Design and Application of Smart Energy Management Platform for Industrial Parks

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บทคัดย่อ ขณะที่เศรษฐกิจและสังคมโลกยังคงพัฒนาต่อไป แรงกดดันด้านสิ่งแวดล้อมก็ทวีความรุนแรงขึ้น ความจำเป็นในการอนุรักษ์พลังงานและการลดการปล่อยก๊าซเรือนกระจกจึงมีความเร่งด่วนมากขึ้น เพื่อตอบสนองต่อความท้าทายเหล่านี้ บทความวิจัยนี้เสนอแพลตฟอร์มการจัดการพลังงานอัจฉริยะที่ออกแบบมาโดยเฉพาะสำหรับสวนอุตสาหกรรมด้วยการใช้เทคโนโลยี Internet of Things (IoT) ขั้นสูงและเครือข่ายเซ็นเซอร์ในตัว แพลตฟอร์มนี้สามารถตรวจสอบอุปกรณ์พลังงานได้แบบเรียลไทม์ การประมวลผลแบบคลาวด์มีหน้าที่จัดเก็บ วิเคราะห์และประมวลผลข้อมูลขนาดใหญ่ การนำเสนอโซลูชันที่ครอบคลุมสำหรับการจัดการพลังงาน แพลตฟอร์มนี้ยังอำนวยความสะดวกในการพัฒนาเพื่อการประสานงานการจัดการพลังงาน ทำให้เกิดการเชื่อมโยงระหว่างทรัพยากรไฟฟ้า ก๊าซ และน้ำ เครือข่ายอัจฉริยะเชิงโต้ตอบถูกสร้างขึ้นเพื่ออำนวยความสะดวกในการใช้งานและบำรุงรักษาอัจฉริยะแบบออนไลน์ รวมถึงบริการแบ่งปันอัจฉริยะที่ใช้งานง่าย ผลลัพธ์เชิงปฏิบัติแสดงให้เห็นว่าระบบการจัดการพลังงานอัจฉริยะแบบบูรณาการนี้ช่วยเพิ่มระดับข้อมูลภายในองค์กรได้อย่างมาก ไม่เพียงแต่ปรับปรุงประสิทธิภาพการใช้พลังงานอย่างมีนัยสำคัญและลดต้นทุน แต่แพลตฟอร์มนี้ยังเพิ่มความสามารถในการสร้างกำไรขององค์กรอีกด้วย ด้วยการจัดการและควบคุมการใช้พลังงานในนิคมอุตสาหกรรมอย่างมีประสิทธิภาพ ระบบจะลดการสิ้นเปลืองทรัพยากรให้เหลือน้อยที่สุด ช่วยให้บรรลุเป้าหมายในการอนุรักษ์พลังงานและลดการปล่อยก๊าซเรือนกระจก

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Abstract: As the global economy and society continue to develop, environmental pressures are intensifying, making the need for energy conservation and emissions reduction increasingly urgent. In response to these challenges, a smart energy management platform specifically designed for industrial parks is proposed. By utilizing advanced Internet of Things (IoT) technology and integrated sensor networks, the platform achieves real-time monitoring of energy devices. Cloud computing is responsible for storing, analyzing, and processing big data, offering a comprehensive solution for energy management. This platform also facilitates the coordinated development of energy management, enabling the interconnection of electricity, gas, and water resources. The interactive smart network has been constructed to facilitate online intelligent operation and maintenance, as well as user-friendly smart sharing services. Practical results demonstrate that this integrated intelligent energy management system significantly enhances the level of information within the enterprise. It not only significantly improves energy efficiency and reduces costs but also enhances the profitability of enterprises. By effectively managing and controlling energy consumption in industrial parks, the system minimizes resource waste, thereby achieving the goal of conserving energy and reducing emissions.

