OVERVIEW OF NEW TECHNOLOGIES, MANAGEMENT MECHANISMS AND BUSINESS MODELS IN THE ENERGY INDUSTRY CREATED WITH THE USE OF ARTIFICIAL INTELLIGENCE TECHNOLOGIES

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Abstract.

The world is increasingly captivated by digital technologies. They permeate every sphere of human life, and energy is no exception.

All its segments are subject to significant changes: management of power systems, response to events, data collection, consumption, generation of electricity by private and industrial sectors.

"Smart" meters are being used more and more actively to collect and process huge amounts of information. Thanks to the received data, accurate forecasts of generation, consumption and the need for maintenance are built, and new offers are prepared for customers.

Thanks to new approaches, companies and private consumers can significantly save on services and energy efficiency.

Key words: management, energy efficiency, innovation, energy industry, artificial intelligence.

Introduction.

The development of the latest energy technologies significantly affects the strategic priorities of energy development. Separate technologies, at the same time, lead to changes in the conditions and principles of functioning not only of individual energy systems, but also of socio-cultural aspects of energy consumption.

Automation of technological processes, development of smart networks (Smart-Grids), artificial intelligence (Artificial intelligence) and innovative digital business platforms will allow effective management of energy supply and consumption regimes. New technological solutions – a wide variety of generating capacities (for example, renewable energy sources or energy storage), energy-consuming installations (for example, household appliances, electric cars, etc.) will allow to balance the demand and supply of energy. Moreover, the use of artificial intelligence (AI) technologies becomes not only a way to reveal new opportunities in the organization of the energy supply process for consumers' needs, but also an effective tool for ensuring sustainable development and operational security of energy supply systems. On the other hand, the use of AI technologies, which contribute to the decentralization of the energy supply system and increase the flexibility of responding to the needs of consumers, significantly affects the functioning of existing centralized energy supply systems. This circumstance is a serious challenge and will require strategic decisions regarding the country's energy development priorities.

The large-scale armed aggression of the Russian Federation against Ukraine, which began on February 24, 2022, destroyed the planned process of gradual modernization of the country's energy assets. However, overcoming the consequences of an armed invasion can become a factor in the transformation of the country's entire energy sector. Ukraine, in the process of post-war recovery, should use the chance to rebuild the energy infrastructure immediately on the latest technological base, already adapted for the widespread use of AI.This publication offers an overview of the possibilities and ways of using AI in the energy sector, reveals new models for the organization of interaction between participants in energy markets and business models arising from the use of digital technologies. Examples are given of how new models of relations between energy producers and consumers transform models of energy markets, creating new investment opportunities not only for energy companies, but also for third parties.

The study also analyzes the state of implementation of AI technologies in the practical activities of energy companies, and identifies obstacles to their widespread implementation. It is noted the need not only to develop and improve actual scientific knowledge and AI technologies, but also to create programs for training specialists in the field of AI for the needs of the energy industry and retraining the personnel of energy companies. A separate direction of ensuring the development of AI and its application should be the formation of reliable protection of information, both personal and commercial, that will be used by AI. Equally important is the task of overcoming society's lack of acceptance of new technologies.

Basic concepts.

Blockchain (Blockchain). In general, Blockchain is a decentralized (distributed) public (open) digital ledger that records any transaction of value: money, goods, property, work or votes. It is also an interconnected and ever-expanding list of records securely stored in a peer-to-peer network. Each member with access can view information simultaneously without a single point of failure, building trust in the system as a whole.

In the energy sector, blockchains are basic digital platforms that allow building automatic, decentralized accounting programs.

Thus, blockchain technology allows for the implementation of smart contracts (Smart Contracts, which are executed automatically according to the established algorithm), which can be used to fix the energy purchase and sale operations of many participants without an intermediary, for better management of energy systems and the integration of a greater share of RES.

Virtual Power Plant (VPP) is a cloud-based distributed power plant that combines the capacities of a network of decentralized, medium-sized power units, as well as flexible consumers and electricity storage systems in order to increase electricity production, as well as trade or sell electricity on the electricity market.

Such a system of decentralized generating capacities is only virtually connected and controlled by a single centralized control system. The components of the system can be electricity producers (for example, wind, biogas, solar, hydropower plants or thermal power plants), electricity consumers (prosumers), electricity storage (accumulators) or installations operating on the principle of "energy to X" conversion (for example, electricity-heat and electricity-gas).

Today's largest virtual power plants have already exceeded the combined capacity of the largest nuclear power plants.

Demand Side Management can be used in different ways. Most often, the service is sold in the form of a guarantee of "stability" of the consumption schedule, provided by large industrial companies, which compensate for the actual irregularity of the schedule by adjusting the equipment. Also, the demand management service is provided by energy suppliers through the use of mechanisms (price incentives) of wholesale markets and power markets applied to consumers, forcing them to change consumption volumes. Expanding the use of demand-side mechanisms can be achieved by encouraging new business models emerging from the use of digital technologies and setting standards for the controllability of smart equipment and appliances.

For example, the IEA estimates that digitalization could reduce global energy demand in the building sector by up to 10% by 2040 and could increase demand response capacity by more than tenfold. This function will be implemented by using the potential of smart equipment. By 2050, 11 billion smart devices (IoT) could be deployed, thus potentially becoming a response tool for consumer-side energy generation.

Peer-to-Peer trading (P2P) is an online trading model where consumers can trade electricity among themselves without intermediaries at an agreed price. It is a model where prosumer consumers can share their excess available/produced energy with other consumers within the decentralized network they belong to, further encouraging the consumption and deployment of distributed renewable generation.

Energy-as-a-service (EaaS) is a business model where customers pay for energy services without having to make any upfront capital investment. EaaS models typically take the form of subscribing to electrical devices owned by a service company or managing energy usage to provide a desired energy service.

