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The role of energy management system in the energy security of an enterprise

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ABSTRACT

Energy is a critical element for any enterprise, regardless of its industry or size. Modern energy management system (EMS) is not only a challenge but also an opportunity to improve efficiency and energy security. This article discusses the role of EMS systems in enhancing energy security, using three industrial plants as examples. The analysis focuses on identifying key factors affecting energy security, such as the availability of energy sources, diversification of supply, energy costs and efficiency, and the impact of energy policy. Using a simplified multi-criteria decision analysis (MCDA) method, the authors evaluate the impact of implementing EMS systems on improving the energy security of enterprises.

Keywords: energy security, energy management system, energy efficiency.

INTRODUCTION

The need for safety is among the most fundamental of human necessities. In 1943, Abraham Maslow introduced this concept through his "Hierarchy of Needs", famously depicted as a pyramid. This framework originally featured five levels, each representing a distinct category of human motivation. At the pyramid's base are the most universal needs, directly tied to physical survival-such as breathable air, potable water, nourishing food, and adequate clothing for protection against the cold.

The second tier centers on security, broadly defined as the need for protection from threats to one's existence. Only after fulfilling the foundational needs of survival and safety does an individual turn their focus to higher-order aspirations: seeking love, building a sense of social belonging, gaining recognition in the eyes of others, and self-realisation, expressed by setting and achieving personal goals (Davtyan, 2017).

As Maslow highlighted in his "Theory of Human Motivation", the need for security ranks among the most crucial drivers of human behavior, immediately following the necessities of breathing and eating. This deep, intrinsic need for security underscores why the concept resonates so naturally and why security-related expectations are often projected onto entities that are anthropomorphized. Among such entities, companies stand out, as they are frequently described using language typically reserved for living organisms (Orkisz, 2018).

A striking example is the way entrepreneurs often speak about their businesses. Founders frequently refer to their companies as "children," deeply intertwined with their personal narratives. The birth of a company is likened to the arrival of a new life, while its collapse is mourned with phrases such as "the nail in the coffin". This metaphorical framing underscores how the pursuit of security, whether financial, operational, or energy-related, is not only economically logical for companies but also instinctively rooted in the human psyche.

EVOLUTION OF ENERGY SECURITY

Energy security has been a fundamental concern since the earliest use of fire within primitive social structures. From the very beginning, humans have recognized that a lack of access to energy (fuel such as wood for lighting fires) results in cold and hunger, threatening survival (Azzuni, 2020).

As humanity's methods of harnessing energy have evolved, from firewood to gunpowder, steam engines, electricity, and nuclear fission, the importance of energy security has only intensified. Its absence, often manifesting as the depletion of a vital energy resource, has historically spelled existential crises. This scarcity frequently led to catastrophic outcomes, particularly in conflicts with rival tribes, kingdoms, or states where energy access became a decisive factor in survival and dominance. Energy security, therefore, is not merely a modern economic or geopolitical concern but a deeply rooted necessity for human advancement and continuity.

The industrial revolution marked a significant shift in competition, elevating it to the realm of mass production. Success was measured by the ability to produce more goods at lower costs for an expanding market. This era saw the emergence of international trade and the rise of the mass consumer – *homo consumptoris* (Latin for "consumer man") for whom the concept of energy security took on a new meaning (Davtyan, 2017). No longer was energy merely about lighting a fire to ward off predators or cook food; it became synonymous with the uninterrupted flow of production.

Energy became the lifeblood of industrial activity, underpinning every stage of manufacturing. Its use is so integral to production processes, particularly in modern contexts, that it almost feels redundant to mention. Anyone who has stepped into a factory or production facility can immediately sense that none of what they observe (machines running, goods being assembled etc.) would be possible without a reliable energy supply in specific forms.

The sheer scale of industrial energy consumption underscores its critical role. According to the International Energy Agency (IEA), manufacturing processes account for approximately one-third of global energy use and contribute an equal share of global carbon dioxide emissions (Singh et al., 2024). In Poland, as an example, electricity and heat utilized by industry represent about 33% of the nation's total energy consumption (Piekarski & Grübel, 2024). This highlights not only the indispensability of energy in production but also the significant environmental and economic implications tied to its use.

Over time, new "players" have joined the global competition for energy, adding significant pressure to already strained resources. The global Internet network, for example, consumed approximately 6% of the world's electricity by 2020 (Kopein et al., 2020). More recently, artificial intelligence (AI) and cryptocurrency mining have significantly increased energy demands, raising serious environmental concerns. In 2024, AI-related activities consumed about 8 terawatt-hours (TWh) of electricity, with projections surging to 652 TWh by 2030 (Beth Kindig, 2024; Reklaitis, 2024). Similarly, Bitcoin mining alone required approximately 143 TWh annually, exceeding the electricity consumption of entire nations such as Argentina – 121 TWh and the Netherlands – 109 TWh (Criddle, 2021).

This surge in energy demand is amplifying the divide between energy-rich and energy-poor nations. Countries without substantial fossil fuel reserves face mounting difficulties in meeting the rapidly growing energy needs of modern technologies. As these disparities deepen, nations struggling with energy poverty may find it increasingly challenging to sustain technological and economic progress, further entrenching global inequality.

MAIN FACTORS INFLUENCING THE ENERGY SECURITY OF ENTERPRISES

In the available literature, several factors are highlighted as critical for ensuring companies' energy security:

- Availability of energy sources in a given location – the geographical location of a company significantly influences its access to various energy sources, impacting the stability and reliability of energy supplies (Azzuni, 2020). Proximity to robust energy infrastructure or local resources can enhance energy security (Masłoń et al., 2024; Żelazna et al., 2019).
- Diversification of energy and fuel sources – is a key strategy for minimizing risks associated with supply disruptions and price volatility in raw materials (Azzuni, 2020; Gola, 2023; Sulimin et al., 2021).

- Energy costs and compatibility – the selection of energy sources should align with both the cost considerations and the compatibility of those sources with the company's existing technologies (Azzuni, 2020; Gola, 2023).
- High efficiency of energy use – optimizing energy consumption through efficiency improvements and recovering energy from production processes contributes to increasing energy security (Azzuni, 2020; Drewnowski et al., 2019; Masłoń et al., 2022; Sulimin et al., 2021).
- Regulators of energy policy – decisions made by energy policy regulators, such as the state, significantly influence the availability and price of energy. These decisions directly impact businesses by affecting energy accessibility, affordability, and the stability of supplies (Gola, 2023).

A violation of an industrial plant's energy security manifests in several forms of losses, including disruptions to production, damage to materials in process, and potential harm to machinery and equipment due to energy supply interruptions (Przygrodzki & Siekierski, 2017). Such disruptions lead to significant costs, such as those associated with restarting production processes, lost revenue from products that fail to reach the market, and potential reductions in the quality of delivered goods.