Keywords: Smart Energy Management Platform, Internet of Things (IoT) technology, Energy Monitoring, Cloud Computing, Energy Conservation and Emission Reduction

1. Introduction

Energy is the basis of human survival and development. Moreover, energy technology change and innovation are related to social progress and development [1-2]. The sharp increase in energy demand for social development has led to the overuse of energy, which has led to a series of environmental pollution and energy problems, thus highlighting the urgent need to strengthen energy conservation and emission reduction measures. As a significant contributor to energy consumption and carbon emissions, industrial parks are implementing sustainable management strategies [3-4]. An enterprise energy management system should not only meet the current energy management needs of the enterprise, but also significantly reduce the costs associated with data collection, maintenance, and analysis. However, existing management platforms suffer from a number of problems, including sloppy and unrefined management, inaccurate carbon accounting and evaluation, and poor multi-energy utilization [5-6], which is the main goal of the proposed smart energy management system. The collaboration helps in aggregating data dispersed in different locations. Real-time energy consumption monitoring is the basis of the system, which is realized through enhanced measurements of major energy-consuming equipment and key production stages [7]. The measurement system enables accurate and up-to-date monitoring of energy consumption patterns. In addition, previous research efforts have focused on individual distribution systems, often neglecting the synergistic management of multiple energy sources such as natural gas and water resources [8]. Utilizing IoT capabilities, the system can collect real-time data on various energy sources in the industrial park, including electricity, water, and natural gas. This data integration is essential for comprehensive analysis and informed decision making [9].

Upon addressing the limitations of previous studies, the proposed system provides real-time energy consumption monitoring, dynamic optimization management, energy efficiency policy integration, and reliable digital evidence of safe production [10]. This paper presents a smart energy management system for industrial parks that aims to improve energy efficiency, reduce costs, and promote sustainable development practices. It promotes the long-term sustainable development of industrial parks through comprehensive data analysis and informed decision making.

2. Tools and Methods

2.1 Research tools

In this study, a range of specialized research tools were used to meticulously collect and measure key data.

A data logger [11] was used to collect data from various energy measurement devices such as electricity meters, power monitors and water meters. Its powerful features, including an Intel Atom CPU, a network interface with electromagnetic isolation, and flexible data collection modes, ensure its versatility. The data logger also excelled in system troubleshooting and diagnostics, supported by a range of interfaces including USB and serial ports, storage media and power management features. The accompanying management software further enhanced its usefulness, providing a total solution for data collection and analysis.

The Siemens Smart Controller (as shown in Figure 1) had integrated input/output points that could be expanded with signaling boards and communication modules [12]. Its features included digital inputs and outputs, analog inputs, pulse outputs, and high-speed counters that provided sophisticated control interfaces. Additional communication interfaces allowed direct expansion using analog or digital signals. At the same time, optional extensions, including storage, PID controllers, and real-time clocks, enhanced its adaptability to a wide range of requirements.

Fig. 1 Siemens Intelligent Controller.

Online instruments, including low-range turbidimeters (as shown in Fig.2), dissolved oxygen meters, and pH meters, contributed significantly to real-time monitoring and analysis.

Turbidimeters [13] with dot-matrix LCD displays had a wide measurement range and operated at temperatures up to 45°C, providing accurate measurements with resolutions down to 0.001 NTU. The Dissolved Oxygen Meter (as shown in Fig.3) had a large LCD display that could display multiple parameters simultaneously and could operate with high accuracy and stability over a temperature range of 0 to 60°C.

Fig. 2 Online Low-Range Turbidity Instrument.

Fig. 3 Online Dissolved Oxygen Meter.

The pH meter had a large LCD display that could display multiple parameters at the same time. Meanwhile, the pH meter (as show in Fig.4) featured a large dot-matrix display for long-term stability and supported both pH and ORP measurements.

Together, these tools formed a powerful framework for comprehensive monitoring and management of the various parameters within the system. Combining accuracy, stability and flexibility, they provided an advanced and reliable infrastructure for the data collection and measurement processes that were critical to achieving project goals.

Fig. 4 Online PH Meter.

2.2 Data collection

The system utilized three main monitoring subsystems to collect and monitor resource data [14]: electricity, water and natural gas. The hierarchical structure of the monitoring system was shown in Fig5.

2.2.1 Electricity monitoring subsystem

According to the Technical Guidelines for Building Energy Efficiency Supervision System and other technical guidelines, the lighting, power, and special power supplies of the park were divided into three levels for detailed measurement and statistical analysis of energy consumption. Detailed information and statistical analysis data were based on electric energy data. Specific detailed information about electricity meters included meter number, meter class, meter code, meter name, meter location, installation time, meter gateway, communication time, and actual power consumption.

