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IMPLEMENTATION OF INNOVATIVE INDUSTRY 4.0 TECHNOLOGIES FOR THE RECONSTRUCTION OF THE ENERGY SECTOR OF UKRAINE

ВПРОВАДЖЕННЯ ІННОВАЦІЙНИХ ТЕХНОЛОГІЙ ІНДУСТРІЇ 4.0 ДЛЯ РЕКОНСТРУКЦІЇ ЕНЕРГЕТИЧНОГО СЕКТОРУ УКРАЇНИ

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Abstract. *The article explores the implementation of innovative Industry 4.0 technologies in the energy sector of Ukraine. It investigates key issues in the energy sector, including the reduction of electricity production capacities due to destruction, capture, and damage to property, low levels of innovation activity in energy enterprises, high energy intensity of production, moral and physical aging of equipment, and a low influx of foreign direct investments into Ukraine's energy sphere. The majority of the analyzed period indicates a relatively low level of interest from foreign investors in the examined sector of the domestic economy. The study identifies the Industry 4.0 toolkit applicable for the restoration of damaged and modernization of outdated infrastructure, enhancing the efficiency of Ukraine's energy sector. It is noted that among the tools, special attention should be paid to monitoring and forecasting systems, the Internet of Things (IoT), big data, integrated digital platforms, smart financial technologies, smart meters, remote monitoring systems, and artificial intelligence. The author emphasizes the peculiarities of applying this toolkit to solve the diagnosed problems in the energy sector of Ukraine. It is noted that the use of Industry 4.0 tools, namely the Internet of Things and big data analytics, can significantly improve the monitoring and management of energy processes. The problem of low innovation activity of Ukrainian energy companies can be solved by creating integrated digital platforms and developing partnerships between companies to share innovations. The use of smart financial technologies can make Ukraine's energy sector more attractive to investors. The high level of electricity losses during generation and distribution can be addressed by introducing smart meters and remote monitoring systems.*

Анотація. *У статті досліджено впровадження інноваційних технологій Індустрії 4.0 в енергетичному секторі України. Встановлено ключові проблеми енергетичного сектору, зокрема скорочення потужностей з виробництва електроенергії внаслідок знищення, захоплення та пошкодження майна, низький рівень інноваційної активності на підприємствах енергетики, високу енергоємність виробництва, моральне та фізичне старіння обладнання та низький приплив прямих іноземних інвестицій в енергетичну сферу України. У дослідженні визначено інструментарій Індустрії 4.0, що може бути застосовано для відновлення пошкодженої та модернізації застарілої інфраструктури, підвищення ефективності енергетичного сектору України. Відзначено, що серед інструментарію слід особливу увагу слід звернути на системи моніторингу та прогнозування, Інтернет речей (IoT), великі дані, інтегровані цифрові платформи, розумні фінансові технології, розумні лічильники, системи віддаленого моніторингу та штучний інтелект. Підкреслено особливості застосування даного інструментарію для вирішення діагностованих проблем в енергетичному секторі України. Зазначено, що використання інструментів Industry 4.0, а саме Інтернету речей і аналітики великих даних, може значно покращити моніторинг і управління енергетичними процесами. Проблему низької інноваційної активності українських енергетичних підприємств можна вирішити шляхом створення інтегрованих цифрових платформ та розвитку партнерства між компаніями для обміну інноваціями. Використання розумних фінансових технологій може зробити енергетичний сектор України більш привабливим для інвесторів. Вирішити проблему високого рівня втрат електроенергії під час виробництва та розподілу можна шляхом впровадження «розумних» лічильників і систем дистанційного моніторингу.*

Keywords: Industry 4.0, the energy sector, digital technologies, the Internet of Things (IoT), and renewable energy.
Ключові слова: Індустрія 4.0, енергетичний сектор, цифрові технології, Інтернет речей,відновлювальна

енергія.

