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THE APPLICATIONS OF USAGE OF BUSINESS ANALYTICS IN ENERGY MANAGEMENT IN INDUSTRY 4.0 CONDITIONS

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Purpose: The purpose of this publication is to present the applications of usage of business analytics in energy management.
Design/methodology/approach: Critical literature analysis. Analysis of international literature from main databases and polish literature and legal acts connecting with researched topic.
Findings: The advantages of using business analytics in energy management are substantial, including cost reduction, enhanced energy efficiency, and sustainability alignment. This approach also provides real-time monitoring and control capabilities, predictive maintenance, and compliance with regulatory requirements. However, it comes with challenges such as data integration complexity, data quality, and security issues, as well as the need to address high implementation costs and talent gaps. Business analytics is a game-changer in energy management within Industry 4.0, offering numerous benefits but also requiring organizations to overcome significant challenges. Embracing these complexities will enable organizations to thrive in this dynamic landscape while contributing to a sustainable and efficient future.

Keywords: business analytics, Industry 4.0, digitalization, artificial intelligence, real-time monitoring; energy management.

Category of the paper: literature review.

1. Introduction

In the era of Industry 4.0, characterized by the integration of digital technologies into industrial processes, businesses across various sectors are harnessing the power of data analytics to optimize their operations. One critical area where data analytics is making a significant impact is energy management (Scappini, 2016). With the increasing emphasis on sustainability and cost-efficiency, organizations are turning to advanced business analytics to not only monitor but also enhance their energy consumption and resource utilization.

This article explores the pivotal role of business analytics in energy management within Industry 4.0 conditions.

The purpose of this publication is to present the applications of usage of business analytics in energy management.

2. The selected aspects of business analytics usage in energy management processes

In Industry 4.0, data is abundant and easily accessible, thanks to the proliferation of sensors, IoT devices, and interconnected systems. These technological advancements enable real-time data collection, allowing businesses to gain deep insights into their energy usage patterns (Wolniak, 2016; Czerwińska-Lubszczyk et al., 2022; Drozd, Wolniak, 2021; Gajdzik, Wolniak, 2021, 2022; Gębczyńska, Wolniak, 2018, 2023; Grabowska et al., 2019, 2020, 2021; Wolniak et al., 2023; Wolniak, Grebski, 2023; Wolniak, Skotnicka-Zasadzień, 2023; Jonek-Kowalska, Wolniak, 2023). Data on electricity, gas, water, and other resources can be continuously monitored and analyzed to identify areas of inefficiency or opportunities for improvement. Predictive analytics tools play a vital role in forecasting energy consumption. By analyzing historical data, weather patterns, production schedules, and other relevant factors, businesses can create predictive models that help anticipate energy demands. This proactive approach allows for better planning and allocation of resources, reducing energy waste and costs (Jonek-Kowalska, Wolniak, 2021, 2022; Jonek-Kowalska et al., 2022; Kordel, Wolniak, 2021, Orzeł, Wolniak, 2021, 2022, 2023; Rosak-Szyrocka et al., 2023; Gajdzik et al., 2023; Ponomarenko et al., 2016; Stawiarska et al., 2020, 2021; Stecuła, Wolniak, 2022; Olkiewicz et al., 2021).

Business analytics tools can pinpoint specific areas within an industrial facility where energy efficiency can be improved. For instance, by analyzing equipment performance data, organizations can identify machines that consume excessive energy or require maintenance. Continuous monitoring enables businesses to fine-tune processes for maximum efficiency. Energy management in Industry 4.0 goes beyond day-to-day operations. Predictive analytics can help businesses participate in demand response programs, where they adjust energy consumption during peak periods to reduce costs. Peak shaving strategies can be implemented to flatten energy demand curves, ensuring efficient use of resources and minimizing expensive peak-time charges. Sustainability is a top priority in Industry 4.0, and business analytics plays a crucial role in achieving sustainability goals. By analyzing energy consumption data and emissions data, organizations can identify opportunities to reduce their carbon footprint. These insights enable the implementation of energy-efficient technologies and renewable energy sources, contributing to a greener and more eco-friendly operation (Greasley, 2019).