2.2.2 Water consumption monitoring subsystem

According to the actual situation of the park buildings, the real-time monitoring included total water consumption and segmented water consumption. Usually, the municipal water supply department installed a total water meter at the main inlet of the park. Segmental water meters were also installed in different areas, functions and buildings. By collecting real-time data from these meters, the overall water usage of the park could be monitored in real-time. This approach was effective in detecting pipeline leaks and supports the implementation of energy conservation strategies throughout the campus.

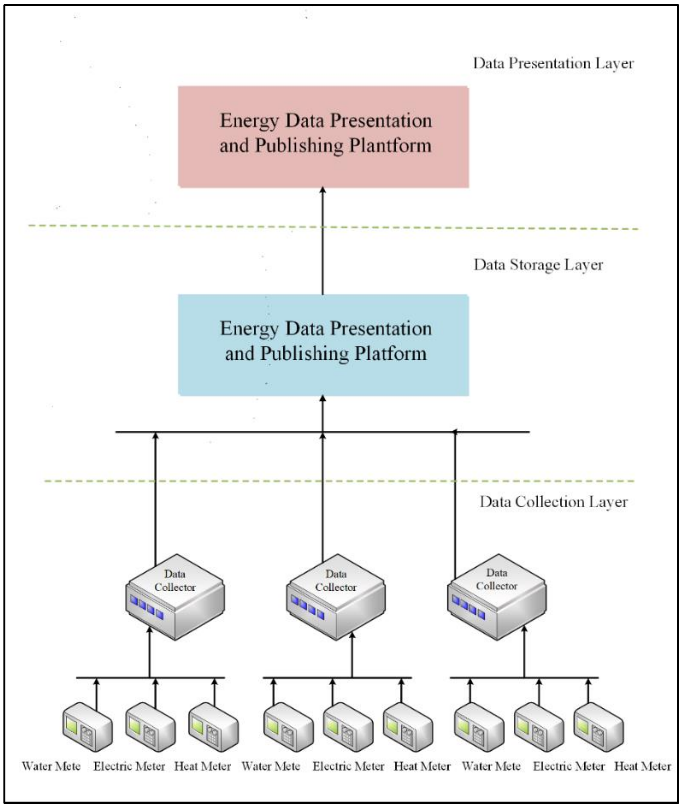

Fig. 5. Surveillance System Layered Structure.

2.2.3 Natural Gas Monitoring Subsystem

The core of the natural gas monitoring sub-system was a dedicated natural gas meter installed at the main natural gas inlet, which provided real-time information on the overall natural gas usage of the entire industrial park. Segmented meters were also installed in different zones, functional areas and individual buildings to improve accuracy. These meters continuously collected real-time data to provide a dynamic view of natural gas.

2.3 Data preparation and analysis

Data preparation and analysis were carried out by using a three-tier architecture energy regulatory platform.

2.3.1 Data Layer

An integrated end-to-end data solution provided by SQL Server provided a secure, reliable, efficient and feature-rich platform for various stakeholders within the organization. It was used to process data within the industrial park and support business intelligence applications. The database management system improved operational efficiency by providing powerful and familiar tools for field operators and building managers while reducing the complexity of creating, deploying, managing, and using data and analytics applications across multiple platforms. The architecture of SQL Server was shown in Fig.6.

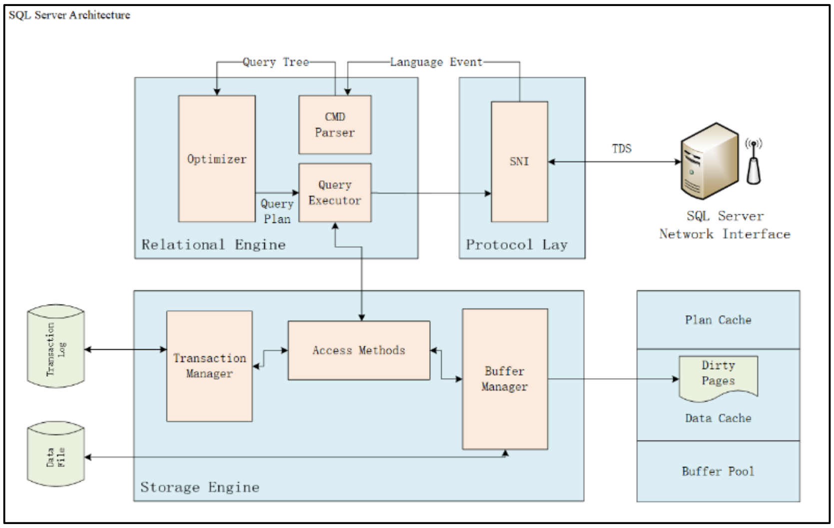

Fig. 6 SQL Server Architecture.