These scenarios can also trigger a cascade of further challenges, including customer complaints, financial penalties, and, most critically, the risk of damaging the company's brand reputation. The erosion of trust in a company's reliability can have long-term implications, making energy security not just an operational priority but a cornerstone of maintaining competitive advantage.

THE ROLE OF EMS IN THE ENERGY SECURITY OF A FACILITY

Energy efficiency is the cheapest way to enhance energy security, as reducing energy consumption decreases dependence on external suppliers and protects against sudden price increases (Eurostat, 2021). In a manufacturing plant, the basic step to achieving these benefits is the implementation of an energy management system (EMS). In its simplest form, this involves installing sensors at key points, particularly in production areas and HVAC systems, that monitor energy consumption. The system collects and analyzes this data (Hargesheimer, 2023), helping to identify areas for optimization. This leads to cost reductions and improvements in the energy efficiency of the company. The main tasks of an energy management system in a company are presented in Figure 1.

Monitoring and controlling energy consumption in EMS systems primarily involves filling in the often-incomplete picture of energy use within a given facility. This is crucial both in a broad sense, understanding the plant's total energy

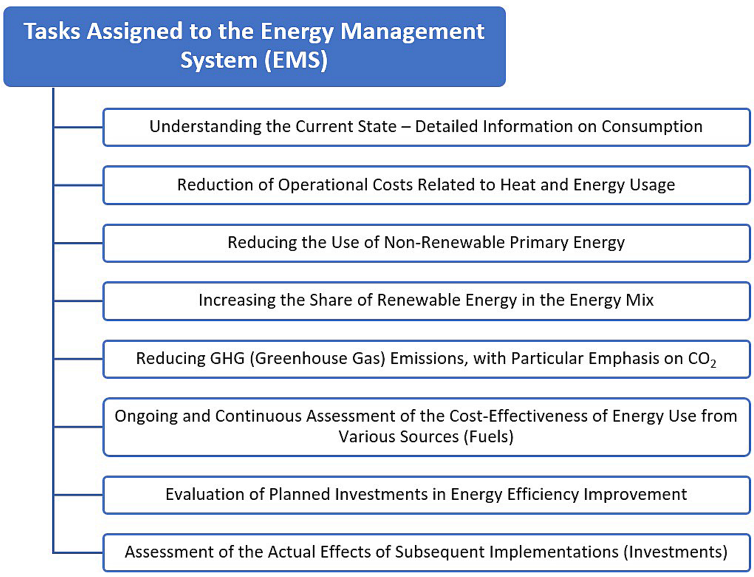

Figure 1. The main tasks of an energy management system in a company

consumption, and in a more detailed context, such as determining the energy usage of specific parts of the facility or individual processes (e.g., production lines). It can even extend to the granular level of analyzing how much energy is consumed by a single machine. This type of comprehensive insight enables more precise optimization and efficient energy management.

METHODOLOGY

For this study, three manufacturing plants from the automotive industry were selected, each possessing key characteristics that enable a comparative analysis. These companies share the following:

- Similar location – all three companies operate production facilities in the southern part of the Silesian Voivodeship, near the city of Bielsko-Biała. This area has been a significant hub for automotive manufacturing since the 1970s, driven primarily by the establishment of Fiat factories (Frigant & Miollan, 2014). After the economic transformation, the decline of traditional industries in Silesia, such as coal mining and metallurgy, was counterbalanced by the rise of new manufacturing sectors, particularly the automotive industry (Domański, 2015). This phenomenon, combined with the dynamic growth of the Bielsko District, has created favorable conditions for automotive enterprises. However, this location also poses challenges related to the proximity of other companies in the sector and competition for skilled labor.
- Facilities of similar size – the selected plants operate on a comparable scale, enabling a meaningful analysis of their performance under similar operational and financial conditions.
- Operates in the automotive industry – each company operates within a similar market segment, enabling an analysis of their strategies under comparable industry standards, requirements, and challenges.

Additionally, the management teams in all three entities participating in the study share a similarly proactive and enthusiastic approach to adopting modern technologies aimed at enhancing energy efficiency. Each company actively utilizes the EnobEMS system, with energy monitoring data collected over a period exceeding three years. This extensive timeframe provides a solid foundation for a detailed analysis and comparison of strategies and outcomes concerning energy efficiency and energy security.

This study focuses on assessing the impact of implementing energy management systems on the energy security of production processes. The analysis employs a combined approach, integrating theoretical exploration with quantitative methods. Changes in energy security at each production facility were evaluated individually, based on specific criteria and research areas.

To analyze the findings, a simplified multi-criteria decision analysis (MCDA) method was selected. In the MCDA approach, the weights of individual criteria can be adjusted to reflect varying priorities. For example, if the stability of energy supply is considered more critical, it can be assigned a higher weight compared to cost-related criteria. To ensure comparability of results across facilities, the assigned weights must sum up to either 1 or 100%. This approach allows for a balanced and customizable evaluation of energy security improvements.

RESEARCH AREAS

When analyzing the relationship between energy security and the EMS system implemented in the company, it is crucial to focus on the key factors influencing security. The analysis is structured around the following areas, selected according to the framework outlined in Figure 2.

Regarding the aforementioned research areas, specific activities and benefits of the EMS can be identified and are detailed in the results section. These activities and benefits illustrate how the implementation of the EMS contributes to improvements in energy security within the analyzed facilities.

SYSTEM EnobEMS

EnobEMS is an advanced system developed by a team of engineers from INSTALPOL Sp. z o.o., designed to monitor and support the activities of companies in the field of improving energy efficiency and optimising energy consumption in the industrial sector. This comprehensive tool encompasses selected energy management functions, making it a comprehensive tool for highly

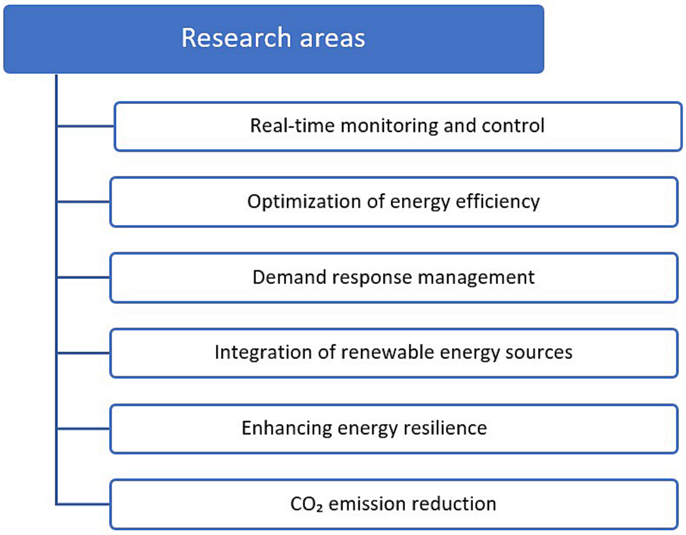

Figure 2. Selected research areas

effective management of energy resources. It provides comprehensive real-time monitoring of energy and heat consumption, enabling companies to accurately analyse key energy efficiency indicators (EnPIs).