Efficient energy management not only reduces costs but also enhances a company's competitiveness (Nourani, 2021). By using data analytics to optimize energy usage, businesses can lower operational expenses, increase profit margins, and offer more competitive pricing to consumers. Additionally, a commitment to sustainable energy practices can enhance a company's reputation and appeal to environmentally conscious customers. Industry 4.0 brings with it a host of new regulations and standards related to energy and environmental management (Wolniak, Skotnicka-Zasadzień, 2008, 2010, 2014, 2018, 2019, 2022; Wolniak, 2011, 2013, 2014, 2016, 2017, 2018, 2019, 2020, 2021, 2022; Gajdzik, Wolniak, 2023; Wolniak, 2013, 2016; Hys, Wolniak, 2018). Business analytics can help organizations ensure compliance by providing accurate data and performance metrics. This reduces the risk of fines and legal issues while demonstrating a commitment to corporate responsibility (Charles et al., 2023).

In Industry 4.0 conditions, businesses cannot afford to overlook the critical role of business analytics in energy management. Leveraging data-driven insights to optimize energy consumption not only reduces costs but also aligns with sustainability objectives. By continuously monitoring, analyzing, and acting upon energy-related data, organizations can thrive in an increasingly competitive and eco-conscious world while making significant strides towards a sustainable future (Peter et al., 2023).

Table 1 contains descriptions of how business analytics is used in energy management. These examples demonstrate the versatile applications of business analytics in energy management, ranging from real-time monitoring to long-term sustainability planning. Organizations can leverage these analytics-driven strategies to optimize energy usage, reduce costs, and achieve their environmental and business objectives.

Table 1.
The usage of business analytics in energy management

Application of Business Analytics	Description
Real-time Energy Monitoring	Continuous monitoring of energy consumption and production in real-time to identify anomalies and optimize usage.
Predictive Maintenance	Using predictive analytics to forecast equipment failures and schedule maintenance to prevent energy waste.
Energy Demand Forecasting	Analyzing historical data and external factors to predict energy demands and optimize resource allocation.
Peak Demand Management	Implementing strategies to reduce energy consumption during peak demand periods to lower costs and avoid penalties.
Energy Efficiency Analysis	Identifying inefficiencies in equipment and processes through data analytics and making adjustments for optimal efficiency.
Renewable Energy Integration	Analyzing data to determine the optimal integration of renewable energy sources like solar and wind into the grid.
Carbon Emissions Tracking	Using analytics to monitor and report on carbon emissions, ensuring compliance with environmental regulations.
Demand Response Optimization	Utilizing analytics to participate in demand response programs, adjusting energy consumption during peak times for cost savings.
Energy Procurement Strategy	Analyzing market data and consumption patterns to optimize energy procurement, considering factors like contract negotiations and tariffs.

Cont. table 1.

Sustainability Reporting	Compiling data on energy usage and emissions for sustainability reports, demonstrating corporate responsibility.
Energy Cost Reduction	Identifying cost-saving opportunities through analytics, such as negotiating better energy contracts or optimizing energy use.
Energy Benchmarking	Comparing energy consumption and efficiency against industry benchmarks to identify areas for improvement.
Energy Performance Dashboards	Creating interactive dashboards that display key energy metrics and performance indicators for easy monitoring.
Energy Portfolio Optimization	Managing a diverse portfolio of energy sources (e.g., gas, electricity, renewables) to balance costs and reliability.
Energy Data Visualization	Visualizing energy data through graphs and charts to make complex information more accessible for decision-makers.

Source: (Adel, 2022; Akundi et al., 2022; Olsen, 2023; Aslam et al., 2020; Bakir, Dahlan, 2022; Cillo et al., 2022; Ghibakholl et al., 2022, Javaid, Haleem, 2020, Javaid et al., 2020; Cam et al., 2021; Charles et al., 2023; Greasley, 2019; Hurwitz at al., 2015; Nourani, 2021; Peter et al., 2023).

3. Software used in energy management in Industry 4.0 conditions

Many types of software has emerged as a crucial tool for optimizing energy management within industrial settings. Leveraging sophisticated software solutions, organizations can monitor, analyze, and control their energy consumption more effectively than ever before. This article explores how software is utilized in energy management within the Industry 4.0 landscape (Cillo et al., 2022).