2.3.2 WEB Layer

The platform would leverage the Microsoft Visual Studio .NET and Microsoft .NET 4.0 frameworks, as well as the cutting-edge applications provided by Microsoft .NET, to provide developers with a suite of development tools that could be used to quickly and easily create state-of-the-art applications while providing applications with offer greater reliability. The ability to develop systems faster by using public language runtime libraries (part of the .NET Framework) dramatically increased the number of resources available to developers. NET services and other .NET building block services provide many of the core functions required by applications, such as user authentication, notification functions, contact lists, and more, without additional coding effort. Therefore, such a platform provided greater reliability for program development with rich processing power and currently available bandwidth. NET framework enforced type safety, explicit code sharing, and application isolation.

Highly Integrated Performance: NET also had database access capabilities that allowed developers to introduce ODBC-compliant data stores into their application architecture. By allowing other departments to utilize their legacy applications and data stores, as well as providing specialized data, departments were able to reduce internal consumption and expand the functionality of the information available to multiple levels of managers.

2.3.3 Seamless Integration of Data and Network Tiers

SQL Server and Microsoft Visual Studio formed an integrated development and database platform (as shown in Fig. 7) that had been fully validated by numerous benchmark tests. Of particular note was the strong support provided by the .NET framework, which gave the platform excellent performance characteristics. This combination not only met the requirements of critical applications in industrial parks but also highlighted the outstanding computing power of SQL Server in benchmarks on the new generation of 64-bit processors.

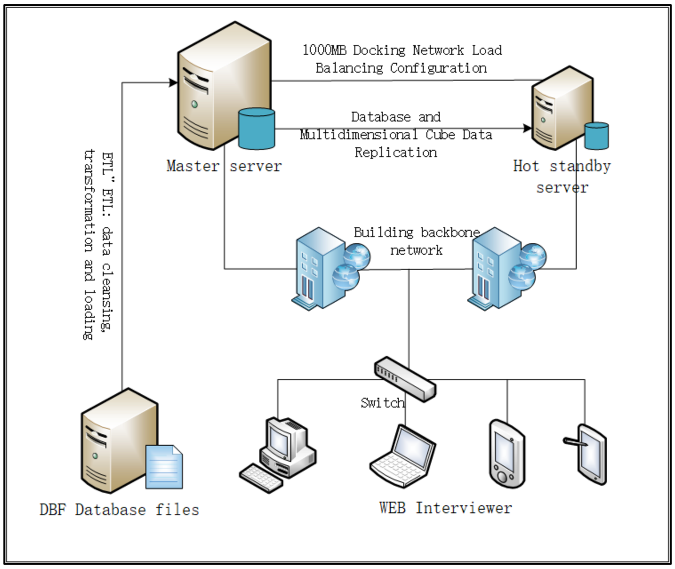

Fig. 7 Data and Web Integration Diagram.

3. Results and Discussion

3.1 Research findings

The results of the study showed that the Intelligent Energy Management System (IEMS) [15] was a pioneering and transformative approach to smart energy systems in industrial parks, providing comprehensive support to governmental agencies, the public, and industrial enterprises. As an intelligent assistant at the governmental level, IEMS provided a scientific basis for decision-making through real-time data and analytics, and facilitated the development of rational and sustainable energy policies. At the public level, IEMS was a guide for energy conservation, disseminating information, providing intelligent suggestions, encouraging the public to actively participate in energy conservation actions, and guiding society towards sustainable development. At the enterprise level, IEMS acted as an energy therapist, conducting comprehensive energy diagnosis and proposing solutions to improve efficiency. At the same time, the platform integrated enterprise control systems, production monitoring and energy management functions, providing a centralized solution for real-time monitoring, reporting and control. This seamless integration formed a powerful energy management system that not only met current operational needs but also laid the foundation for strategic decision-making, cost reduction, and environmentally sustainable practices, making the platform a key enabler for efficient, environmentally friendly energy management across different organizational structures and deployment scenarios.

3.2 Quantitative and qualitative analysis

3.2.1 Energy consumption structure report

Users could flexibly customize the report content, format, generation cycle and export/send rules according to management needs. The report included data on regional energy consumption, equipment energy consumption and energy-consuming organizations (as shown in Table 1). This feature provided powerful data support for management decisions and facilitated energy audits.