Pay-as-you-go (PAYG) (Pay-as-you-go model) is a cloud-based energy payment model that charges based on resource usage, i.e. when only the resources actually needed are calculated. Such a model relieves customers in the markets of the burden of fully reimbursing the cost of investments in generating capacity in advance. Instead, ownership of the energy-generating equipment (for lighting or cooking) is transferred to the consumer over time, according to an agreed plan of periodic fixed payments.

The Internet of Things (IoT) (Smart Equipment) are smart devices that monitor, transmit and interpret information from the environment in real time. The Internet of Things (IoT) makes it possible to collect meaningful data and optimize the system, enables the creation of smart networks (Smart Grids) as it improves the visibility of energy systems that are becoming increasingly complex and decentralized and increase the speed of response to changes in the operating modes of devices connected to the network.

Smart Grids are electrical grids that use digital and other advanced technologies to monitor and manage the supply of electricity from all sources to meet the diverse needs of end-users of electricity. Smart grids coordinate the needs and capabilities of all electricity producers, grid operators, end-users and electricity market stakeholders to ensure that all parts of the system operate as efficiently as possible, minimizing network costs and environmental impact, maximizing system reliability, resilience and stability.

The world's energy companies have a strategic plan to become companies - leaders in the application of digital technologies and are directing significant resources to innovation, smart equipment and the deployment of smart electricity networks.

For example, Enel has launched Network Digital Twin, a digital platform that creates modern and accurate virtual copies of physical power supply networks and their components and system dynamics, enabling improved network operation and design, integration of distributed energy resources and workforce management. In 2020, the State Grid Corporation of China also announced plans to invest around US$3.5 billion in digital infrastructure. In 2021, it and the National Development and Reform Commission of China announced a pilot project to develop a green energy trading platform based on blockchain technology. Power grid equipment manufacturers such as Siemens, General Electric and Hitachi Energy have made digital technology the core of their business.

Distributed Energy Resources (DER) are small or medium-sized resources that can potentially provide services to the power system and are directly connected to the local distribution network or to end-user networks. DER includes distributed generation (RES), end-user energy storage (accumulators behind the meter) and load regulation services (consumption management), which is implemented by responding to the operating modes of smart equipment, household appliances, the use of electric vehicles with smart charging (EM), heating systems (heat pumps, electric boilers enabled by smart meters and data services) etc.

Dynamic line rating (DLR). Dynamic Transmission Line Rating (DLR) allows you to determine the actual (rather than predicted) carrying capacity of transmission lines, taking into account real weather conditions (ambient temperature, solar radiation, wind speed and direction, humidity, etc.) in combination with real-time line condition monitoring. DLR technology reduces congestion on transmission lines, optimizes asset utilization, increases efficiency and lowers costs. The network operator analyzes the DLR constantly in real time in order to minimize congestion in the network.

Net billing schemes are a pricing system, a way of charging and compensating consumers based on the actual market value of electricity that balances what they consume and what they feed into the grid.

Virtual power lines (VPLs) (Virtual transmission lines). VPLs provide large-scale integration of solar and wind energy without grid overload or redistribution, avoid the need for large investments in grid development due to the need to connect RES. VPLs consist of local utility energy storage systems connected to the grid at two key points: one on the supply side, storing excess generation from renewable sources that could not be transferred due to grid congestion; the other on the demand side, charging when grid capacity allows and then discharging when needed.

Time-of-use tariffs (Multi-zone tariffs) are a system of time-varying tariffs (in Ukrainian terminology, zone tariffs) that stimulate load adjustment, whether manual or automatic. This allows customers to save on energy costs while benefiting the system.

Energy Storage (Energy accumulators, batteries) are technologies that can store excess energy in the network/producer at one point in time and return it to the network/consumer at another. Technologies help to level the system load schedule and create better conditions for RES integration into the system.

Today, large-capacity industrial stationary batteries are used by large utilities and distribution networks to balance energy supply and demand. By 2030, the capacity of small storage batteries is expected to increase significantly, complementing industrial systems.

Batteries (in the premises/on the customer's territory) are connected behind the meter of industrial or domestic consumers, primarily for the purpose of saving electricity bills.

As of the end of 2020, the total capacity of storage batteries installed in power grids was about 17 GW. In 2020, the number installations increased by 50% compared to the average year of 2019. In total, more than 5 GW of capacity was added, of which countries such as China and the US installed more than 1 GW each. The market continues to be dominated by installations installed in distribution networks.

Total investment in battery cells increased by almost 40% in 2020 to US$5.5 billion. Battery costs in grid (high-capacity) equipment increased by more than 60%, driving investment in renewable energy sources and the growing presence of digital electricity trading platforms, particularly energy storage auctions. However, investment in private (by the meter) batteries fell by 12%, as these assets tend to be financed by households and small and medium-sized companies, which have generally been more affected by the Covid-19 crisis. In Europe, there is a reverse trend, when the fall in the installation of storage devices in local networks was compensated by the installation of batteries in private premises. The leading market in Europe is now Germany, where the number of metered installations has almost doubled. A similar trend is observed in Japan, where the capacity of home battery systems has increased to 300 MW in 2020.

In July 2021, China announced plans to install more than 30 GW of energy storage by 2025 (not including pumped storage (SHP), which would provide a nearly tenfold increase in its installed capacity as of 2020. The IEA estimates that the total installed capacity of battery energy storage systems in in the world by 2030 will reach more than 500 GW.

We are standing on the threshold of decentralization of energy supply, when each village or even a separate district of the city will not depend on the general electric network, as it is now, but will have its own capacities.

These "energy islands" will be controlled by an internal system that will synchronize with the general network if necessary.

Every year, electricity consumption increases along with the unpredictability of loads. The emergence of a large number of electric vehicles, private and "green" generation, as well as the global growth in the use of various gadgets lead to the fact that it becomes more difficult for operators to predict consumption peaks.

This leads to destabilization of the network and significant costs for attracting shunting power and dispatching electricity. News about the creation of micro-networks on the basis of cottage towns is appearing more and more often.

