consequently, energy conservation constitutes the main approach for reducing industrial carbon emissions. Reducing energy waste—defined as energy consumption exceeding optimal levels [3]—represents an innovative strategy. Conservative estimates suggest that 10%-20% of energy waste exists in China' s industrial enterprises, corresponding to approximately 300 Mt of potential carbon emission reductions.

The Chinese government has paid close attention to industrial energy waste. A series of policy documents have been issued, including the *Measures for Energy Conservation Management of Key Energy-Using Units* released by the National Energy Administration in 2011, the *Comprehensive Work Plan for Energy Conservation and Emission Reduction During the 13th Five-Year Plan Period* issued by the State Council in 2016, and the *Energy Production and Consumption Revolution Strategy (2016–2030)* jointly issued by the National Development and Reform Commission and the National Energy Administration in 2017. These documents require key energy-consuming industries to implement online energy consumption monitoring to continuously reduce energy use. In 2021, the white paper *China' s Policies and Actions on Climate Change* proposed strengthening energy conservation and efficiency improvement to achieve visualization, automation, and intelligentization of electricity management.

Compared to visible resources such as materials and human resources, energy possesses inherent invisibility. While lean production methodologies have been widely applied to address waste in visible resources, energy waste has often been neglected due to its invisibility and historically low energy prices. Digital energy management systems enable enterprises to monitor production energy consumption data in real time, analyze high-energy-consumption operations in production processes, and thereby reduce energy waste, delivering substantial energy-saving benefits. For example, Hebei JinYu Dingxin Cement Company established a digital energy management system in 2015. By analyzing daily energy consumption, the company discovered correlations between electricity consumption and machine speed and frequency. Adjusting machine operating schemes saved 488,000 kWh of electricity annually [5].

This paper addresses the issues of energy waste in China' s industrial sector and the immature application of digital energy management systems. It analyzes the application status of digital energy management systems in foreign industries and examines the challenges and opportunities China faces. The paper proposes the concept of a "standardized energy consumption label based on production steps" and a methodological framework for digital energy consumption data analysis. It analyzes the roles of stakeholders, including enterprises and governments, and proposes policy recommendations for industrial emission reduction through digital energy management systems.

1.1 Introduction to Digital Energy Management Systems

Digital energy management systems primarily employ technologies such as the Internet of Things, cloud computing, and big data analytics. By monitoring and analyzing energy consumption data in real time and visualizing energy usage, these systems ultimately improve energy efficiency and reduce consumption. Several cases demonstrate their advantages. For instance, China Baowu Steel Group utilized a digital energy management system to optimize energy consumption during production, achieving goals of carbon emission reduction and improved energy utilization efficiency. Germany' s BASF employs digital energy management systems for energy management and control, enhancing energy efficiency. Additionally, the U.S. Department of Energy' s Superior Energy Performance (SEP) program, proposed in 2011, is an ISO50001-based certification initiative that provides a systematic approach for improving corporate energy performance and verifies these improvements through certification procedures. Large U.S. enterprises such as Ford, 3M, and Procter & Gamble have established their own energy management systems with clear emission reduction targets, while specialized energy management companies like Johnson Controls leverage their expertise in digital solutions and hardware equipment to build digital energy management systems for numerous industrial enterprises.

1.2 International Application of Digital Energy Management Systems

Internationally, digital energy management system applications have achieved significant progress (Table 1).

United Kingdom. In 2014, the UK Department of Energy & Climate Change and regulator Ofgem released the *Smart Grid Vision and Routemap*, promoting the deployment of standardized digital energy management systems to enable real-time monitoring and optimization of enterprise energy consumption [6]. The smart grid can collect and analyze electricity demand in real time, helping enterprises adjust between peak and off-peak consumption periods and supporting grid integration of distributed energy sources (e.g., solar and wind), thereby reducing dependence on traditional energy sources. The system also transmits real-time electricity price information, enabling enterprises to consume more power when prices are low and less when prices are high, reducing industrial energy waste overall. However, smart grids have drawbacks: high construction and maintenance costs may create significant short-term financial pressure for enterprises, and the collection and transmission of large volumes of user data may raise data security and privacy concerns.