Table. 1 Energy consumption statement for 2022

Months	Electrical power (10,000)	Natural gas (10,000 m^3)	Water (10,000 tons)	Equivalent standard coal (tce)
1	497.10	31.00	16.22	1001.27
2	298.41	17.40	14.69	590.62
3	493.86	130.85	16.31	2209.84
4	529.03	64.22	17.11	1444.66
5	648.26	67.10	16.19	1625.38
6	563.95	68.65	17.01	1541.29
7	744.18	66.97	15.21	1740.85
8	631.51	60.69	14.75	1525.73
9	410.06	45.61	15.77	1071.32
10	308.02	44.98	15.88	938.36
11	132.98	43.95	12.09	707.48
12	43.64	40.27	14.45	555.02
Total	5301.00	681.69	185.68	14951.82

3.2.2 Electricity management

The system's electricity consumption management relied heavily on the development of an advanced real-time data gathering and monitoring system, which was specifically developed to extract vital information from the operating data of the enterprise's electricity equipment. Its primary goal was to provide the monitoring center with a comprehensive overview of the power condition, encompassing load distribution, total power usage, and other data, while simultaneously managing power-consuming gadgets around the enterprise. The interface enabled the continuous, real-time capture of operational data, resulting in a dynamic snapshot of the power condition. The monitoring center was able to collect and successfully analyze complex power metrics by employing data analytics and visualization capabilities. Table 2 showed the year-over-year monthly electricity use.

3.2.3 Water use management

Important information was extracted from the operational data of water-using equipment within the enterprise, aiming to provide a comprehensive understanding of the status of water resources. The platform's water monitoring system included the flow status of the distribution network, leakage detection, and total water consumption, thus ensuring seamless integration of real-time data collection. Using data analytics tools, the monitoring center could track water use patterns and interpret complex metrics to make informed decisions for optimizing water use and improving operational efficiency [17]. The ability to respond to water fluctuations in a timely manner enabled a balance to be struck between operational needs and sustainable resource utilization, thereby facilitating targeted water management and reducing environmental impact.

Table. 2 Year-over-year monthly electricity use

Months	Electricity consumption (10,000 kwh)	Year-over-year decline
1	497.10	32.40%
2	298.41	29.50%
3	493.86	35.20%
4	529.03	21.60%
5	648.26	30.15%
6	563.95	22.26%
7	744.18	31.70%
8	631.51	28.35%
9	410.06	17.16%
10	308.02	26.32%
11	132.98	24.37%
12	43.64	26.73%

The water use structure of industrial parks could be categorized into the following four main types (daily water use by structure was shown in Fig. 8).

(1) Cooling Water: Cooling processes required large quantities of water to lower the temperature of equipment and furnaces. The water used for cooling equipment, cooling towers and cooling circulation systems was included.

(2) Process water: Water was required at all stages of the production process, including raw material processing, smelting, steelmaking and rolling. Examples include pickling, alkaline washing, cold rolling and hot rolling.

(3) Cleaning water consumption: In industrial parks, water was needed to clean equipment, pipelines and product surfaces during the production process to ensure product quality and normal operation of the equipment. Cleaning water included equipment cleaning water, product cleaning water and equipment maintenance water.

(4) Water for domestic use: Industrial parks had to provide water for the daily life of employees, including water for toilets, drinking water and bathing. Although a small percentage of total water use, it was still an important category of water use.

3.2.4 Natural gas consumption management

The Natural Gas Management System was designed to provide comprehensive monitoring and intelligent supervision of natural gas usage. The following were the main functions and modules that this study offers:

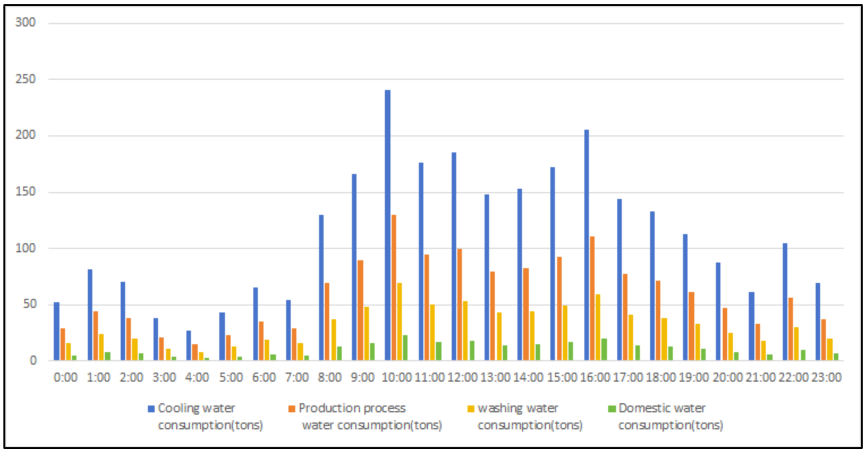

Fig. 8 Substructure Daily Water Use.

(1) Real-time parameter monitoring: Using real-time monitoring, historical data logging, and intelligent analysis, the gas management solution helped users manage and optimize gas usage more effectively, ensuring a safe and efficient system. It included the operating status of natural gas equipment (valve position, pressure, etc.), real-time monitoring of natural gas flow to ensure that the system operates within safe and efficient limits and provided real-time data on current natural gas consumption.

The real-time parameter monitoring of the natural gas equipment, including the daily monitoring data of operation status, valve position, and pressure, was shown in Table 3.

(2) Historical data recording: The system recorded historical data on various parameters of natural gas equipment as a basis for performance evaluation and troubleshooting. Historical data was utilized to analyze trends and fluctuations in natural gas usage.

A system for trend analysis using moving averages had been implemented for natural gas usage. For example, assume a 3-month moving average was used:

Table. 3 Daily Natural Gas Monitoring Data.

Time	Operational status	Valve status	Pressure value (kPa)
08:00:00	Running	Open	345.7
09:00:00	Running	Half-open	334.8
10:00:00	Running	Open	359.2
11:00:00	Stopped	Closed	314.6
12:00:00	Running	Half-open	325.4
13:00:00	Running	Open	354.1
14:00:00	Stopped	Closed	301.2
15:00:00	Running	Half-open	333.5
16:00:00	Running	Open	362.8
17:00:00	Stopped	Closed	310.7

A moving average was calculated for each month: A moving average was calculated by taking the average of the data over a certain period and using that average as a proxy for that period. Assume a 2-month period was selected (the first month's usage was counted as a_0):

$$\text{Moving Average} = \frac{\sum_{k=0}^{1} a_k}{2} \quad \dots (1)$$

For the first month, no moving average was calculated, as no data were available for the first three months. The raw data and the calculated moving averages were plotted as a trend chart (as shown in Fig.9). The chart showed an increasing, decreasing, or steady trend.

3.2.5 Implementation effects

(1) Economic benefits

The implementation of the energy Internet project in industrial parks promoted the synergistic development of electronic information, energy conservation and environmental protection industries and industrial Internet. With the energy internet cloud platform as the core, the Internet was deeply integrated with energy production, transmission, and consumption to comprehensively manage various energy forms. This integration ensured that the multi-energy flow system operated efficiently and safely, improving economic benefits, operational efficiency and competitiveness.

The construction of the energy internet platform was expected to improve energy utilization efficiency by about 10% and save a large amount of energy costs of about RMB 9.93 million per year for the industrial park. Through the platform, the expected profit of related industrial projects was expected to be between 15% and 20%, and by 2025, the annual revenue output would be about RMB 100 million. It was shown that the demonstration and promotion of this study were expected to accelerate the investment and construction of smart energy projects and promote the rapid and steady development of the industrial chain, thereby promoting the synergistic growth of related industries. Details of energy cost expenditure of energy-using units in the past three years were shown in Fig.10.

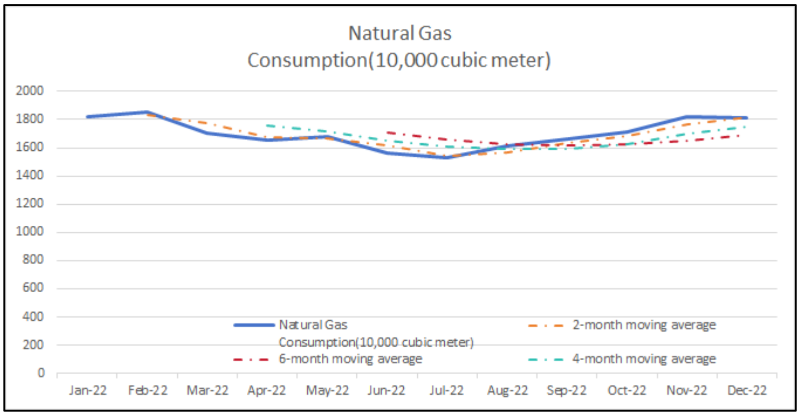

Fig. 9 The Monthly Usage of Natural Gas.