One of the cornerstones of Industry 4.0 is real-time data. Specialized software, often integrated with sensors and IoT devices, allows industries to continuously monitor energy consumption across their operations. Real-time data enables immediate responses to anomalies, optimizing energy usage and minimizing wastage. Operators can also remotely control equipment and processes to achieve peak energy efficiency. Industry 4.0 software employs predictive analytics algorithms to forecast energy demand and consumption patterns. These predictive models consider factors such as historical usage, production schedules, and external variables like weather conditions. By anticipating energy needs, organizations can proactively adjust operations to minimize costs and avoid disruptions. Software solutions are adept at identifying inefficiencies in industrial processes. They analyze data from various sources, including equipment sensors and production logs, to pinpoint areas where energy consumption can be optimized. Adjustments can then be made to machinery settings, production schedules, and logistics to achieve greater energy efficiency (Adel, 2022).

Energy management software supports demand response strategies, enabling industries to participate in demand-side management programs. When demand on the grid is high, these programs allow companies to reduce their energy usage or shift it to off-peak hours, reducing energy costs and supporting grid stability. Many organizations are adopting renewable energy sources as part of their sustainability efforts (Javaid, Haleem, 2020). Energy management software helps integrate renewable energy, such as solar panels or wind turbines, into the energy mix. These systems optimize the generation, storage, and distribution of renewable energy, ensuring its effective use. Software solutions analyze energy procurement options, track energy prices, and manage contracts to minimize energy costs. They provide insights into the most cost-effective energy sources, suppliers, and tariff structures, helping companies make informed decisions (Di Marino et al., 2023).

In the complex regulatory landscape of Industry 4.0, energy management software helps organizations stay compliant with environmental and energy efficiency regulations. It automates the collection and reporting of energy data, reducing the risk of non-compliance and associated penalties. Software platforms offer interactive dashboards and reporting tools that transform complex energy data into actionable insights. Visualization simplifies the communication of key energy performance indicators to decision-makers, facilitating informed choices (Bakir, Dahlan, 2022).

As industries continue to evolve in this digital age, software-driven energy management will play a pivotal role in reducing costs, enhancing competitiveness, and meeting environmental objectives. By embracing advanced software solutions, companies can navigate the complexities of Industry 4.0 while creating a more sustainable and efficient future (Olsen, 2023).

Table 2 highlighting examples of software and applications used in energy management, along with descriptions of their usage. These software and applications play aa important role in energy management, enabling organizations to monitor, analyze, and optimize their energy usage, reduce costs, and meet sustainability objectives in an increasingly data-driven and interconnected world.

Table 2.
The usage of business analytics in energy management

Software/Application	Description of Usage
Energy Management Systems (EMS)	EMS software is used for real-time monitoring, control, and optimization of energy consumption within facilities. It provides insights into energy usage patterns, manages equipment, and automates responses to reduce energy costs and wastage.
Building Energy Management Systems (BEMS)	BEMS software focuses on energy management within commercial and residential buildings. It monitors HVAC systems, lighting, and other building services to optimize energy usage for comfort and efficiency while reducing costs.
SCADA (Supervisory Control and Data Acquisition)	SCADA systems are used in industrial settings to monitor and control processes, including energy-related operations. They provide real-time data visualization and control capabilities for energy-intensive industries like manufacturing and utilities.
Demand Response (DR) Platforms	DR platforms help organizations participate in demand response programs. They allow users to adjust energy usage during peak periods or in response to grid conditions, helping reduce energy costs and support grid stability.

Cont. table 2.