United States. The U.S. government launched the Federal Energy Management Program in 1978. In 1992, the Environmental Protection Agency and Department of Energy introduced the ENERGY STAR voluntary energy efficiency program, simultaneously promoting widespread adoption of digital energy management systems. The U.S. has established clear emission reduction targets, and its energy management systems require specific energy-saving measures [8]. Bearing manufacturer SKF, commercial vehicle manufacturer Scania, and telecommunications equipment manufacturer Ericsson have all established digital energy management systems in compliance with regulations, significantly reducing energy consumption. Swedish enterprises also prioritize energy management system development; for example, SKF was among the first globally to achieve ISO 50001 certification, deploying energy management systems both internally and throughout its supply chain. Swedish companies collaborate with other industrial steel end customers in initiatives like Steel Zero and Responsible Steel to drive net-zero transformation in the steel industry. Sweden' s institutional framework for promoting energy management system deployment is internationally leading, though this benefits from the country' s relatively small number of industrial enterprises and relatively large profit margins, making its experience somewhat limited in applicability to other countries.

Germany. The German government passed the *Energy Transition and Climate Protection Act* in 2011, launching the "Energiewende" (energy transition) program. In 2023, it released the *Climate Protection Act* and *Energy Efficiency Act*, requiring enterprises above certain energy consumption thresholds to establish energy management or environmental management systems. German energy supplier E.ON installs sensors and smart metering equipment at customer facilities, collecting real-time energy data including electricity, gas, and water consumption. This data is uploaded to cloud platforms where big data analytics identify anomalies and waste in energy usage, helping customers discover potential energy-saving opportunities and providing customized optimization recommendations [7]. The advantages and disadvantages of Germany' s digital energy management systems are similar to those of the UK' s smart grid program. Additionally, numerous German industrial enterprises have obtained ISO 50001 energy management system certification and published clear 2030 carbon reduction targets. Many industrial leaders, including BASF, BMW, and Siemens, have significantly reduced energy waste through energy management systems.

Japan. Since 1979, Japan has implemented an energy management system based on the *Energy Conservation Act*, requiring high-energy-consuming factories to establish energy management systems, designate energy management personnel, and conduct regular energy audits. Meanwhile, the National Institute of Advanced Industrial Science and Technology has led the "Industrial Energy Management System" project, developing digital energy management systems and promoting their standards and certification mechanisms. Japanese industrial leaders such as Hitachi have developed comprehensive energy management system solutions, using these systems internally and providing energy system services to other companies.

Sweden. The Swedish government imposes strict requirements on corporate energy management, implementing energy audit programs and establishing clear energy efficiency standards. The Sustainable Productivity Initiative (SPI), launched in 2003, aims to improve industrial energy efficiency and reduce waste. Swedish law requires enterprises with annual sales exceeding €50 million to conduct energy audits every four years; companies with certified energy management systems are exempt. While Sweden' s regulations for promoting energy management system deployment are internationally advanced, this reflects its well-developed economy, strong industrial foundation, and high proportion of large enterprises and Fortune 500 companies with sufficient economic and technological strength to implement energy management systems throughout their supply chains.

In summary, the construction of digital energy management systems requires collaboration among governments, enterprises, and other stakeholders, along with high technical requirements. Deployment must be led by either leading enterprises or governments to form unified, standardized industrial clusters for digital energy management systems, thereby reducing energy waste across entire industries.