The system also includes a module that supports the planning, monitoring and evaluation of efficiency improvement investments, providing forecasts and analysis of the expected return on investment, such as simple payback time (SPBT). By integrating data from multiple sources, EnobEMS allows for continuous process monitoring and optimization, enabling rapid responses to inefficiencies and contributing to reduced operating costs.

The EnobEMS system comprises several interconnected modules that collectively monitor and optimize energy usage in industrial facilities:

The monitoring module

Enables continuous, real-time monitoring of energy and heat consumption. It supports the integration of diverse data sources, including meters and sensors, to provide a comprehensive view of energy use.

EnPI analysis module

Focuses on analyzing energy efficiency performance indicators (EnPIs). This module helps identify areas for optimization, enabling targeted actions to reduce energy consumption and improve efficiency

Investment planning module

Assists in planning efficiency-improving activities and investments. It offers accurate forecasting and payback analysis, including calculations like SPBT, to evaluate the feasibility and benefits of proposed investments

Reporting module

Produces detailed reports that aid decision-making and track the progress of energy efficiency initiatives. These reports provide actionable insights to ensure that energy goals are met effectively.

It should be emphasized that the primary objective of implementing the EnobEMS system in the analyzed companies has been to enhance energy efficiency by monitoring energy consumption and executing iterative investment activities. Notably, the investments and projects aimed at improving energy efficiency are at varying stages of progress across the companies. Some initiatives are still in the planning phase, others are currently being implemented, and certain solutions have already been put into practice and are yielding results.

It should be emphasized that the main purpose of the implementation of the EnobEMS system in the analyzed companies was and is to improve energy efficiency through the monitoring of energy consumption and the implementation of iterative investment activities. Notably, the investments and projects aimed at improving energy efficiency are at different stages of implementation in each of the companies. Some initiatives are still in the planning phase, others are currently being implemented, and certain solutions have already been put into practice and are yielding results.

It should be noted that, in the system, detailed consumption measurements are recorded and presented as useful energy.

MONITORED ENERGY TYPES

In the EnobEMS interface, the system provides users with clear information about the type of energy represented in each graph. The system's definition of final energy, a key concept adopted and predominantly used in the results presented in this EMS, is as follows:

- Final energy – an industrial context refers to the amount of energy delivered and consumed after being processed and distributed – in other words, what a facility manager reads on gas meters or main energy meters. It includes electricity, fuels, steam, and heat used in production processes. Final energy differs from primary energy, which comes directly from natural resources (e.g., coal, gas, biomass) and must be processed and delivered before it can be useful in industry. It also differs from usable energy, which is I the portion of final energy that actually converts into work in industrial processes.
- Useful energy – the portion of final energy that effectively converts into work within industrial processes. It represents the energy efficiently used for powering machines, devices, or heating, without accounting for losses incurred during transmission, Processing, or energy conversion. It differs from primary energy, which is raw, unprocessed energy obtained directly from natural sources (e.g., coal, gas, biomass). Primary energy must be transformed before it can be utilized in industry. Usable energy also differs from final energy, which includes losses such as heat dissipated in devices. This means not all of the delivered final energy is effectively used.

ENTERPRISE PROFILES

Following the political transformation of the late 1980s, Poland, particularly its southern provinces, emerged as a significant production hub for the automotive industry. This sector, closely tied to cooperation with its western neighbor, Germany, has greatly benefited from strong geographical and economic connections (Guzik et al., 2020). In this context, the Silesian Voivodeship has played a pivotal role in driving industrial development and strengthening its position as a key component of the automotive supply chain.

This study was conducted in three companies operating in the automotive industry in Poland, specifically within the Śląskie Voivodeship. The analysis was based on data regarding the use of all heat and energy for their production needs, provided by the EnobEMS system developed by INSTALPOL Sp. z o.o. This system enables precise monitoring and evaluation of energy consumption, as well as the effectiveness of investments aimed at improving energy efficiency. Additionally, the study includes a theoretical analysis of the impact of energy management systems on energy security.

The companies were selected on the basis of the following criteria:

- similar size of production facilities,
- similar production profile,
- regional proximity.

The comparison of key energy efficiency indicators in the studied production facilities is presented in Table 1.

Table 1. Comparison of key energy efficiencyindicators in the examined production facilities

Type of indicator	Object A			Object B			Object C			Measure
	kWh	PLN	CO_2	kWh	PLN	CO_2	kWh	PLN	CO_2	
e-KPI surface	607	509	300	585	503	288	268	212	126	m^2
e-KPI volume	127	107	62.9	73.4	63.1	36.1	37.1	29.3	17.4	m^3
e-KPI product	n/a	n/a	n/a	0.661	0.568	0.326	0.242	0.191	0.113	unit
e-KPI sales	0.110	9.25	0.054	0.029	2.47	0.014	0.026	2.01	0.012	PLN

Production facility A

The overall energy consumption of the facility A, measured in terms of final energy (all types) used for production and internal needs, amounts to 607 kWh/m² annually. Facility A relies on two external energy sources, with a dominant share of electricity. The consumption proportions over the past twelve months are as follows (Figure 3):
- 88.4% electricity,
- 12.6% district heating (medium-parameter water system).

Over the past twelve months, facility A has indirectly emitted 2,884.9 tons of CO_2 as a result of its energy consumption (across all types) within the production facility (Figure 4):

Production facility B

The overall energy consumption of facility B, measured in terms of final energy (all types) used for production and internal needs, amounts to 585 kWh/m² annually. Facility B relies on three external energy sources and fuels, with electricity as the dominant contributor. The consumption proportions over the past twelve months are as follows (Figure 5):
- 94.4% electricity,
- 1.8% district heating (medium-parameter water system),
- 3.8% hydrogen (used in production).

In the past twelve months, facility B's energy consumption across all types has resulted in 2,466.5 tons of indirect CO_2 emissions (Figure 6):

Production facility C

The overall energy consumption of facility C, measured in terms of final energy (all types) used for production and internal needs, amounts to 268 kWh/m² annually. Facility C relies on two