This makes it possible to use the potential of "green" energy, electric energy accumulators and "smart" approaches in its use to the maximum. It is impossible to deny the positive impact of such systems on the cost of electricity and the stability of the power grid.

In the future, more and more communities will create their own micro-networks. Technologies of "smart" networks and high-speed data transmission play an important role in their development. A "smart" network allows you to use resources as efficiently as possible, to respond to events faster.

The "green" generation has not been a miracle for a long time. Windmills and solar panels can be seen not only in closed fields and large factories, but also in the yards of private homes and on the roofs of apartment buildings.

"Green" energy allows you to significantly save on electricity bills, and sometimes to completely refuse the services of suppliers.

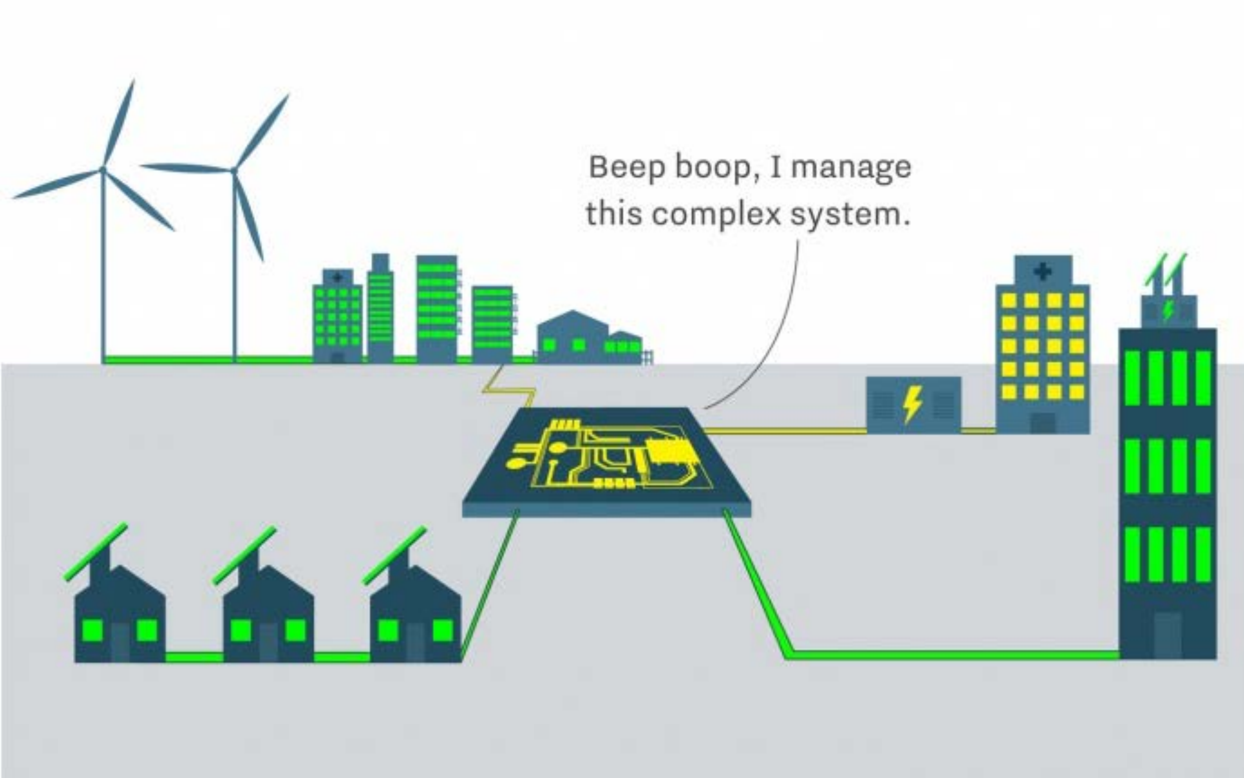

Figure 1. Energy microsystem work.

These are undeniable advantages for the private sector, but when it comes to global energy, where the "green" part wins an increasing share of generation, we face a number of large-scale problems.

Among them are excess energy in the hours of maximum efficiency and absence of a consumer, limitation of the transmission capacity of power lines, lack of generation in hours when productivity is low.

To solve these problems, solutions are being developed to optimize the generation, distribution and use of electricity within the network.

For example, the Luxoft company developed a POC (proof of concept) system for accurate management of microgrid resources with a small number of users (up to 10,000) and the ability to synchronize and work with external service providers.

Such a platform is built on the basis of "smart" meter and blockchain technologies. It allows not only to change the cost of electricity within a short time and depending on network capabilities, but also to keep safe and accurate records of all operations.

The introduction of 5G provides new opportunities in the transmission of data from the consumer to the system: faster response to events, a greater amount of useful information for building forecasting models of electricity production and consumption, operational tracking of thefts and losses.

Analysts believe that the introduction of 5G will also reduce the cost of data transmission with higher stability and quality.

This will make it possible to quickly develop "smart" microgrids and distributed generation, to create virtual electricity storages. They will allow to control a huge number of scattered energy generation installations.