Characteristics and application conditions of energy management systems in typical international countries

Country	Characteristics of Digital Energy Management System Application	Application Conditions
UK	Strong government driving force; energy and power companies can provide comprehensive, unified, and standardized energy data and technical services to production enterprises	Strong government promotion willingness; UK energy companies can ensure data security while collecting energy data; energy-consuming enterprises are willing to cooperate in deploying standardized sensors
US	Government promotes digital energy management system establishment through policy formulation and department setup; numerous large enterprises have deep application of digital energy management systems	US enterprises generally possess internationally leading technologies in digital energy management systems
Germany	Well-developed industrialization with strong government driving force and high penetration of digital energy management systems; large enterprises take the lead under government policy guidance	Strong government promotion willingness; large enterprises actively cooperate with government policies
Japan	Government issues relevant policies; large enterprises demonstrate strong autonomy, establishing comprehensive energy management service systems and new business models, providing software and hardware supporting services for small and medium-sized enterprises	Japanese large enterprises possess high technological and economic strength and focus on digitalization and energy conservation

Country	Characteristics of Digital Energy Management System Application	Application Conditions
Sweden	Swedish government has strict requirements for energy management and greenhouse gas emissions, implementing energy audit programs and establishing a series of clear energy efficiency standards	Sweden has a developed economy, strong industrial foundation, and high proportion of large enterprises and Fortune 500 companies with sufficient economic and technological strength to adopt energy management systems throughout supply chains

1.3 Application Status of Digital Energy Management Systems in China

Compared to international advanced levels, China' s digital energy management systems still have considerable room for improvement in terms of popularization and development, comprehensive operational capabilities, policy support, system functional diversity, energy consumption data completeness, and technological innovation. Japan developed its first energy management system as early as 1960. Following the 1973 energy crisis, energy consumption attracted great attention in Western industrialized nations. After decades of development, these countries have gradually established robust, intelligent, and highly efficient digital energy management systems. China only began promoting energy management in the mid-1980s, starting with "energy balance testing" and "energy audits" to encourage energy-consuming units to install metering instruments, then progressing to eliminating high-energy-consuming equipment and conducting factory energy-saving renovations, and now witnessing the rise of digital energy management systems. Due to insufficient policy support and low enterprise awareness and popularization of energy management, development levels vary significantly across industries and regions [9].

Currently, most existing energy management systems in Chinese factories have single functions, capable only of simple energy consumption measurement and analysis based on electricity meter data. They have substantial room for improvement in real-time data flow analysis, identifying management blind spots, and recognizing energy-saving methods. Meanwhile, most enterprises' energy consumption-related data remains scattered across various production systems without integrated analysis, making it difficult to further 挖掘 the value of energy management systems. Additionally, domestic enterprises lack unified industry standards for energy waste assessment. In terms of operations management, the involvement of numerous management personnel and technical departments requires large numbers of interdisciplinary talents and sound management systems. Overall, China is currently in an initial development stage that emphasizes system infrastructure construction while neglecting operations.

Most small and medium-sized enterprises (SMEs) in China lack experience and technology for building digital energy management systems, as well as knowledge of algorithms, analysis, and operations management for these systems. Currently, China' s digital energy management systems are primarily built and promoted by internet and technology companies such as Alibaba, Huawei, and Tencent, with industrial enterprises purchasing these system solutions and implementing them internally. However, building the system is only the first step; dynamic adjustment, data analysis, identifying energy waste points, and implementing corresponding energy-saving measures during later operations are crucial. Relying solely on external companies makes it difficult to maximize the application value of digital energy management systems for production enterprises.

2 Challenges Faced by Chinese Industrial Enterprises in Deploying Digital Energy Management Systems

As an important product of smart IoT in Industry 4.0, digital energy management systems present various opportunities and challenges for energy management in China' s industrial sector. Figure 1 [Figure 1: see original paper] summarizes the challenges at three levels: government, technology, and enterprise.

2.1 Government-Level Challenges

(1) Resistance in promoting enterprise deployment of digital energy management systems. Promoting deployment is constrained by the lack of relevant laws and regulations, making it impossible to mandate installation for all enterprises. Currently, the Chinese government primarily uses incentives to encourage enterprises to install digital energy management systems. However, government promotion faces a series of challenges: How can enterprises be most effectively encouraged to deploy these systems? Which enterprises should be prioritized? What standards should enterprises follow when deploying energy management systems?

(2) Standardization issues in government regulation of digital energy management systems. For enterprises that have deployed systems, the government faces challenges in standardizing and normalizing system construction.