Energy Analytics Software	Energy analytics tools analyze historical and real-time data to identify energy inefficiencies, forecast consumption, and suggest optimization strategies. These tools provide actionable insights for decision-makers.
Renewable Energy Management Software	This software is designed to monitor and manage renewable energy sources like solar panels and wind turbines. It tracks energy production, forecasts generation, and optimizes storage and distribution.
Carbon Emissions Tracking Software	Carbon tracking software helps organizations monitor and report greenhouse gas emissions, ensuring compliance with environmental regulations and facilitating sustainability reporting.
Smart Grid Management Software	Smart grid software enables utilities to manage and optimize the distribution of electricity in real-time, incorporating renewable energy sources and improving grid reliability. It also supports demand-side management.
Energy Procurement and Contract Management Software	This software assists organizations in optimizing their energy procurement strategies by analyzing market data, tracking contracts, and managing suppliers. It aims to reduce energy costs and risks.
Energy Simulation and Modeling Software	These tools create virtual models of buildings or industrial processes to simulate and optimize energy usage under different conditions. They are used in design and planning phases to maximize efficiency.
Energy Data Visualization Platforms	Visualization tools display energy data through interactive dashboards, graphs, and charts, making it easier for users to understand and act upon complex energy-related information.
Energy Auditing Software	Energy auditing software facilitates energy assessments of buildings and industrial sites. It helps identify energy-saving opportunities, track improvements, and calculate potential cost savings.
IoT (Internet of Things) Energy Monitoring Devices	IoT devices and sensors collect real-time data on energy consumption and equipment performance, which can be integrated with various energy management software systems for analysis and control.

Source: (Adel, 2022; Akundi et al., 2022; Olsen, 2023; Aslam et al., 2020; Bakir, Dahlan, 2022; Cillo et al., 2022; Ghibakholl et al., 2022, Javaid, Haleem, 2020, Javaid et al., 2020; Cam et al., 2021; Charles et al., 2023; Greasley, 2019; Hurwitz at al., 2015; Nourani, 2021; Peter et al., 2023).

4. Advantages and problems with business analytics usage in energy management

By harnessing data analytics, organizations can unlock a plethora of advantages that not only enhance efficiency but also align with sustainability goals. One of the primary benefits of business analytics in energy management is cost reduction. Organizations can identify energy inefficiencies, optimize consumption, and streamline procurement strategies. This leads to substantial savings in operational expenses, a critical advantage in the competitive environment of Industry 4.0 results (Wolniak, Grebski, 2018; Wolniak et al., 2019, 2020; Wolniak, Habek, 2015, 2016; Wolniak, Skotnicka, 2011; Wolniak, Jonek-Kowalska, 2021; 2022).

Analytics-driven insights enable organizations to fine-tune their equipment, processes, and operations for maximum energy efficiency. This translates to reduced energy waste and a reduced environmental footprint. Improved efficiency also enhances overall productivity and competitiveness (Ghibakholl et al., 2022).

Sustainability is a cornerstone of Industry 4.0, and business analytics plays a pivotal role in achieving eco-friendly objectives. By effectively monitoring and managing energy usage, organizations can significantly reduce carbon emissions, aligning with global sustainability initiatives and demonstrating a commitment to environmental responsibility (Aslam et al., 2020). Business analytics provides real-time visibility into energy consumption and performance. This enables organizations to make immediate adjustments and respond swiftly to anomalies. Proactive management enhances operational reliability, reduces costly disruptions, and ensures continuous production and uptime (Akundi et al, 2022).

Table 3 contains the advantages of using business analytics in energy management within Industry 4.0 conditions, along with descriptions for each advantage. These advantages underscore the pivotal role of business analytics in energy management within Industry 4.0 conditions. They not only contribute to cost savings and operational efficiency but also enable organizations to thrive in an era focused on sustainability, innovation, and competitiveness.