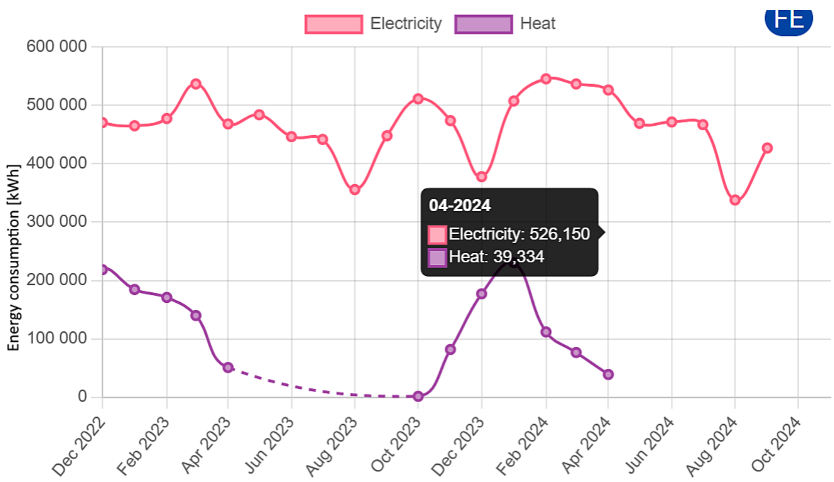

Figure 3. The energy consumption by facility A in period 2022–2024

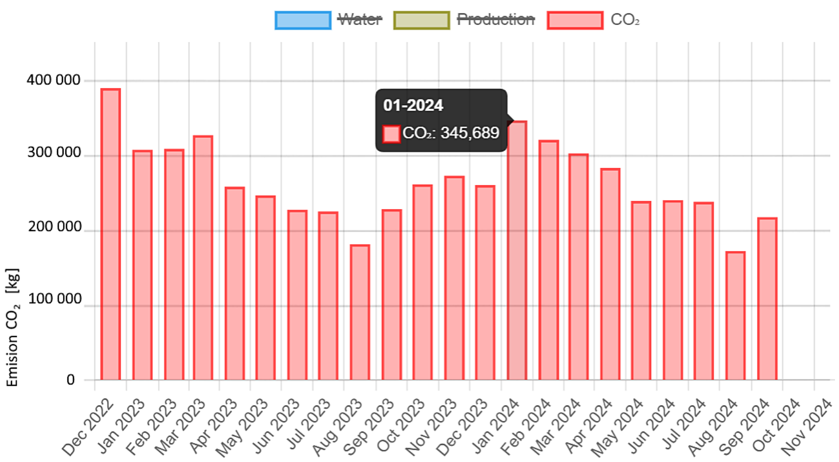

Figure 4. The emission of CO_2 by facility A in period 2022–2024

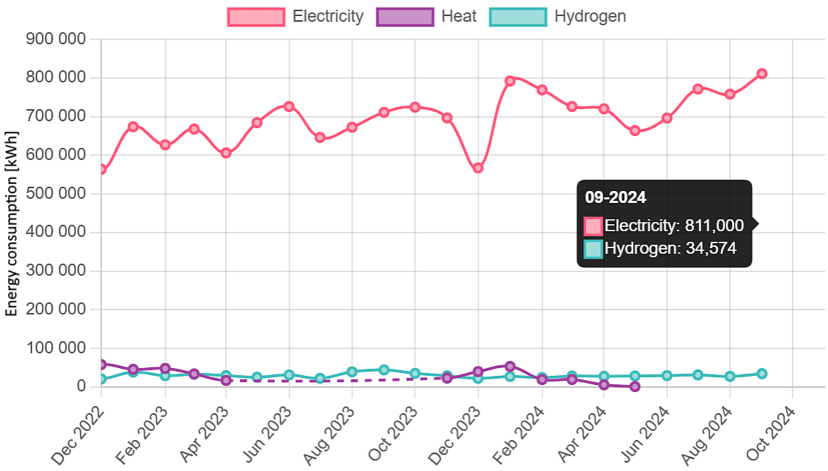

Figure 5. The energy consumption by facility B in period 2022–2024

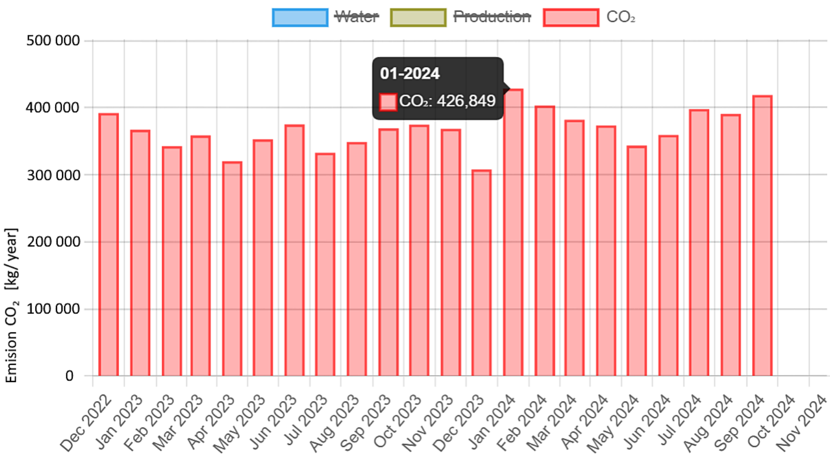

Figure 6. The emission of CO_2 by facility B in period 2022–2024

external energy sources and fuels, with electricity being the dominant contributor. The consumption proportions over the past twelve months are as follows (Figure 7):

- 87.4% electricity,
- 12.6% natural gas.

In the past twelve months, facility C indirectly emitted 876.5 tons of CO_2, associated with the consumption of all types of energy within its production facility (Figure 8).

RESULTS

The key aspects related to the role of EMS in energy security have been divided into segments according to the research areas outlined in section above and discussed in the following subsections. The assessment of improvement or deterioration in the facility's energy security within each research area has been conducted using a proposed point-based scale, which is detailed in section on methodology.

Real-time monitoring and control

- Action – EMS enables real-time monitoring of energy consumption and efficiency.
- Benefit – by providing continuous and improved control over energy resources, EMS helps prevent production interruptions by enhancing awareness of the supply of critical energy carriers. Additionally, through early detection of issues, it supports their swift resolution (predictive maintenance).

In each of the examined facilities (A, B, and C), real-time measurement of energy consumption is conducted, with various energy carriers converted into a common unit, kWh (kilowatt-hour), and its derived units, such as MWh, GWh, or TWh. This standardization allows for direct