Introduction

The full-scale military actions on the territory of Ukraine have led to extensive destruction of the energy infrastructure, posing new challenges to ensuring energy security in the country. Moreover, in the face of intensified global competition and rapid technological progress, Ukraine's energy sector has been facing the strategic task of adapting to modern requirements for several years. The post-war recovery is inconceivable without the active implementation of innovative Industry 4.0 technologies, which define a new era in the development of the energy industry, transforming it into an efficient, environmentally friendly, and resilient system.

Literature review and problem statement.

The issue of modernization and increasing the efficiency of the energy sector has been studied by many foreign and domestic scientists. Zaverbnyi A.S. (2019) considered the formation of Ukraine's economic policy in the field of energy in the context of European integration, the issue of energy efficiency of the national economy was considered in their works by Skrypnyk D.M. (2021), Ziabina Ye. A. (2021) and other researchers.

It should also be noted scientific works devoted to renewable energy Babyna O.M. (2020), Riazanova N. O. (2021), Bashynska Yu. I. ((2017), a team under the general editorship of Kudri S.O. (2020).

Acknowledging the substantial contribution of thorough scientific and practical research dedicated to the issues of technological modernization in the energy sector, the challenges of implementing innovative Industry 4.0 technologies in the process of rebuilding the domestic energy industry require further development and refinement.

The aim and tasks of the research is to deepen theoretical concepts and develop scientific-practical recommendations for the implementation of innovative Industry 4.0 technologies in the energy sector of Ukraine.

To achieve this goal, the following tasks were formulated and addressed:

- diagnosis of the main challenges and issues in modern conditions;
- analysis of the main types of innovative technologies of Industry 4.0 that can be implemented in the energy sector and the prospects for their use to ensure the energy security of the country.

Research Methods. In investigating this issue, a range of different research methods was employed, including methods of system analysis and synthesis, generalization method for studying and systematizing issues in the domestic energy sector; methods of comparison, statistical grouping, and economic analysis for examining the performance indicators of the energy sector; systemic and process approaches, formalization method for developing the concept of implementing Industry 4.0 tools aimed at modernizing the energy sector during the reconstruction process.

Results of the research.

Diagnosis of the main challenges and issues of the energy sector in Ukraine in modern conditions.

Energy is an integral part of the economic and social development of any country worldwide. Ensuring the stable and efficient functioning of the energy sector defines the energy security of a nation. For Ukraine, this is particularly crucial in contemporary times. Massive destruction of the energy infrastructure and the loss of energy assets in the occupied territories pose new challenges that can only be overcome by actively implementing innovative technologies.

Analyzing the volumes of domestic energy consumption in Ukraine from 2013 to 2022 (Fig. 1), it becomes evident that the efficient utilization of electricity, coal, gas, and oil is critical for ensuring energy stability and reducing dependence on imports.

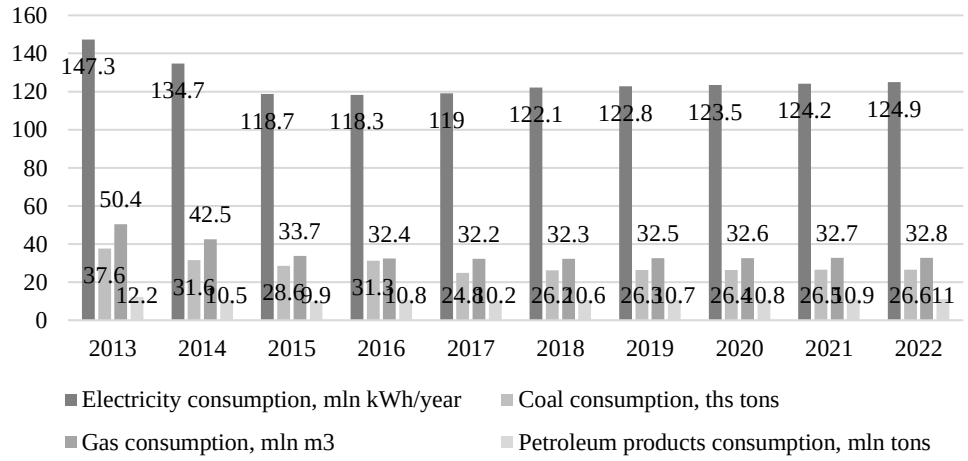

Fig. 1 - Volumes of energy consumption in Ukraine for 2013–2022

Composed based on: [7]