Table 3.
The advantages of using business analytics in energy management

Advantage	Description
Cost Reduction	Business analytics enable organizations to identify and eliminate energy inefficiencies, resulting in substantial cost savings. By optimizing energy consumption and procurement strategies, businesses can lower operational expenses, which is especially critical in the competitive landscape of Industry 4.0.
Energy Efficiency Improvement	Analytics-driven insights allow for the fine-tuning of equipment, processes, and operations to maximize energy efficiency. This leads to reduced energy waste and a smaller environmental footprint. Improved efficiency also enhances the overall productivity and competitiveness of organizations in Industry 4.0.
Enhanced Sustainability	Industry 4.0 emphasizes sustainability, and business analytics play a crucial role in achieving eco-friendly goals. By monitoring and managing energy usage effectively, organizations can reduce their carbon emissions and demonstrate a commitment to environmental responsibility, aligning with global sustainability initiatives.
Real-Time Monitoring and Control	Analytics provide real-time visibility into energy consumption and performance, allowing organizations to make immediate adjustments and respond to anomalies promptly. This proactive approach enhances operational reliability and helps avoid costly disruptions, ensuring continuous production and uptime.
Predictive Maintenance	Predictive analytics predict equipment failures based on historical and real-time data, allowing for preventive maintenance. By addressing potential issues before they escalate, organizations reduce downtime, extend equipment lifespans, and avoid energy waste associated with inefficient or failing machinery.
Optimized Resource Allocation	Energy demand forecasting through analytics helps organizations allocate resources more effectively. By accurately predicting energy requirements, businesses can allocate resources, including labor and materials, to match production needs. This ensures resource optimization and reduces waste, contributing to cost-efficiency in Industry 4.0 conditions.
Competitive Advantage	Leveraging business analytics in energy management provides organizations with a competitive edge. Companies that can lower their energy costs, enhance sustainability, and meet regulatory requirements more efficiently are better positioned to compete effectively in the dynamic landscape of Industry 4.0, attracting environmentally conscious customers and investors.

Cont. table 3.

Regulatory Compliance	In Industry 4.0, regulations and standards governing energy and environmental management are complex and stringent. Business analytics simplify compliance by providing accurate data and automated reporting, reducing the risk of fines and legal issues associated with non-compliance. Ensuring regulatory adherence is essential for avoiding costly penalties and reputation damage.
Data-Driven Decision-Making	Analytics transform vast amounts of energy-related data into actionable insights. This data-driven decision-making empowers organizations to make informed choices about energy procurement, efficiency projects, and sustainability initiatives, resulting in more effective strategies and resource allocation. In Industry 4.0, data-driven decision-making is a key driver of success.
Operational Resilience	Real-time monitoring and predictive analytics bolster operational resilience. By quickly identifying and responding to energy-related issues, organizations can maintain consistent production and minimize disruptions. This resilience is critical in Industry 4.0, where downtime can have far-reaching consequences on production schedules and customer commitments.

Source: (Adel, 2022; Akundi et al., 2022; Olsen, 2023; Aslam et al., 2020; Bakir, Dahlan, 2022; Cillo et al., 2022; Ghibakholl et al., 2022, Javaid, Haleem, 2020, Javaid et al., 2020; Cam et al., 2021; Charles et al., 2023; Greasley, 2019; Hurwitz at al., 2015; Nourani, 2021; Peter et al., 2023).

Table 4 contains the problems of using business analytics in energy management within Industry 4.0 conditions, along with descriptions for each advantage. These problems and challenges underscore the complexity and multifaceted nature of implementing business analytics in energy management within Industry 4.0 conditions. Addressing these issues requires careful planning, investment, and ongoing commitment to ensure that organizations can harness the full potential of analytics for efficient energy management.

Table 4.

The problems of using business analytics in energy management

Problem/Challenge	Description
Data Integration Complexity	In Industry 4.0, data is generated from numerous sources, including IoT devices, sensors, and legacy systems. Integrating this diverse data into a coherent analytics platform can be challenging. Data integration complexity can hinder the seamless flow of information required for accurate energy management, potentially leading to incomplete or inaccurate analyses.
Data Quality and Accuracy	The quality and accuracy of data are paramount for effective analytics. Inaccurate or incomplete data can lead to faulty conclusions and suboptimal energy management decisions. Maintaining data quality, cleaning and preprocessing data, and addressing data gaps are ongoing challenges in Industry 4.0, where data volumes are massive and diverse.
Data Privacy and Security	With the increased reliance on data analytics comes the concern of data privacy and security. Energy consumption data and related information are sensitive and must be protected from unauthorized access and breaches. Balancing the need for data accessibility with robust security measures is a challenge, especially in interconnected Industry 4.0 environments where cyber threats are prevalent.
Complexity of Analytical Models	Developing and deploying sophisticated analytical models for energy management can be complex and resource-intensive. Many organizations lack the in-house expertise to create and maintain these models effectively. The complexity of models can lead to delays in decision-making, making it challenging to respond promptly to changing energy conditions.
High Initial Implementation Costs	Implementing advanced analytics systems for energy management in Industry 4.0 conditions often requires significant upfront investments in hardware, software, and talent. These costs can be prohibitive for smaller organizations or those with limited budgets, posing a barrier to entry for advanced energy analytics.