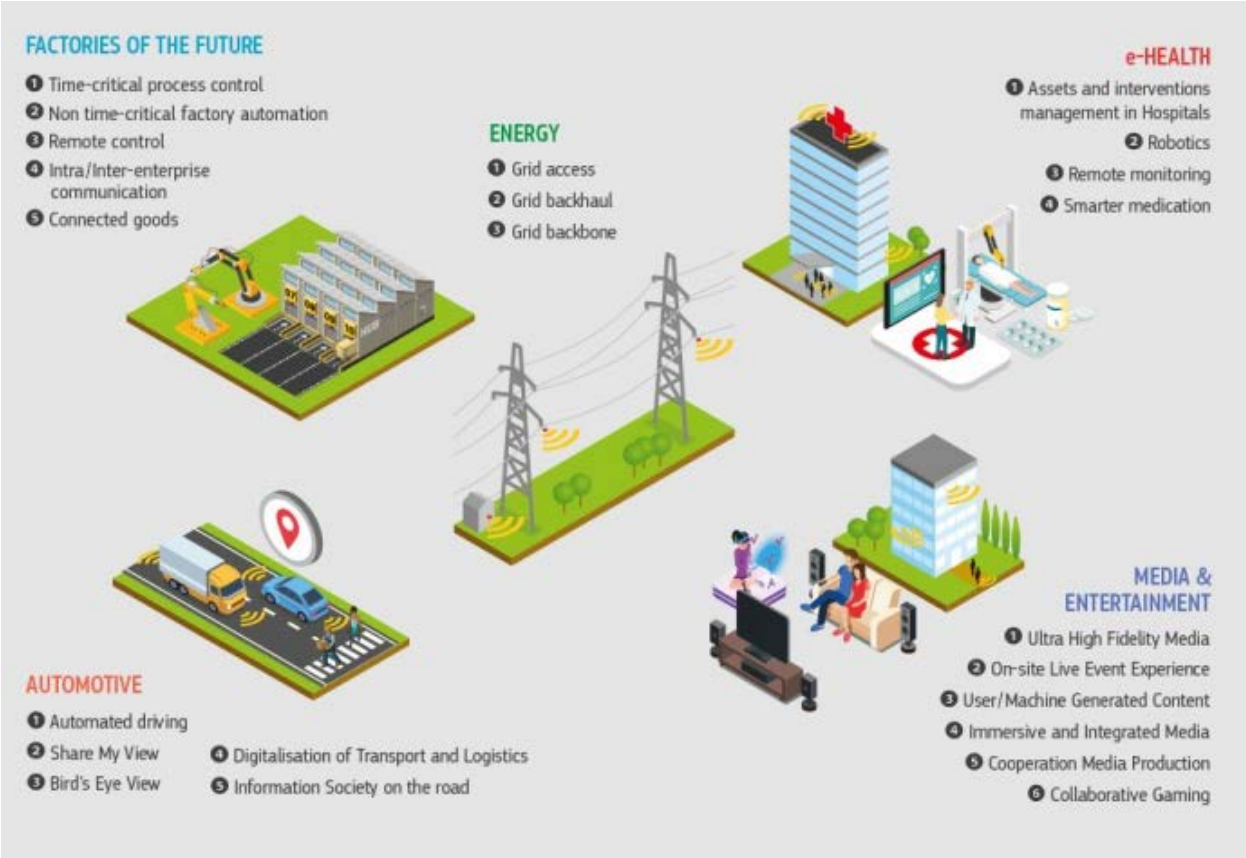

Figure 2. Areas that 5G brings to a new level. Energy is among them.

Source: 5GROWTH.EU.

In mid-November, the British edition of The Economist published a traditional puzzle cover with forecasts for the coming year. Among the top topics, as expected, the war in Ukraine, the elections in the USA and Russia, the conflict in the Middle East, artificial intelligence and much more remained.

Economists paid special attention to the "new energy geography of the world".

The key emphasis is on the transition to clean energy, which should redraw the energy map of the world and create new "green" superpowers. In them, lithium, copper and nickel will be much more important, while the role of oil and gas, as well as the regions that dominate their supply, will decrease.

This year, for the first time in three decades of various UN climate conferences, the world community called for the abandonment of fossil fuels in energy systems. And although the final decision of the last COP28 conference did not spell out a clear plan to abandon the use of coal, oil and gas, this event still became historic: before that, none of the COP documents mentioned it.

As the Bloomberg agency notes, in order to find a compromise that would satisfy the USA and the EU on the one hand, and Saudi Arabia on the other, the final text of the decision had to be changed at the last moment.

The shift away from fossil fuels to renewables has been named as one of several measures to reduce greenhouse gas emissions aimed at stopping global warming at 1.5 degrees Celsius compared to pre-industrial levels. Currently, fossil fuels account for about 80% of the world's electricity production.

The statement also set out plans to triple global renewable energy capacity by 2030 and step up efforts to reduce coal consumption.

Global coal-fired power generation will peak in 2023 as renewables continue to supplant it, according to the latest research from Rystad Energy. According to him, about 10,373 TWh of electricity will be produced this year by burning coal around the world. In 2024, this indicator will decrease to 10,332 TWh.

Coal has dominated the global energy sector for the past 30 years, but Rystad data shows that 2024 will mark the start of a decline in the use of this fuel, with the parallel rise in popularity of solar and wind generation.

It is expected that from next year, the supply of "green" electricity will outpace the overall growth in electricity demand, which will gradually lead to the displacement of coal.

The coal-fired power sector is the largest source of global pollution, accounting for about 40% of all emissions today. And this problem was only getting bigger.

Asia has added more than 40 GW of new coal capacity each year over the past five years and is expected to add another 52 GW next year. Most of the new capacity is in China, followed by India and Indonesia.

According to Rystad Energy's forecast, the increase in capacity in these countries will continue until 2027, albeit at a slower rate, after which the number of coal-fired power plants there will also begin to decline.

In parallel with the increase of coal generation in Asia in the next few years, the European Union will continue to systematically abandon this type of fuel.

In recent years, thanks to the reduction of production costs and ambitious plans for the "green" transition, global renewable energy has been growing by tens of percent every year. For example, EU countries installed a record 56 GW of solar power plant capacity in 2023, which is 40% more than last year.

In general, the European solar energy market has been growing by at least 40% for the third year in a row. According to SolarPower Europe, the record holder in 2023 was Germany, which installed 14.1 GW of new SPP capacity. It is followed by Spain with 8.2 GW, Italy with 4.8 GW, Poland with 4.6 GW and the Netherlands with 4.1 GW.

The constant decrease in the cost of producing solar modules leads to setting new records every year.

So, over the last year, the cost of production in China fell by 42% - to $0.15 per W. In India - up to $0.22, Europe - $0.3, and the USA - $0.4 per W.

Rystad forecasts that a total of about 300 GW of solar and 140 GW of wind capacity will be installed worldwide next year, more than half of which will be in Asia, where there is a more pressing need to begin displacing coal generation.