The data presented in Fig. 1 indicate a significant reduction in the consumption of coal and gas in Ukraine since 2017. In 2013, coal consumption amounted to 37.6 thousand tons, while in 2022, it was 26.6 thousand tons, representing a 29.3% decrease. Gas consumption also decreased by 34.9%, from 50.4 million m3 in 2013 to 32.8 million m3 in 2022. The consumption of oil products remained almost unchanged during the study period.

Simultaneously, there is a consistent trend of increasing electricity consumption. In 2022, compared to 2019, electricity consumption grew by almost 5%.

The reduction in the consumption of coal and gas can be attributed to the annexation of Crimea, military actions in eastern Ukraine, and the loss of territories and industrial facilities. The decrease in the consumption of energy resources (coal, gas) in Ukraine over the study period can be considered a positive trend, indicating a reduction in the country's dependence on imported energy resources. However, like any phenomenon, it has a negative aspect, namely, it may lead to a decrease in industrial production and an increase in energy prices for the population.

The increase in electricity consumption underscores the necessity for the strategic development of this sector, becoming a key factor for the country's economy and energy security.

Considering the growing demand for electricity, the strategic development of the energy sector requires not only the expansion of production capacities but also emphasizes the need for attracting direct investments. Attracting investors becomes a strategically important task for the effective expansion of the energy infrastructure and improvement of its technical condition.

The analysis of foreign direct investment data from 2010 to 2022 demonstrates significant fluctuations in different years of the analyzed period (Fig. 2). For instance, in 2020, the energy sector in Ukraine experienced the highest volume of foreign direct investment. However, the majority of the analyzed period indicates a relatively low level of interest from foreign investors in the examined sector of the domestic economy.

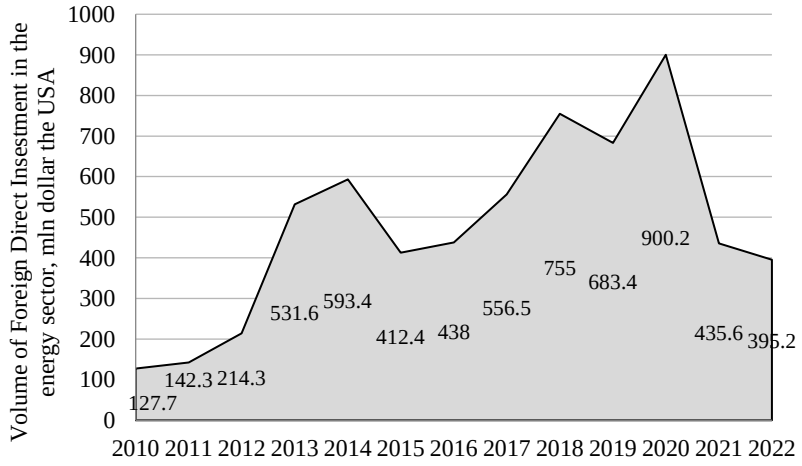

Fig. 2 - The volume of FDI (Foreign Direct Investment) in the energy sector, million USD, 2010-2022

Composed based on: [8] [11]

One of the problems that significantly impacts investors' perception of the viability of investing in the Ukrainian energy sector is the bureaucratic procedures associated with connecting to the power supply system. One of the components of the Doing Business rating is the indicator related to connecting to the power supply system (Fig. 2).