What energy information should enterprises be required to report? What reporting mechanisms should be established to ensure enterprise data privacy and security? Without appropriate standardization and normalization, digital energy management systems deployed by different enterprises may vary in various aspects, hindering horizontal comparison of energy consumption data between enterprises and making it difficult for the government to collect corresponding data for overall planning and management.

(3) Lack of reference value in government-published data for energy-consuming enterprises. For high-energy-consuming industries and products, the Chinese government has issued documents such as the *Action Plan for Carbon Peak Before 2030* and the *Comprehensive Work Plan for Energy Conservation and Emission Reduction During the 14th Five-Year Plan Period*, disclosing standard and benchmark values for energy consumption. However, current government-provided energy consumption standards are often vague total unit consumption values for broad product categories or industries. Even when producing similar products, different enterprises have numerous differences that result in vastly different energy consumption patterns. Moreover, the government lacks explanation for published energy consumption standards, leaving enterprises unable to understand how data is obtained, processed, and analyzed. Consequently, existing energy consumption standards provide limited substantive guidance for enterprises to identify energy waste.

2.2 Technical Challenges

(1) Hardware equipment limitations. Constrained by energy sensor hardware conditions, some energy data cannot be obtained or cannot guarantee accuracy and long-term stability. This is particularly true for non-electric energy sources such as gas and steam. If sensor ranges are incorrectly selected, energy data measurements may become distorted during periods of excessively high or low instantaneous energy consumption. Additionally, energy management systems must interact with various equipment, and factory production equipment often comes from different manufacturers using different communication protocols and interfaces, creating compatibility issues.

(2) Issues arising from massive data volumes. Factory production systems are highly complex with large output volumes. Real-time monitoring of energy consumption and data collection generates enormous data volumes, creating additional burdens for enterprises. Moreover, massive data volumes require high computing power from energy management systems; insufficient computing power leads to slow system operation, inability to conduct real-time analysis, various vulnerabilities, equipment disconnection, and mismatched data between devices. Failure to address this challenge significantly impacts the stability, real-time performance, and accuracy of energy management systems.

(3) Data security issues. Since energy data is closely related to production data, enterprises are concerned about data security to prevent competitors and other relevant parties from reverse-engineering production data from energy data, which could adversely affect core business operations. However, current digital energy management systems place insufficient emphasis on data security, risking the leakage of corporate secrets.

(4) Lack of analysis and identification capabilities for energy waste issues. For invisible energy, digital energy management systems hold tremendous practical value in helping enterprises understand their production energy consumption. However, most current energy management systems remain in early development stages, only feeding back enterprise energy consumption data without analyzing or identifying energy waste points. Professional personnel are still required to analyze energy information to identify genuine improvement opportunities, causing enterprises to question the actual value of digital energy management systems.

2.3 Enterprise-Level Challenges

The emergence of digital energy management systems also presents numerous challenges for industrial production enterprises.

(1) Insufficient enterprise awareness of the potential value of digital energy management systems. In many non-energy-intensive enterprises, energy expenditures represent a relatively small proportion of costs. Consequently, many enterprises are skeptical about the economic returns that digital energy management systems can deliver. However, recent developments indicate that enterprise energy performance will increasingly impact corporate development. First, since "black swan" events such as the Russia-Ukraine conflict and oil crises, energy prices have continuously risen, increasing enterprise energy expenditures. Although China' s energy price increases are relatively modest compared to some international regions, prices are trending upward. Second, domestic and international attention to carbon neutrality and carbon peak goals continues to intensify, and corresponding laws and regulations will inevitably become stricter. For example, the promotion of carbon trading and carbon taxes will potentially increase energy costs, making proactive energy management essential. Third, energy management—skills directly related to carbon emissions —will evolve into one of enterprises' core competencies against this backdrop. Many Western companies, such as Apple, Toyota, and Microsoft, already promote energy conservation, emission reduction, and carbon neutrality as core competitive advantages and impose carbon emission restrictions on their supply chain enterprises. Chinese enterprises should also make early arrangements in this regard to secure long-term development.