In terms of money, global capital investment in solar and wind capacity next year should exceed $600 billion.

In the coming decades, the world also plans to completely abandon fossil fuels, while at the same time increasing the capacity of renewable energy at a record pace.

The planned "green" transition requires a huge amount of metals used in the production of batteries for electric cars, charging stations, wind turbines, solar panels and energy storage (Energy Storage - EP). The most popular of them today are lithium, nickel, copper and cobalt.

Metals critical to clean technologies are scattered all over the world, but most of them are in China. Beijing today controls 60% of the world's lithium processing capacity and 80% of rare earth metals, produces 77% of batteries, 75% of solar panels and 60% of electric cars, which has made EU countries dependent on its supplies.

In order to achieve independence in "green" technologies, the EU countries set a goal by 2030 to extract 10% of critical raw materials, localize 40% of their processing, and also produce 40% of the attributes of the "green" economy: electric cars, solar panels, wind generators. To implement this plan, it will be necessary to win competition from the USA and China.

However, victory in this struggle promises considerable profits. According to the assessment of the consulting company Benchmark Mineral Intelligence, by 2035 profits from the sale of lithium-ion batteries alone will increase to 700 billion dollars.

But by that time, at least 730 billion dollars will have to be "poured" into factories, mines and other production lines in order to satisfy the demand not only for lithium, but also for other important metals - nickel, cobalt, copper, etc. "It's going to be a race to see who can develop the most advanced technology in the world," says Glen Merfeld, chief technical officer of Albemarle, the world's largest lithium company.

And the global oil giants have already joined this struggle. American ExxonMobil recently announced plans to become the leading supplier of lithium for electric vehicles by 2030.

The Great War in Ukraine, the energy crisis provoked by the actions of the Russians, and a significant increase in prices forced countries that do not have sufficient gas and coal production to look for an island of stability. And they found it in atomic energy.

A great example is Japan. After the accident at the Fukushima-1 nuclear power plant, the authorities closed most of the nuclear reactors and reduced the share of nuclear power plants in the production of electricity from 30% to 4%. The energy system was rebuilt for natural gas and coal, which were bought on the world market.

As a result, the country suffers from rising energy prices and is forced to make compromises with the terrorist state, buying Russian liquefied gas. And in the event of a military conflict in the region, the country's entire energy sector will be at risk due to the vulnerability of the ports.

All this pushed the authorities to revive atomic energy in Japan. About 20 reactors are being prepared for restart. According to the plan, in 2030, nuclear power plants will produce 20-22% of the country's electricity.

Turkey found itself in a similar situation. The country is trying to mitigate its dependence on gas and coal by implementing large nuclear projects with the Russians and Chinese.

China is constantly growing and needs more energy, but produces 60% of its electricity from coal. The authorities plan to abandon this energy carrier by 2060. To replace coal-fired power plants, the country plans to build six to eight new nuclear reactors per year. Together, China and India are currently building 29 of the 57 new reactors being built around the world.

A few years ago, the United States took a course to extend the service life of its nuclear power plants, as well as the development of small modular reactor technologies. They are expected to be cheaper, easier to build and more commercially attractive. Billions of dollars in government subsidies will be spent on their construction and testing in the US.

After heated discussions, the nuclear "break" happened in the European Union as well. A group of countries, led by France, achieved the inclusion of nuclear energy in the list of environmentally friendly, which improved the industry's access to financing from investors and governments. The "break" was facilitated by the gas war with Russia and the bloc's desire to be the first to achieve "carbon neutrality".

Of the major countries in opposition to nuclear power, only Germany is standing, which closed its last nuclear power plant this year under the pressure of the "greens". However, there is no complete political consensus on this decision. There are already calls not to dismantle the German reactors, but only to preserve them.

In general, it can be said that the whole world finally believed in nuclear energy, so its share will grow every year. According to the forecast of the World Nuclear Association, in the next 17 years, the production of nuclear energy in the world will increase by 75%.

Complex management systems that monitor and manage production are a specific case of practical application of an AI system with the "physical dimension" of implementing its solutions. Various sources of information, algorithms for its collection and processing related to a specific physical technological process are used for the operation of such a system. In the future, AI can forecast demand, optimize production goals, issue tasks for stages of the technological process, detect events/anomalies on production lines, etc.

It should be noted that more and more individual elements of the technological process are controlled by AI systems, and production processes are becoming more and more autonomous. The set of all AI algorithms/models used to manage technological processes form an analytical model of production ("digital twin" of the enterprise), which significantly increases the efficiency of management activities.

However, today not all AI capabilities are used by energy companies. For example, the EDF campaign uses AI for a limited set of tasks, namely: predicting equipment maintenance needs at power plants, identifying parameters/components to display in digital models of equipment operation processes, and to better understand consumer energy consumption behavior.

The widespread use of AI for the purpose of managing technological and management processes still requires time to eliminate technology imperfections and change business culture. Despite the above-mentioned possibilities of using AI, traditional energy companies (the energy sector based on the existing concept of large centralized systems) are cautious about the widespread use of the new technology, which is partly related to the perception by energy companies and consumers of the potential risks of its use.

At the same time, in the renewable energy sector in the development of decentralized systems, there is a trend towards a significant growth of digital energy business projects. In 2020, early-stage venture capital investments in energy-efficient and flexible startups with new or innovative business models amounted to about USD 900 million (excluding external investments of an average of USD 150 million per deal), which 20% more than in 2019 and three times the level of funding in 2016.

At the same time, the main barrier to the further implementation of AI in the energy industry is resistance to change/conservatism of employees (chosen by 85% of survey respondents24). Such inertia to the introduction of new technology is often explained by the existing organizational culture in companies, when employees are afraid of losing their jobs (AI will replace them) and entrusting AI to make important decisions that will affect the assets for which they are responsible.