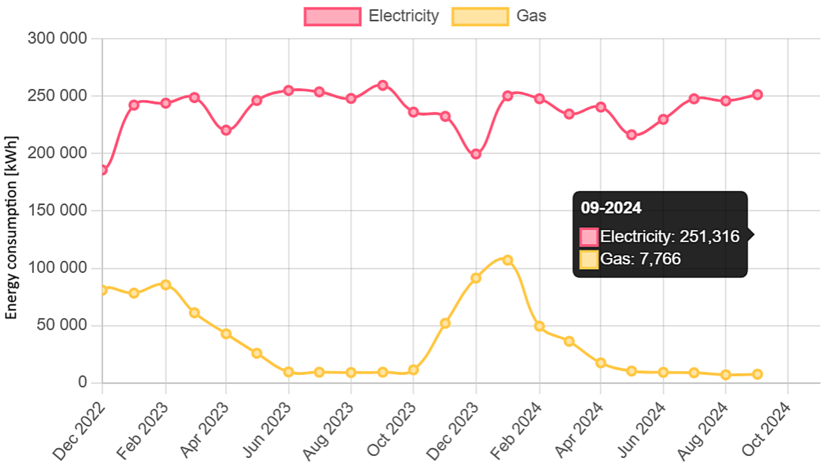

Figure 7. The energy consumption by facility C in period 2022–2024

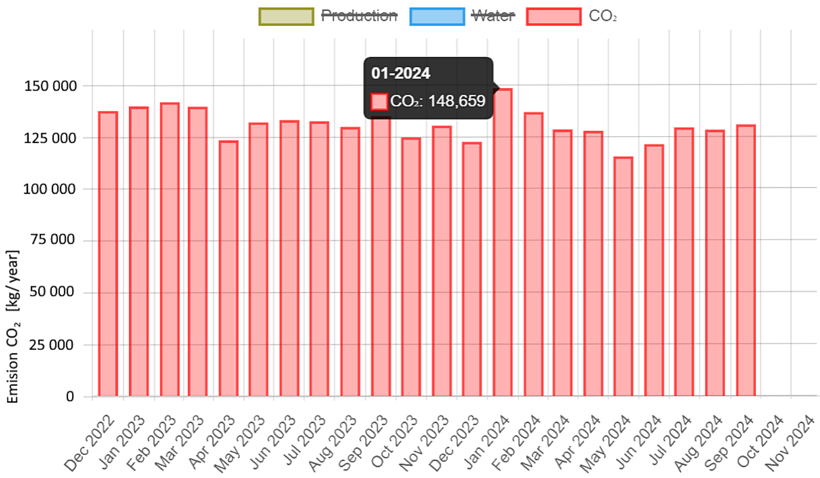

Figure 8. The emission of CO_2 by facility C in period 2022–2024

comparison of actual consumption across different energy carriers within the EMS system. Utilizing the data collected, periodic analyses are performed to assess energy consumption patterns, identify trends, and evaluate key energy performance indicators (EnPIs).

Facilities A and B exhibit comparable energy consumption per unit area, with facility A consuming 607 kWh/m² and facility B consuming 585 kWh/m², both measured relative to their usable areas over the past twelve months. In contrast, facility C demonstrates significantly higher energy efficiency, consuming just 268 kWh/m² annually, making it more than twice as efficient as facilities A and B.

Facility B employs its own sub-metering systems for electricity and district heating, both of which measure useful energy consumption. Similarly, useful energy consumption data for facilities A and B are gathered through their respective EMS systems. In the case of facility C, energy data is based on final energy consumption measurements logged in its EMS.

To varying extents, all three facilities collect, analyze, and maintain up-to-date knowledge regarding the supply and consumption of key energy carriers. However, none of the examined facilities have yet implemented a predictive maintenance management system directly integrated with EMS data. Instead, the upkeep of production equipment remains the responsibility of skilled Maintenance Department teams in each facility. These teams rely on isolated tools specific to individual production lines or machines for predictive maintenance. While this approach proves effective at a localized level, it lacks a systematic, facility-wide perspective and does not incorporate comprehensive data on heat and energy consumption.

The assessment of the impact of real-time monitoring and control on energy security shows that all three facilities benefit significantly from increased awareness of their energy sources and patterns of consumption (both current and historical). This positions them well ahead of facilities that lack such insights, providing them with enhanced operational control and energy management capabilities.

Optimization of energy efficiency

- Action – the EMS analyzes energy consumption patterns to optimize energy use, minimizing waste and improving overall efficiency.
- Benefit – efficiency optimization ensures that available energy resources are utilized more sustainably, reducing overall energy demand and thereby enhancing energy security.

Energy optimization is fundamentally about reducing energy consumption, a primary goal of implementing and operating EMS systems in industrial settings. However, the impact of improved energy utilization in industrial production is closely tied to production volumes. This relationship necessitates the use of, or the development of, dedicated energy performance indicators (EnPIs) that accurately reflect energy usage relative to production metrics. Examples of such metrics include energy consumption per production unit, energy consumption per financial unit (e.g., currency of sales), or the proportion of energy costs relative to total enterprise revenue.

The specifics of energy consumption within a production facility are inherently linked to its operational profile, particularly the volume of goods produced. Changes in production volume, whether an increase or decrease, naturally influence the facility's overall energy consumption. To accurately assess and track these changes, it is essential to monitor energy performance using appropriate and well-defined EnPIs. These indicators provide a meaningful context for evaluating energy efficiency and the impact of optimization efforts over time. The impact of implementation of EnobEMS on the total energy consumption in facilities A-C was presented in Table 2.

Facility A

The facility reduced its total energy consumption by 1.1% year-over-year (Table 2). This improvement was partly driven by three energy efficiency investments implemented over the past 24 months. One of the key projects leveraged the facility's operational specificity, particularly its significant municipal water usage (approximately 60,000 m³ annually). As part of this project, a system for recovering cooling energy from municipal water was introduced. This innovation reduced the load on the chilled water units, thereby enhancing the facility's overall energy efficiency.

The facility monitors changes in energy efficiency using the following key energy performance indicators (EnPIs):

- kWh/m² – represents the total heat and energy consumption in the facility relative to the usable area of its buildings.

Table 2. Impact of implementation of EnobEMS on the total energy consumption in facilities A–C

Parameter		2022-10-01 to 2023-09-30	Change	2023-10-01 to 2024-09-30	Measure
Facility A	Electrical energy	5568.5	+1.5%	5650.0	MWh
	District heating	871.2	-17.3%	720.5	MWh
	Sum	6439.7	-1.1%	6370.5	MWh
	Tap water	55980.0	+7.1%	59978.0	m³
	CO_2	3051889.0	-5.5%	2884962.0	kg
Facility B	Electrical energy	7990.0	+8.8%	8695.2	MWh
	District heating	234.0	-30.5%	162.7	MWh
	Hydrogen	379.8	-8.5%	347.4	MWh
	Sum	8603.7	+7.0%	9205.3	MWh
	Tap water	5307.0	-9.6%	4800.0	m³
	CO_2	4008120.0	+3.8%	4158764.0	kg
Facility C	Electrical energy	2876.5	-1.6%	2831.8	MWh
	Natural gas	449.3	-8.8%	409.8	MWh
	Sum	3325.7	-2.5%	3241.6	MWh
	Tap water	2498.0	+3.3%	2581.0	m³
	CO_2	1485163.0	-5.8%	1398924.0	kg

- PLN/PLN (%) – denotes the monetary share of heat and energy consumed in the facility relative to the total value of goods sold, expressed as a percentage.

Facility A does not have the third type of EnPI present in facilities B and C (namely, kWh/unit), as there is no suitable reference to which it can be applied. This is because facility A's management practices do not incorporate the measurement of a standardized production unit, such as a product, as a basis for evaluation. The monthly changes in the EnPI values for both areas are presented in the chart below (Figure 9).

The facility has reduced overall heat and energy consumption through investment and optimization activities, enhancing not only its efficiency but also its energy security.

Facility B

The facility experienced a 7.0% increase in total energy consumption, which corresponded with a 5.0% year-over-year growth in production volume (Table 2). Currently, the facility is in the process of investing in two new energy efficiency improvement projects, while analytical work is ongoing for the implementation of three additional projects, which are still in the planning phase. However, none of these investments have been fully completed or brought into operation over the past 24 months.