(2) Financial constraints for SMEs. The installation, operation, and management costs of digital energy management systems are relatively high, and installation may require upgrading existing production lines. Although overall costs are decreasing year by year due to China's rapid IoT industry development, the economic pressure remains substantial for Chinese enterprises, particularly numerous SMEs. Additionally, deploying digital energy management systems means enterprises must add a new focus beyond regular production activities, requiring personnel with relevant expertise. This further increases financial pressure related to human resources.

(3) Lack of awareness regarding data value and content. Similar to insufficient awareness of digital energy management system value, many enterprises that have deployed these systems lack awareness of the value of collected energy data, resulting in inadequate internal attention to data management, analysis, and communication. In some cases, large amounts of data are collected but receive no internal attention. This constraint stems from both enterprises' lack of understanding of energy data implications and the government' s insufficient guidance and regulations. Enterprises may also lack personnel with in-depth expertise in energy data, preventing them from analyzing energy consumption issues, identifying performance improvement points, and implementing optimization solutions. Furthermore, when third-party technology suppliers build digital energy management systems, their generic technical solutions may not match enterprises' actual needs, preventing enterprises from achieving genuine in-depth analysis and understanding of their energy consumption.

3 Recommendations for Deploying Digital Energy Management Systems in Chinese Industrial Enterprises

To address the challenges currently faced by Chinese industrial enterprises in deploying energy management systems, this paper proposes that digital energy management systems should closely integrate energy consumption status with production activities. Existing systems only provide descriptive analysis of enterprise production energy consumption—for example, reporting total daily energy consumption of a factory or hourly consumption curves of production equipment. However, current systems lack the ability to identify and analyze energy waste points. This paper proposes that digital energy management systems should more closely integrate energy consumption with production activities, developing the capability to distinguish between value-adding energy and non-value-adding energy. The concepts of value-adding and non-value-adding activities originate from lean production philosophy: value-adding activities directly create value for enterprise customers, while non-value-adding activities do the opposite and are considered waste. Based on this logic, value-adding energy in production is energy that directly contributes to product creation. Since the primary valuable output of production factories is the product itself, value-adding energy is that which directly facilitates product production.

Distinguishing between value-adding and non-value-adding energy is challenging. Energy consumption conditions, equipment, production processes, and specifications vary across industries, making it difficult to develop a universal method for differentiation. Leveraging the real-time energy consumption monitoring capabilities of digital energy management systems, this paper proposes conducting comparative analysis of energy consumption per unit product across multiple batches for each production step to understand optimal energy consumption, then combining these to create a step-based standardized production energy consumption label for the product. Such a label describes the optimal energy consumption for one product across all production steps, serving as a reference benchmark for each production run. This label enables enterprises to quickly locate production steps where energy waste occurs and identify waste points. For products with identical or similar production steps, this label establishes a foundation for comparative analysis between different enterprises. Enterprises with lower energy efficiency can benchmark against excellent performers' labels, identify steps with higher energy waste, and implement solutions to ultimately reduce industry-wide energy waste.

The step-based standardized production energy consumption label concept is particularly applicable to highly homogeneous industrial commodities. Such products have extremely similar production processes, and their energy consumption and greenhouse gas emissions account for significant proportions—steel and cement alone represent 26% of national greenhouse gas emissions [10]. Taking the cement industry as an example, factories using new dry-process cement production all follow the same process: crushing and pre-homogenization; raw meal homogenization; clinker burning; rapid clinker cooling; and cement grinding [11]. If optimal enterprises' minimum unit energy consumption can be identified for each production step and combined, a step-based standardized production energy consumption label for new dry-process cement production can be created, representing the currently achievable optimal level in this industry.

3.1 Methodology for Energy Consumption Data Analysis in Energy Management Systems

The methodology for analyzing energy data after building an energy management system is as follows: Energy data should be analyzed by product, by batch, and by production step to ultimately determine the minimum energy consumption value per unit product at each production step. Based on the product' s production process, these values compose the product' s step-based standardized production energy consumption label.