Another factor in the formation of resistance to AI is the imperfection of technologies in terms of specific technical aspects of their application and interoperability with other equipment. The wide variety of "smart equipment" and the large number of manufacturers do not allow at the moment to standardize the requirements for the design, production and use of such equipment, as well as for data processing and information exchange with other equipment. Users of such equipment need to make additional efforts to choose a certain type of equipment and its manufacturer, which must be consistent with the requirements set by the operators of individual services during the connection process, for example, the requirements of distribution network operators.

In addition, quite often the main modes of operation of the equipment do not agree with the modes and procedures of the operator of distribution networks. For example, in the case of disconnection of the consumer from the network due to an emergency shutdown and when the operator subsequently restores the power supply, the smart equipment will not be included in the operation by default (appropriate settings at the software and hardware level), which will require manual connection of the equipment and adjustment of its operating modes. This can become a significant problem when consumers, especially households, do not have a sufficient level of knowledge to carry out such procedures.

Another problem is that AI systems themselves, as systems connected to digital networks, are vulnerable to cyber attacks. The number and scale of cyberattacks and the spectrum of cyberthreats to energy infrastructure are constantly growing. A cyberattack can cause loss of control over technological equipment and processes, which in turn will cause physical damage and widespread disruption of power supply functions.

In addition to affecting equipment operations (critical services, households, and businesses), a cyberattack can cost electric utilities millions or even billions of dollars, including the costs of combating a cyberattack (i.e., detection, investigation, containment, and recovery) and its aftermath (eg business interruption losses, loss of information, loss of revenue and damage to equipment).

Important aspects that today form a whole set of problems related to the application of AI are issues of security and protection of human rights, in particular in the area of personal data protection.

This also applies to household consumers. In particular, owners of "smart home" systems or smart equipment fear the disclosure of private information, which can be indirectly done by reading data from sensors installed in the house and equipment. Research has shown that the biggest barrier to smart meter adoption is the fear of exposing private information without knowing exactly how it is being used. These fears are justified, as there is still no regulation on the handling of this confidential data, which is important for the electricity system of the future.

Another direction of criticism of AI is the increase in energy consumption. Processing large amounts of data consumes a lot of electricity. When using AI to transform the energy system, it is also important to consider that the data centers themselves will affect the amount of energy consumption, accordingly, they should be designed as energy-efficient and climate-neutral as possible. The growing use of IoT also has major implications for energy consumption. First of all, these are energy costs associated with connecting devices to the network. This is a problem that needs to be managed and ensured that the power consumption of the network connection does not become excessive as more and more devices are designed with network capabilities.

The conducted analysis demonstrates the positive aspects of the use of AI and the factors that significantly inhibit its implementation in the energy sector. In the coming years, however, the inevitable penetration of AI into various aspects of the activities of energy companies is expected. Digitization and the application of AI is a key way and tool to manage large and increasingly complex systems.

AI is a tool for the successful transformation of the energy sector, as it allows the integration of the latest and promising technological innovations in the energy sector and the resulting changes in the organization of the functioning of energy supply systems (decentralization of energy production and distribution and electrification of various technological processes).

Decentralization is driven by the increased deployment of small, geographically distributed generating capacities, such as solar and wind farms, which are connected to the local distribution network. Electrification of transport and buildings (heating and cooling), household consumption, includes a large number of new loads, such as electric transport, heat pumps and electric boilers, household works, etc. All of these new assets on both the supply and demand sides are complicating the energy sector, while making the application of AI for monitoring, management and control critical to the success of the energy transformation.

AI technologies can support the functioning of energy supply systems, taking into account the existing trends of technological development and the transformation of energy market organization models34 in several ways, including better monitoring, operation and maintenance of energy assets; more advanced system operations and real-time control; introduction of new models of energy markets and business models, etc.

Implementation of the energy transition, expanding the use of RES, increasing the flexibility of energy systems and energy demand requires significant investments in the modernization of the energy infrastructure. Business models based on the use of digital technologies enable this modernization in cheaper and more efficient ways.

The further development of new technologies and business models depends on the state policy of introducing AI and the corresponding legislative and regulatory framework. Energy companies need defined government priorities and legislative frameworks that can help them develop their activities in this direction.

Consumers need regulations that can protect them from abuse, ensure transparency of use and security of their personal data that they share with digital companies.

Therefore, it is necessary not only to understand the barriers to the application of AI in the practical activities of energy companies, but also to find adequate solutions.

Next, we will highlight some areas of efforts to expand the scope of AI applications.

Introduction of new business models

Analysis of the existing obstacles to the application of AI allows us to propose a number of ways to overcome them, from the point of view of business process management models (Table 1).

Digitization also leads to changes in the management and development of human capital. Government officials, energy policy makers should be informed about the latest developments in the digital world, its trends and future consequences. This can be achieved through the recruitment of digital experts to energy policy agencies, through in-house staff development programs, regular participation in conferences, workshops and trainings.

Energy sector entities and businesses in general need to invest in upskilling and training their employees to manage and operate digital energy assets and systems, otherwise the potential benefits of adopting new technologies will not be fully realized. Retraining is a means of overcoming the fear of job loss. On the other hand, training can have a positive effect on public readiness to accept and effectively use AI in production and everyday life.

For end consumers, it is advisable to introduce information companies aimed at demonstrating the capabilities of AI technologies to realize the potential of energy efficiency or the benefits of participation in demand regulation mechanisms and potential cost savings for consumers.

The analysis of obstacles to the application of digital technologies allows us to conclude that for the purposes of the managed process of expanding the use of AI in practical activities, it is necessary to form a comprehensive strategy that would cover various aspects.

The discussion, conducted by leading experts in the fields of AI and energy, made it possible to identify nine principles that will allow to activate this process69.

Table 1. Overcoming obstacles to the application of AI in energy.