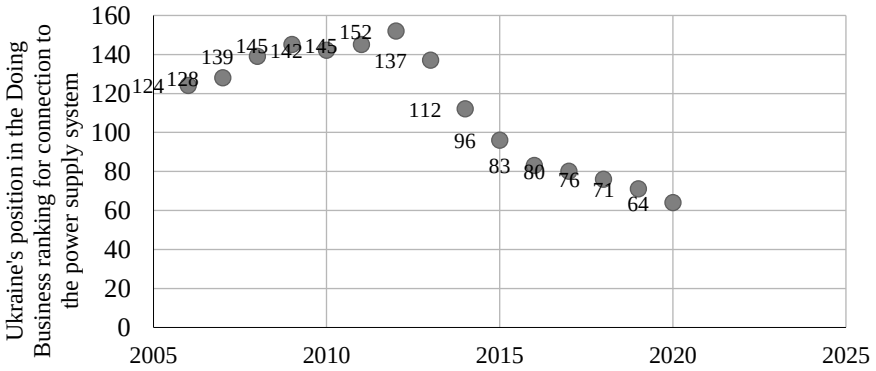

Fig. 3 - Ukraine's position in the Doing Business ranking for connection to the power supply system

Composed based on: [9]

Analyzing the Doing Business indicator of connecting to the power supply system in Ukraine from 2006 to 2020, several key points can be highlighted. There is a positive trend in improving business conditions in the energy sector. Ukraine moved from the 152nd position in 2012 to the 64th position in 2020. Since 2017, Ukraine has maintained this positive trend, indicating systematic efforts and positive transformations in the energy infrastructure.

However, despite the positive progress, it is crucial to emphasize the need for sustained improvement in business conditions in the energy sector, specifically addressing the remaining challenges and optimizing connection procedures. Ukraine's success in enhancing the business environment in the energy sector signals development prospects but underscores the necessity for continued efforts to achieve sustained improvement.

As noted by domestic researchers (Shimanyuk, Miroshnyk & Blinov, 2022), Ukraine continues to face challenges with electricity losses during distribution. While European countries typically have electricity loss rates ranging from 4-6%, Ukraine's figure exceeds 10%, reaching up to 20% in certain regions. [12]

It's worth acknowledging that Ukraine's energy sector has taken significant steps to reduce energy consumption (Fig. 1) and enhance energy efficiency, along with increasing the share of renewable energy. According to the Ministry of Ecology and Natural Resources (2021), the proportion of renewable energy sources in electricity production increased from 7.9% in 2015 to 11.3% in 2020. [13] Despite this intensive growth in the share of renewable energy sources, Ukraine has not yet caught up with Europe, where solar and wind energy accounted for 22% of total electricity production in 2022 (Centre for Research on Energy and Clean Air, 2023). [14]

Diagnosing the main problems in the domestic energy sector allows asserting that for its further modernization, Ukraine needs to more actively utilize the Industry 4.0 toolkit. This approach opens up new possibilities for enhancing the efficiency of energy production, transmission, and consumption, ultimately ensuring the overall energy security of the country.

Analysis of the main types of innovative technologies of Industry 4.0 that can be implemented in the energy sector and the prospects of their utilization for ensuring the country's energy security.

Over the past decade, the world has undergone significant advancements in technology, reshaping the paradigm of management and operation across various economic sectors. Consumer demands and contemporary global challenges necessitate the energy sector to adopt intelligent and innovative solutions for efficiency and resilience.

Industry 4.0, characterized as the fourth industrial revolution, provides a unique toolkit for transforming the energy sector. The use of modern technologies such as the Internet of Things (IoT), big data analytics, artificial intelligence, integrated digital platforms, and smart financial technologies becomes a key factor in achieving high efficiency, resilience, and competitiveness in the energy industry.

In this context, it is crucial to analyze and determine how the Industry 4.0 toolkit can be employed to optimize production, enhance reliability, and ensure the sustainable development of the energy sector. The following provides a detailed overview of the tools that will form the basis of our further analysis and investigation.