Cont. table 4.

Scalability and Infrastructure	As organizations grow and expand their operations, the scalability of energy analytics solutions becomes critical. Scaling up analytics infrastructure and processes to accommodate larger data volumes and more complex operations can be challenging. Ensuring that the analytics infrastructure remains efficient and effective while scaling is an ongoing concern in Industry 4.0 conditions.
Talent and Skill Gap	Leveraging business analytics in energy management requires a skilled workforce capable of understanding data analytics tools and techniques. The shortage of data scientists, analysts, and engineers with domain expertise in both energy management and Industry 4.0 technologies can hinder the effective implementation of analytics initiatives. Bridging this skill gap is essential for realizing the full potential of analytics.
Interoperability of Systems	Industry 4.0 environments often consist of heterogeneous systems and technologies from different vendors. Ensuring the interoperability of these systems with energy analytics platforms can be challenging. A lack of standardization and compatibility issues can result in data silos, limiting the comprehensive analysis needed for efficient energy management.
Regulatory and Compliance Complexities	Industry 4.0 is subject to evolving regulations and standards in the realms of energy management and environmental compliance. Navigating these complexities while integrating analytics solutions can be daunting. Organizations must remain up-to-date with changing regulations and ensure that their analytics systems align with compliance requirements, which can be resource-intensive and time-consuming.
Change Management and Adoption	The adoption of analytics-driven energy management often necessitates a cultural shift within organizations. Employees must embrace data-driven decision-making, which can be met with resistance. Implementing change management strategies and fostering a culture of data literacy and analytics adoption is a challenge, as it requires buy-in from all levels of the organization to ensure successful integration and utilization of analytics solutions.

Source: (Adel, 2022; Akundi et al., 2022; Olsen, 2023; Aslam et al., 2020; Bakir, Dahlan, 2022; Cillo et al., 2022; Ghibakholl et al., 2022, Javaid, Haleem, 2020, Javaid et al., 2020; Cam et al., 2021; Charles et al., 2023; Greasley, 2019; Hurwitz at al., 2015; Nourani, 2021; Peter et al., 2023).

5. Conclusion

In the era of Industry 4.0, businesses are undergoing a transformative journey by integrating digital technologies into their industrial processes. Data analytics has emerged as a critical tool in this evolution, and its impact on energy management is particularly noteworthy. This article has explored the significant role of business analytics in optimizing energy consumption and resource utilization within the context of Industry 4.0.

The advantages of using business analytics in energy management are substantial. Firstly, it leads to cost reduction by identifying and addressing energy inefficiencies, thus lowering operational expenses in a highly competitive landscape. Secondly, it enhances energy efficiency by fine-tuning equipment, processes, and operations, resulting in reduced energy waste and a smaller environmental footprint. Thirdly, it contributes to enhanced sustainability by monitoring and managing energy usage effectively, aligning with global sustainability initiatives and demonstrating environmental responsibility.

Additionally, business analytics provides real-time monitoring and control capabilities, ensuring prompt responses to anomalies and minimizing costly disruptions. Predictive maintenance forecasts equipment failures, allowing for preventive maintenance and reduced downtime. It also enables participation in demand response programs, peak demand management, and regulatory compliance, all crucial aspects of Industry 4.0.

However, there are challenges and complexities to navigate in the application of business analytics in energy management within Industry 4.0. These include the complexity of integrating diverse data sources, ensuring data quality and security, developing and maintaining complex analytical models, managing high initial implementation costs, and addressing scalability concerns as organizations expand. Furthermore, bridging the talent and skill gap, ensuring interoperability of systems, navigating regulatory complexities, and managing the cultural shift toward data-driven decision-making pose additional hurdles.

In summary, business analytics is a game-changer in energy management within Industry 4.0 conditions. It offers a multitude of benefits, including cost reduction, enhanced efficiency, sustainability, and regulatory compliance. However, organizations must be prepared to address the challenges associated with data integration, quality, security, complexity, and talent to fully realize the potential of analytics in energy management. Embracing these challenges will empower organizations to thrive in the dynamic landscape of Industry 4.0 while contributing to a sustainable and efficient future.

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