Barriers to the introduction of AI	Possible digital solutions	Examples of business models
Potential benefits are limited and distributed among different organizations	Development of monitoring systems, forecasting and trading services to expand the circle of participants benefiting from the application of AI. Creation of resource "pooling" systems to achieve sufficient scale to attract investors.	Virtual power plants that aggregate distributed energy resources and allow participation in electricity markets.
Insufficient incentives, low and/or slow return on investment	Digital applications and platforms that integrate multiple value streams to improve economies of scale. This method, known as "value stacking", can increase returns and shorten payback periods.	Technological solutions such as "electric car to the grid" allow you to send electricity to the grid when they are not in use. Using decentralized systems (DER) to reduce electricity bills, reduce peak demand or regulate voltage and frequency.
High initial asset costs and/or financial risk, lack of access to financing	Applications, management platforms, or licensed software that eliminate the need to own or invest in hardware or infrastructure. Remote monitoring and control.	Applying the “energy-as-a-service” model to efficient and smart cooling or heating systems, charging infrastructure or other services.
End-users have limited access to energy, smart technologies, payment means or finance	Autonomous smart equipment. Mobile payments, virtual wallets and other digital payment applications or platforms.	Introduction of “Pay-as-you-go” service for offline users.
Lack of regulatory regulation/requirements for the use of AI in distribution networks	Multilateral agreements in the buyer-seller configuration using IT platforms.	Online (peer-to-peer) platforms that allow users to trade electricity generated by their own assets without an intermediary/network.

It is advisable to combine these principles into three groups:

- Designing.

1. Automation - it is necessary to immediately design generating and network equipment for automated work and increasing the autonomy of AI.
2. Sustainability – the most energy-efficient infrastructure should be implemented, as well as the best methods of preventing environmental damage.
3. Design - it is necessary to ensure the development of AI based on the criteria of ease of use and ease of data interpretation.

- Implementation.

4. Data – Data standards, data sharing mechanisms and platforms should be established to improve data availability and quality.

5. Incentives - it is necessary to create such a market design and legal framework that will allow to fully use the advantages of AI.

6. Education – a human-centric approach to the use of AI should be formed among consumers and personnel of energy companies, and investment should be made in education according to the level of development of AI technologies and skills for working with it.

- Management.

7. Risk management – it is necessary to agree on a general technological, methodological and educational approach to the management of risks presented by AI.

8. Standards – compatible software standards and interaction interfaces should be implemented.

9. Responsibility – Ensure that ethics and responsible use are at the core of AI development and deployment processes.

All subjects of the energy sector, primarily energy companies and state authorities, should join the development of a policy in the field of the use of AI technologies in the energy sector and ensure its implementation in order to create a favorable environment for revealing the full potential of AI.

It should be noted that the process of applying AI in Ukraine is at an initial stage. Only general conceptual approaches to the development of artificial intelligence technologies in Ukraine (December 2020) and a preliminary general plan for its development (May 2021) were approved.

The approved Concept of the development of AI in Ukraine defines the purpose, principles and tasks of the development of artificial intelligence technologies in Ukraine, although it focuses more on the field of scientific and technological research. The Concept defines the priority directions for the introduction of AI, among which, in view of its application to the field of energy, the following should be highlighted:

- implementation of artificial intelligence technologies in the field of education, economy, management and defense, and other areas to ensure Ukraine's long-term competitiveness on the international market;

- ensuring access to information (databases, registers, etc.), its use during the development of artificial intelligence technologies for the production of goods and the provision of services;

- increasing the level of professional training of specialists to ensure.

the field of artificial intelligence technologies by qualified personnel.

When applied to the energy sector, we note the following tasks of the Concept:

- stimulating the development of entrepreneurship in the field of artificial intelligence by ensuring access of innovative enterprises to investments, partnerships with venture funds, organization of business events with the participation of Ukrainian IT entrepreneurs abroad, improvement of the business climate, etc.;

- motivation of business entities to introduce AI by ensuring their access to educational programs/information portals;

- retraining of people whose work may be automated in the next five to ten years, introduction of a state order for the training of IT specialists and data researchers;

- stimulation of partnership between the state and business in the field of innovative projects, as well as improvement of legislation in the relevant field.

In turn, the Action Plan for the implementation of the adopted Concept provides for the introduction of practical tools:

- adoption of the draft law on the development of artificial intelligence;

- conducting information campaigns aimed at popularizing the basics of artificial intelligence in secondary education institutions, holding conferences and seminars on the introduction and use of artificial intelligence technologies; - provision of state support for the use of artificial intelligence technologies in priority sectors of the economy (adopting the State Program);

But so far AI technologies are implemented in practice at the initiative of only a limited circle of Ukrainian companies. The use of the latest energy technologies in general and digital technologies in particular require legislative stimulation. An example of such legislative stimulation of the development of digital technologies in power supply systems and, accordingly, the use of AI technologies is the EU Electricity Market Directive of 201972. At the same time, Ukraine is only at the beginning of this long journey, and even the requirement to adapt Ukrainian legislation to the provisions of EU legislation does not ensure the rapid introduction of legislative incentives for the use of AI.

For example, the Law of Ukraine "On the Electric Energy Market" in the period 2019-2021 (after the adoption of the mentioned EU Directive) was only amended regarding the use of energy storage systems. It is obvious that this fact indicates the current level of technological unpreparedness and social rejection of the new mechanisms for the organization of the energy market proposed by the EU Directive, as well as fears of the use of AI technologies by experts in the electric power industry of Ukraine. Moreover, the lack of adjustment of the legislation regulating the operation of the electricity market, while certain provisions of the mysterious EU Directive are reflected in other branch legislation, demonstrates the fact of the lack of a systematic strategic plan for the transformation of the energy sector of Ukraine.

In particular, the Law of Ukraine "On Energy Efficiency" introduces the concept of "smart networks" and sets the task of approving the Concept of implementation of "smart networks" in Ukraine and the medium-term Plan of measures for their implementation. At the same time, the development of a road map for the implementation of "smart networks" in Ukraine is envisaged (Article 15 of the Law), which should include measures in the following areas: geo-information systems; power grid monitoring and control systems; systems of intelligent electricity accounting; integration of renewable energy; integration of electrical energy storage; infrastructure for electric cars; development of communication channels; cyber security.