The facility monitors changes in energy efficiency using the following key energy performance indicators (EnPIs):

- kWh/m² – represents the total heat and energy consumption in the facility relative to the usable area of its buildings.
- PLN/PLN (%) – denotes the monetary share of heat and energy consumed in the facility relative to the total value of goods sold, expressed as a percentage.
- kWh/unit – this metric represents the amount of heat and energy consumed in the facility per unit of product produced.

The monthly changes in the values of these EnPIs across all three areas are presented in the Figure 10.

The facility has experienced an increase in overall heat and energy consumption, primarily

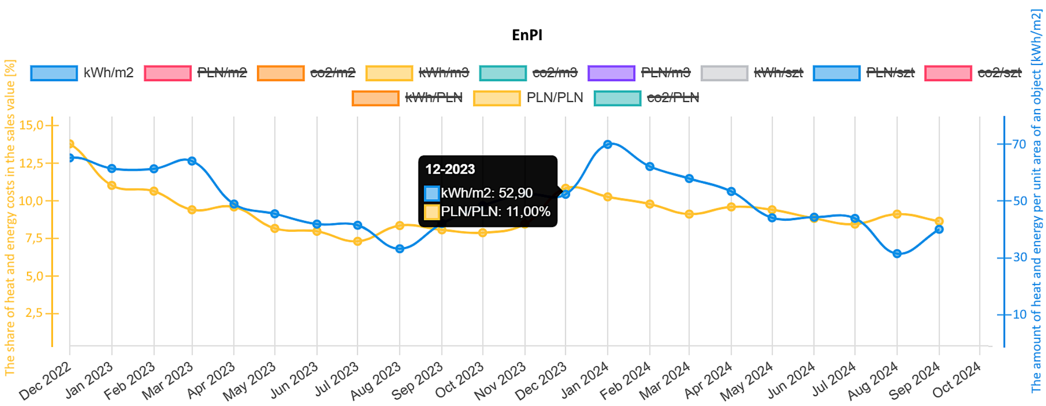

Figure 9. Monthly variations in the EnPI values at facility A during the 2022–2024 period

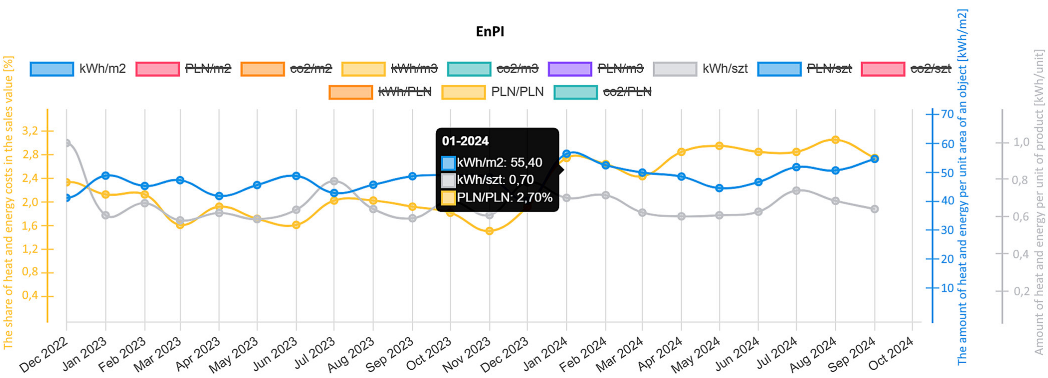

Figure 10. Monthly variations in the EnPI values at facility B during the 2022–2024 period

driven by a rise in production volume. At the same time, investment and optimization activities are underway, although their full benefits have yet to materialize. Among the key projects being implemented is a heat recovery system for the production hall, which redirects recovered heat into a water-based heating system. This recovered heat is then used for practical applications such as heating office spaces and preparing hot water for sanitary facilities.

A notable feature of the facility is its historically minimal reliance on district heating, which has accounted for less than 2% of its total energy consumption. The implementation of the heat recovery system will enable the complete replacement of this energy source, resulting in substantial economic savings.

However, this transition will bring the facility closer to mono-energy dependence, which could be less advantageous from an energy security perspective. Nevertheless, given the historically marginal role of district heating and its lack of direct relevance to production processes, this change is considered neutral in terms of its impact on the facility's overall energy security.

Facility C

The facility has achieved a 2.5% reduction in total energy consumption, despite a remarkable 33.5% year-over-year increase in production volume (Table 2). This impressive outcome is primarily attributed to a shift in the production profile, which likely optimized energy utilization relative to output.

At present, the facility is conducting analytical work to prepare for the implementation of two energy efficiency improvement investments, both of which remain in the planning phase. No new energy efficiency investments have been initiated in the past 24 months.

The facility monitors changes in energy efficiency using the following key energy performance indicators (EnPIs):

- kWh/m² – represents the total heat and energy consumption in the facility relative to the usable area of its buildings.
- PLN/PLN (%) – denotes the monetary share of heat and energy consumed in the facility relative to the total value of goods sold, expressed as a percentage.
- kWh/unit – this metric represents the amount of heat and energy consumed in the facility per unit of product produced.

The monthly changes in the EnPI values across these areas are presented in the accompanying chart (Figure 11). The facility successfully reduced its overall heat and energy consumption solely through production process optimization, achieved by altering its production profile, despite the absence of new investment activities. This approach has not only improved energy efficiency but also strengthened the facility's energy security.

Demand response management

- Action – the EMS facilitates participation in demand response programs by adjusting energy consumption during peak demand periods or in response to energy price fluctuations.
- Benefit – by helping to balance energy supply and demand, the EMS reduces the risk of grid overloads and enhances energy supply stability during periods of high demand, contributing to overall energy security and cost efficiency.

The EnobEMS system does not have demand response management functionality.

In Facility A, no measures have been implemented to support demand response for heat and energy. Moreover, the facility lacks the necessary

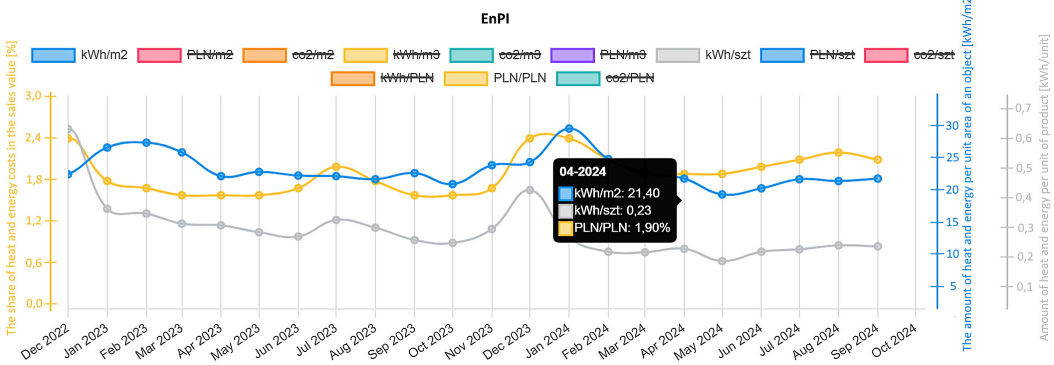

Figure 11. Monthly variations in the EnPI values at facility C during the 2022–2024 period

infrastructure, such as backup energy sources, to facilitate demand response management.