Table 1 - The conceptual foundations of implementing innovative Industry 4.0 technologies for the reconstruction of Ukraine's energy sector

The problem aspects of the functioning of Ukraine's energy sector	The toolkit of Industry 4.0	Features of applying the toolkit of Industry 4.0
Reduction of electricity production capacities due to destruction, seizure, and damage to property	Monitoring and Forecasting Systems, Internet of Things (IoT), Big Data	Utilizing sensors and analytics for real-time equipment monitoring and forecasting, enabling efficient planning for repairs and maintenance, involves the application of the Internet of Things (IoT) and processing large volumes of data (big data). These technologies allow for the automated collection and analysis of data from equipment sensors, providing operators of energy systems with the necessary information for effective facility management and maintenance planning.
The low level of innovation activity of energy enterprises.	Integrated digital platforms.	Creating integrated digital platforms in the energy sector promotes the collaboration of various sectors and companies, facilitating effective exchange of innovations and joint development of strategies to enhance competitiveness. These platforms also expand opportunities for integrating renewable energy sources and modernizing energy infrastructure, strengthening energy resilience, and contributing to the sustainable development of the sector.
Low level of foreign direct investment inflow into the energy sector of Ukraine.	Smart financial technologies.	The use of fintech solutions in the energy sector allows for optimizing financial planning, cost control, and risk analysis. This enhances the transparency of finances in energy enterprises, fostering investor interest. Fintech tools also aid in collecting and analyzing data on energy production and consumption, contributing to the precise development of investment strategies for sector development. This approach amplifies investor interest in renewable energy sources and the modernization of energy infrastructure.
High level of electricity loss during its production, transmission, and distribution.	Smart meters and remote monitoring systems, artificial intelligence.	The use of 'smart' meters and remote monitoring systems allows for the automatic regulation of electricity transmission modes and ensures its efficient distribution, preventing energy losses. The application of artificial intelligence (AI) in conjunction with these technologies enables the forecasting and adaptation of the energy system's operation to changes in demand and conditions, contributing to the prevention of energy losses and the overall improvement of the energy sector's efficiency.

Examining the conceptual foundations of implementing innovative Industry 4.0 technologies for the reconstruction of Ukraine's energy sector allows for the following observations.

Firstly, the application of Industry 4.0 tools such as the Internet of Things and big data analytics can significantly

enhance the monitoring and management of energy processes. Developed countries, like Germany, have successfully utilized smart grid systems to optimize the energy grid.

Secondly, the issue of low innovation activity in Ukraine's energy enterprises could be addressed by establishing integrated digital platforms and fostering partnerships between companies for the exchange of innovations. Drawing lessons from the United States, where digital platforms are effectively implemented in the energy sector, could provide valuable insights.

Thirdly, the use of smart financial technologies can make Ukraine's energy sector more attractive to investors. It is advisable to leverage the experiences of countries such as Switzerland and Singapore.

Fourthly, addressing the high level of electricity losses during production and distribution can be achieved through the implementation of 'smart' meters and remote monitoring systems, as successfully demonstrated in Japan. These solutions allow for the automatic regulation of electricity transmission modes and ensure efficient distribution, thereby preventing energy losses.

The overarching trend emphasizes the imperative need for the active implementation of innovations to enhance Ukraine's energy sector and improve its efficiency in the face of global challenges and energy market demands.

Conclusions.

This researched work meticulously examines the significant role played by digital technologies, the Internet of Things (IoT), and artificial intelligence in transforming Ukraine's energy sector. The emphasis is placed on key aspects of implementing "smart" systems in energy, including production and distribution optimization, loss reduction, and increased efficiency and reliability of energy networks.

The paper outlines the major advantages of digital transformation in the energy sector, particularly in the context of increasing the use of renewable energy sources and improving energy independence. It underscores that digital technologies can help address crucial challenges such as aging infrastructure, lack of investment, hindering the rapid development of the industry.

In conclusion, the paper asserts that the modernization of the energy sector through digital technologies is a strategically vital factor for enhancing efficiency, competitiveness, and energy security in Ukraine's future.

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