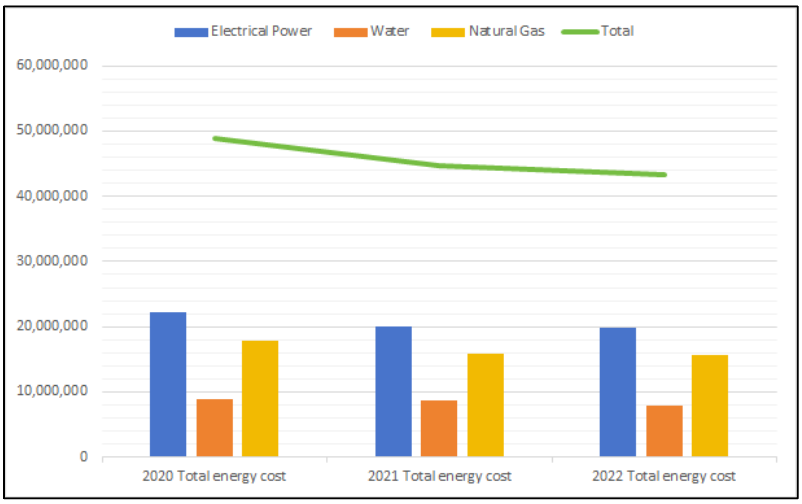

Fig. 10 Total Energy Cost (RMB).

(2) Social benefits

Through the construction of this project, it aimed to realize accurate monitoring and intelligent control of energy consumption and carbon emission activities. The goal is to reduce the intensity of energy consumption per unit of GDP and the total amount of carbon dioxide emissions in the whole zone. Integrate innovative energy-saving and low-carbon system overall solutions, and deeply explore the energy-saving and emission reduction potential of the development zone. It was important to adjust and optimize the energy supply and consumption structure of the development zone, increase the proportion of clean and renewable energy consumption, and ultimately improve the overall energy utilization efficiency of the entire region.

In the "Citizen's Energy Saving and Emission Reduction Handbook" of the Ministry of Science and Technology [18], the energy consumption of saving 1 kWh of electricity was explained as follows: Every 1 kWh of electricity saved was equivalent to saving 0.4 kg of standard coal and 4 liters of clean water. At the same time, it could reduce pollutants such as 0.272 kg of carbon dust, 0.997 kg of carbon dioxide, 0.03 kg of sulfur dioxide and 0.015 kg of nitrogen oxides. By 2022, the park could save 11,132,100 kWh of electricity through project construction and operation. It was equivalent to saving 0.14 million tons of coal equivalent, reducing 0.03 million tons of carbon dust emission, 11,000 tons of carbon dioxide emission, 0.033 million tons of sulfur dioxide emission, and 0.017 million tons of nitrogen oxides emission in the planning area that mainly relied on thermal power generation. Calculated by the domestic carbon emissions trading price of 67.738 RMB per ton, the reduction of carbon dioxide emissions could bring the equivalent of 220,000 RMB profit for the enterprise.

4. Conclusions

The implementation of the platform has enabled energy managers to make informed decisions, set efficiency targets and foster a culture of energy conservation in industrial parks. The deployment of smart energy management platforms in industrial parks has yielded significant results. Real-time monitoring enables energy managers to make informed decisions, identify areas for optimization and implement proactive measures. Setting efficiency targets, establishing consumption standards, conducting regular audits, and actively managing and controlling energy use. The platform also helps to disseminate information on energy efficiency and promote services that encourage a culture of sustainability in industrial parks. These findings highlight the potential of smart energy management platforms in achieving sustainable development goals. By improving energy efficiency and reducing costs, such platforms can contribute not only to individual industrial parks but also to broader energy efficiency and environmental protection goals. The experience gained from this study provides valuable resources for future research and implementation in different industrial settings, advancing the field of energy management and facilitating the transition to a more sustainable future.

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