Similarly, facilities B and C do not possess backup heat or energy sources. However, both facilities are engaged in a partnership program with an electricity distributor. This program involves testing the feasibility of temporarily reducing electricity consumption during peak periods in exchange for financial compensation. This collaborative approach represents an initial step toward integrating demand response practices, albeit without dedicated infrastructure.

Participation in such a program highlights the facilities' capacity to temporarily scale down production, including halting specific processes for up to one hour, provided prior scheduling for testing is arranged. However, the absence of alternative energy sources or redundant facility infrastructure means that this action does not have a significant or tangible impact on the energy security of the facilities.

Integration of renewable energy sources

- Action – EMS plays a critical role in integrating variable renewable energy sources, such as solar and wind power, into the enterprise's energy network.
- Benefit – EMS enables efficient management of integrated energy sources by automating the switching processes between different sources based on availability and energy costs. This not only improves efficiency but also enhances the energy independence of facilities.

EnobEMS provides advanced tools for monitoring heat and energy tariffs, which are primarily utilized in engineering optimizations, especially within the HVAC systems of industrial facilities. However, it does not support real-time monitoring of market prices and energy availability. Additionally, none of the facilities – A, B, or C – independently engage in purchasing energy at current market prices.

Facility A has implemented a small photovoltaic installation with a capacity of 50 kWp, located on the roof of the production hall. The energy generated is fully consumed by the production process, which requires significantly more energy than the photovoltaic system can produce.

Facilities B and C, in contrast, do not currently utilize renewable energy sources. Instead, they rely entirely on purchasing electricity from the power grid distributor.

The limited adoption of renewable energy in these facilities can be attributed to the long payback period for such investments. Photovoltaic systems, when exclusively used for production without feeding surplus energy back into the power grid, typically have a simple payback time (SPBT) of approximately 5–7 years. This economic factor likely influences decision-making regarding the adoption of renewable energy solutions.

Enhancing energy resilience

- Action – in the event of network failures or overloads, EMS enables companies to better manage local energy resources, including distributed energy sources such as backup generators or energy storage systems.
- Benefit – by integrating various energy sources and emergency systems, EMS enhances the facility's resilience to unforeseen disruptions, which is critical for maintaining operational continuity in production.

EnobEMS does not provide functionality for the automatic activation or integration of backup energy sources, such as electricity generators or energy storage systems.

Moreover, none of the analyzed facilities (A, B, or C) have emergency power supply systems in place for electricity or heat. This lack of backup infrastructure means that the primary risk to the energy security of these enterprises lies in the potential disruption of electricity supply from the power grid operator, which could significantly impact their operations.

CO_2 emission reduction

- Action – EMS supports industries in reducing energy consumption by continuously monitoring and optimizing production processes, thereby lowering CO_2 emissions and other pollutants.
- Benefit – with EMS, manufacturing companies can manage energy resources more efficiently, enabling them to meet environmental standards and avoid penalties for excessive environmental impact. Improved energy efficiency leads to a reduction in CO_2 emissions, enhancing the facility's operational security by minimizing the risk of public administration intervention, including potential restrictions on high-emission activities.

EnobEMS calculates and displays real-time CO_2 emissions associated with the consumption of each type of heat and energy at the analyzed facilities. The emission value is determined by multiplying the amount of energy consumed (for a specific type) by the emission factor corresponding to the energy carrier and the time period of usage. This feature provides precise insights into the environmental impact of energy consumption, enabling facilities to track and manage their emissions effectively.

Facility A achieved a 5.5% reduction in CO_2 emissions associated with energy consumption across all types over the past twelve months (Table 2). The key energy performance indicators (EnPIs) used to track changes in CO_2 emissions at this facility are:

- kg CO_2/m^2 – represents the amount of CO_2 emissions relative to the usable area of the facility's buildings,
- kg CO_2/PLN – indicates the amount of CO_2 emissions relative to the monetary value of goods sold.

The monthly changes in the values of these EnPIs related to emissions are presented on Figure 12. Facility B has experienced a 3.8% increase in CO_2 emissions associated with energy consumption across all types over the past twelve months (Table 2). The key energy performance indicators (EnPIs) used to monitor changes in CO_2 emissions at this facility are:

- kg CO_2/m^2 – the amount of CO_2 emissions relative to the usable area of the facility's buildings,