This law also establishes a requirement for the regulator of energy markets (of the National Commission, which carries out state regulation in the spheres of energy and communal services), within the scope of competence to ensure: stimulation of participation consumers who have the opportunity to manage their consumption in the electricity market; simplify their access to participation in the balancing, reservation, auxiliary and other services markets; stimulating the introduction of "smart grids" by establishing a system of economic incentives for transmission system operators and operators of electric energy distribution systems.

It is obvious that the success of the development of "smart networks", increasing the flexibility of the system due to "demand regulation" services and expanding the use of AI for the realization of these opportunities depends on the clear coordination of the actions of all participants of the energy market. The creation of such coordination will require a clearer reflection of EU Directive 2019/944 in the sectoral legislation of Ukraine and the involvement of transmission and distribution system operators.

Industry development policy makers and system operators will need to review existing energy market practices and create truly developed and liberalized electricity markets. To do this, it is necessary to create truly equal conditions for distributed generation in relation to powerful power units and eliminate regulatory obstacles. Since many AI use cases in the energy sector concern owners of small distributed energy resources, they must have non-discriminatory access to the energy supply system and the corresponding modes of its operation (ancillary services market).

The existing problems with the introduction of a full-fledged electricity market in Ukraine, the preservation of obstacles to the free connection of consumer installations to the power grid, the preservation of the practice of administrative regulation of prices and tariffs on the energy markets of Ukraine significantly limit the specific advantages of new energy technologies and business models using digital technologies and automated trading platforms electricity.

Accordingly, the first priority of state policy in the energy sector is to correct deficiencies in the organization of energy markets and introduce competitive energy markets that are truly free from manual control.

As the energy system decarbonizes and decentralizes, the grid management model must be rethought and new and more decentralized architectures for grid access, operation, and management solutions should be considered. In particular, in regional and national energy system modeling and infrastructure planning, planners must consider the role that AI-enabled intelligent distributed energy resources (DER) can play. Today's energy modeling often ignores distribution networks and does not take into account the possibility for them to become a source of flexibility of the energy system and become valuable participants in the process of managing its regimes.

In order to accelerate the penetration of digital technologies into the practical activities of the energy sector of Ukraine, it is necessary to review the existing legislative and regulatory framework and remove obstacles to the integration of new technological solutions into the activities of the energy markets of Ukraine. In particular, it is necessary to ensure the development of appropriate regulatory and technical support for the development of "smart networks" to facilitate the integration of distributed energy sources with the use of energy storage, the creation of a power management platform for integrated distributed energy sources, and the implementation of international standards for the functional compatibility of smart network equipment. As a first step in this direction, it is expedient to complete the development of a conceptual document on the principles of state policy on the comprehensive implementation of "smart networks" in Ukraine.

Expanding the use of decentralized energy supply systems based on the use of local generating capacities of various types and the use of digital technologies can become a component of planning regional energy supply systems, in particular local energy plans. In this regard, the metrological and regulatory framework of the National Energy Regulator (NERCP) needs to be improved regarding the preparation and approval of investment plans of regional companies for the development of energy supply systems in order to eliminate obstacles to the implementation of digital technologies, third-party access to networks and work on energy markets, application of new business models of work in the energy market.

In particular, we are talking about creating opportunities for the formation of a new category of players in the energy market, such as "energy service companies", which provide turnkey services (energy products: lighting, heat, air conditioning) to end consumers. The latest energy technologies and the use of "smart equipment", together with new business models enabled by AI, are becoming an increasingly attractive niche in the energy market.

As the management and operation of networks become increasingly complex, particularly at the level of distribution networks, grid operators must review the potential of a range of digital technologies (e.g., machine learning, quantum computing, blockchain technology, etc.) to expand the ways in which digital technologies are used in their practical operations.

Conclusions.

The latest energy technologies and business models of work in energy markets open up new opportunities for producers, suppliers and consumers of energy both in terms of increasing the efficiency of their production activities or energy consumption, and in terms of the possibility of receiving economic benefits from participation in the market. It is about expanding the use of renewable energy sources, decentralizing energy supply, participating in demand regulation, providing system balancing services, or direct online trading of electricity on exchanges.

At the same time, the use of new opportunities depends on the energy market participants mastering intelligent management and accounting systems, digital platforms for information exchange and processing, artificial intelligence and machine learning technologies. In fact, the success of the next technological revolution in energy depends on the use of artificial intelligence technologies by all participants involved in the energy supply process.

This situation creates significant challenges for any country, as it requires both the technological readiness of the energy sector, that is, the availability of appropriate intelligent equipment and software, as well as the professional readiness of personnel to apply AI technologies and their socio-cultural perception of these technologies.

Today, these directions of expanding the use of AI in energy are a priority for the sphere of public administration and the formation of the necessary strategic documents of state policy and program decisions regarding the financing of energy development projects in the country. It is necessary to adopt, at least at the level of the energy sector, a general concept of AI implementation in energy, programs for the development of AI technologies on a national basis, programs for education and training of personnel of energy companies in the field of AI.

In addition to strategic tasks, there is the problem of readiness of the current model of the energy market to use the latest technologies based on AI. This primarily concerns the transparency and stability of the country's electricity market. If the rules of the market are unstable, not to mention direct administrative intervention in its work, which will affect the price parameters and terms of execution of agreements (operations), the realization of the potential of using AI and the latest energy technologies will be leveled. This situation will continue to hold back the modernization of Ukraine's energy sector.

At the same time, Ukraine's forced need to rebuild its energy infrastructure after large-scale destruction caused by Russia's aggression, the practical integration of Ukraine's energy systems into European systems (for example, the synchronization of the work of the United Energy System of Ukraine with the European Network of System Operators of Electricity Transmission (ENTSO-E)) give Ukraine a chance to modernize the country's energy sector on a modern technological base and with the use of AI technologies.

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