As previously mentioned, existing digital energy management systems can only provide descriptive analysis. The proposed methodology involves real-time measurement and analysis of optimal energy consumption per unit product at each production step, creating product production energy consumption labels and promoting the establishment of industry-standardized and popularized labels. This creates a unified energy consumption information "language" between different enterprises, providing production personnel with valuable energy usage information to help identify energy waste more quickly. Figure 2 [Figure 2: see original paper] illustrates the basic concept of the step-based standardized production energy consumption label and the relationships among various stakeholders in digital energy management systems.

3.2 General Recommendations for Deploying Digital Energy Management Systems in Chinese Industrial Enterprises

(1) Continuously promote the construction of digital energy management systems in enterprises. Chinese governments at all levels have already initiated efforts to encourage enterprise deployment, but this remains a challenging task. Governments should continue to improve incentive mechanisms, such as providing tax incentives, subsidies, or priority project approvals for enterprises adopting digital energy management systems. Based on enterprises' energy consumption levels, deployment should be progressively promoted among "hundreds, thousands, and ten-thousands" enterprises. A complete monitoring and evaluation mechanism should be established, and relevant laws and regulations continuously improved. Cross-departmental collaborative supervision mechanisms should be created to ensure effective promotion and application of digital energy management systems.

(2) Continuously support cooperative development among stakeholders. To strengthen the role of digital energy management systems in reducing energy waste across the industrial sector, continuous support for cooperative development among system stakeholders is essential (Figure 2 [Figure 2: see original paper]), particularly between energy-consuming enterprises and digital energy management system technology providers. Technology providers should engage in deep communication with users to make systems more targeted in assisting enterprises. Certification bodies should strengthen communication with energy-consuming enterprises and technology providers, collaborating with governments to promote standardization and unification of digital energy management systems in industry. Other stakeholders should also be supported in participating in industrial digital energy management system development, such as promoting industry-academia-research collaboration to enhance system technology and management through academic knowledge. Additionally, academia should focus on cultivating interdisciplinary talents with backgrounds in both energy management and digital technology to support digital energy management system development.

(3) Gradually establish energy consumption benchmarks by product and production step. To implement the methodology described in Section 3.1, enterprises must analyze their minimum energy consumption at each production step to obtain step-based standardized production energy consumption labels. This methodology should be promoted across entire industries. For products with identical or similar production steps, multiple enterprises' optimal unit energy consumption at each step should be analyzed and combined to create industry-wide step-based standardized production energy consumption labels as benchmarks. These benchmarks should be promoted to all enterprises in the industry to help identify energy waste.

(4) Actively guide enterprises to benchmark industry best practices. Objectively, enterprises differ in knowledge and experience regarding energy management system deployment. To promote progress in eliminating energy waste across industry, the government should identify and screen enterprises with best practices in energy management system deployment. Industry benchmarks should be established, and experiences from best-practice enterprises summarized in documents to guide other enterprises. Additionally, after establishing unit production energy consumption benchmarks for specific products or product categories, these should be promoted throughout the industry. During this process, data sources for production energy consumption benchmarks must be explained to help enterprises understand the specific circumstances of optimal practices.

4 Conclusion

The "dual-carbon" goals demonstrate China' s responsibility as a major international player in addressing global environmental challenges while recognizing carbon emissions as a critical factor affecting future global economic and social development. China is actively advancing concepts, strategies, and technological development for carbon emission reduction to lead the world toward a cleaner environment.

Digital energy management systems can help discover and identify energy waste-related issues, monitor and optimize energy use, and reduce carbon emissions. Globally, many leading enterprises have successfully applied digital energy management systems, significantly improving energy efficiency and reducing carbon emissions. Therefore, China should vigorously promote their application in industry through policy support, industry collaboration, technological innovation, and customized solutions to form advanced green industrial clusters with low energy waste.

Global carbon emissions concern human survival and development. Promoting the deployment of digital energy management systems in industry is an effective means of building a carbon-neutral and green Earth. To enable humanity to live sustainably on this beautiful planet, we must build greener and cleaner industrial systems. Achieving this vital cause, which concerns everyone, requires continuous efforts from all parties to realize the long-term dream of maintaining a green Earth.

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Note: Figure translations are in progress. See original paper for figures.