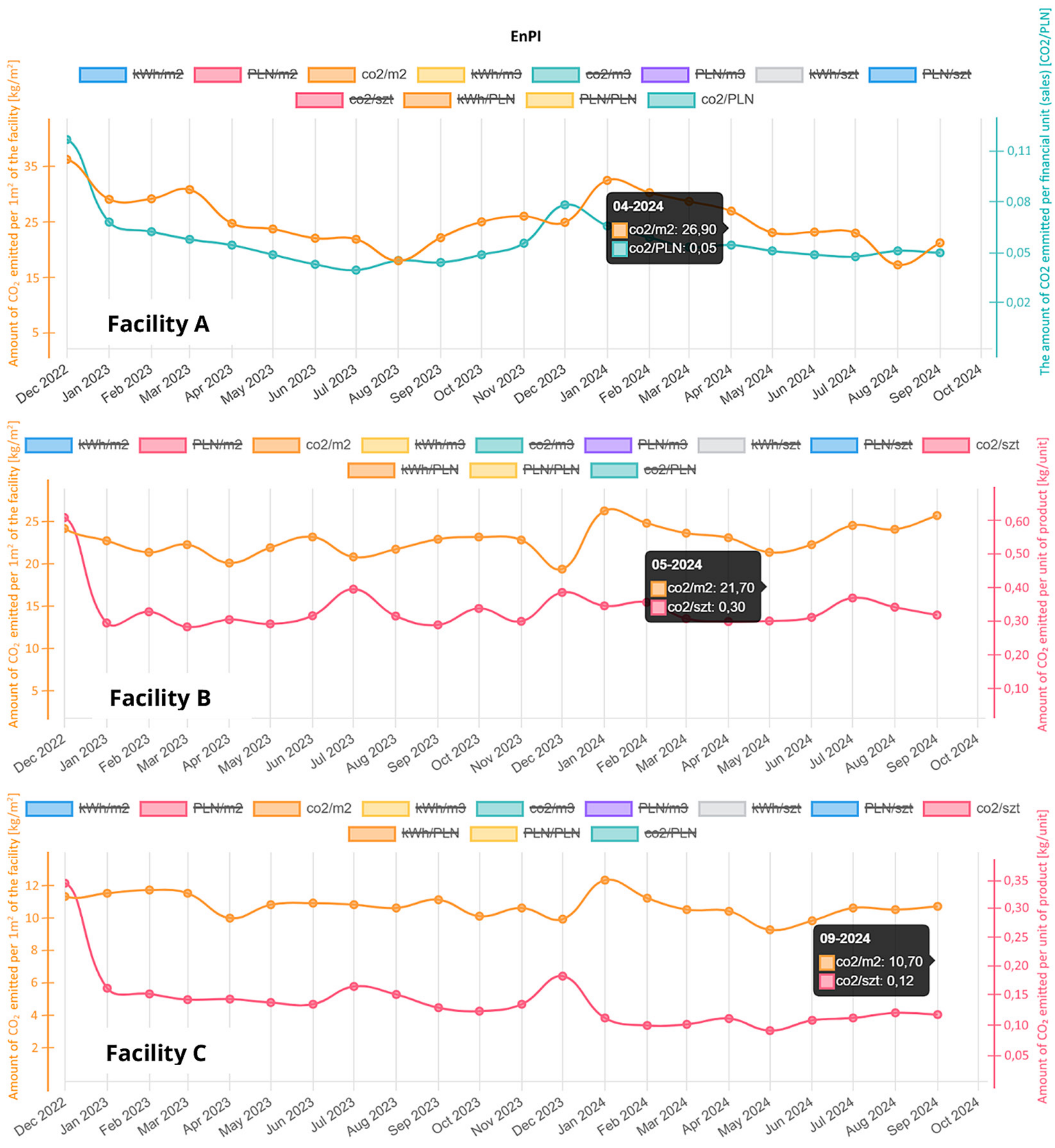

Figure 12. The monthly changes in the values of these EnPIs related to emissions in facilities A–C

- kg CO_2/unit – the amount of CO_2 emissions relative to a single product unit.

The monthly changes in the values of these EnPIs related to emissions are presented in Figure 12. Facility C has reduced its CO_2 emissions associated with energy consumption (of all types) by 5.8% over the past twelve months.

The key energy performance indicators (EnPIs) used to monitor changes in CO_2 emissions at this facility are:
- kg CO_2/m^2 – the amount of CO_2 emissions relative to the usable area of the facility's buildings,
- kg CO_2/unit – the amount of CO_2 emissions relative to a single product unit.

The monthly changes in the values of these EnPIs related to emissions are presented in Figure 12. The evaluation of fluctuations in energy security across the examined areas, facilitated by the use of the EMS system, was conducted using a simplified Multi-Criteria Decision Analysis (MCDA) method. The scoring system for the selected research areas was as follows:
- +1 point – improvement in energy security in the given area
- 0 points – no impact or insufficient data for assessment
- -1 point – deterioration of energy security in the given area

Given the significant number of 0-point assessments resulting from insufficient data to evaluate the EMS's impact on the enterprise's energy security, the authors chose not to differentiate the weights assigned to results across the various areas. This approach ensures a uniform evaluation framework, avoiding potential bias and maintaining the integrity of the assessment despite data limitations (Table 3).

CONCLUSIONS

The implementation of EMS systems, with a focus on monitoring and optimising energy consumption, allows for accurate identification of the actual energy needs of companies and has a significant impact on their energy efficiency. This type of activity opens up the possibility of achieving savings of up to 20% of the energy consumed (Singh et al., 2024). This will undoubtedly lead to an increase in the energy security of the facilities studied.

It is important to note that while the pursuit and implementation of more efficient energy solutions, which is an integral function of energy management systems, enhances energy security, this benefit has its limitations. Reducing energy consumption does contribute to a more secure energy supply, but an excessive focus on cost optimization can have the opposite effect. Cost-cutting measures may sometimes lead to decisions that undermine energy security, particularly when they result in over-reliance on a single energy source.

A notable trend observed in the studied plants is that competitive market pressures are compelling companies to aggressively seek strategies to reduce energy costs. Economic optimization often focuses on solutions with lower unit energy expenses, thereby improving the companies' market position and competitiveness. However, it is important to note that while electricity costs dominate industrial energy expenses, in the three analyzed companies, these costs remain relatively low compared to other price-determining factors (Bukowski & Sniegocki, 2014).

Despite their economic rationale, such cost-focused strategies carry the risk of fostering excessive reliance on a single energy source, leading to what is termed "monoenergety" – a suboptimal

Table 3. Assessment of energy security fluctuations in facilities A–C

Research areas and scores	Facilities		
	A	B	C
Real-time monitoring and control	1	1	1
Optimization of energy efficiency	1	0	1
Demand response management	0	0	0
Integration of renewable energy sources	1	0	0
Enhancing energy resilience	0	0	0
CO_2 emission reduction	1	0	1
Total scores:	4	1	3

situation from an energy security perspective. Over-dependence on one source reduces a company's flexibility to adapt to market fluctuations or supply disruptions. This tension between minimizing energy costs and maintaining energy security is a critical issue highlighted by the implementation of EMS systems.

Another key functionality of the implemented EMS system is its ability to respond swiftly to market changes, such as using rising fuel prices as a signal to explore alternative energy sources. Given the rapid and frequent nature of such fluctuations, EMS is crucial for maintaining adaptability. However, the study revealed that neither market price responsiveness nor the anticipated enhancement of energy resilience through EMS was sufficiently observed with EnobEMS. This indicates that the system's performance in these important areas requires further, more detailed investigation to draw comprehensive conclusions.

Some energy sources and fuels used in industrial processes are interchangeable. For example, steam production can be achieved either by burning fuels or by using electricity through resistance heaters. In contrast, machines and power tools typically rely on a single energy type throughout their depreciation period. Even so, alternatives can still be explored, such as switching to a different energy supplier. Technologies that enhance energy efficiency, such as those in biofuel production, are also gaining importance. One notable innovation is the recovery of biogas from industrial wastewater, which promotes more sustainable resource utilization while minimizing waste in production processes (Michalski et al., 2024). Biogas, along with other renewable energy sources, can significantly reduce the risk of excessive reliance on a single energy source (energy mono-dependence), which threatens enterprises – provided it is implemented at scale and carefully managed. In this context, EMS plays a pivotal role, integrating efforts to reduce CO_2 emissions, adopt renewable energy sources, and improve the energy efficiency of processes and buildings.

Monitoring energy consumption through energy management systems plays an undeniably crucial role in ensuring the energy security of enterprises. A comprehensive understanding of heat and energy usage patterns is essential to effectively address and mitigate risks associated with supply-demand imbalances in production facilities. To reinforce energy security, industries should adopt advanced EMS that optimize energy utilization, encourage diversification through renewable energy sources, and balance cost efficiency with long-term resilience. Crucial steps include implementing sustainable innovations, providing staff with energy management training, and conducting regular EMS evaluations to ensure adaptability and continuous improvement.

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