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DIGITAL FOUNDATIONS FOR BUSINESS DEVELOPMENT IN THE FIELD OF RENEWABLE ENERGY

ЦИФРОВІ ЗАСАДИ РОЗВИТКУ ПІДПРИЄМНИЦТВА У СФЕРІ АЛЬТЕРНАТИВНОЇ ЕНЕРГЕТИКИ

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The article focuses on specifying the digital foundations for the development of entrepreneurship in the field of alternative energy. It's proven that these technologies are a catalyst for innovation, process optimization, and the creation of new business models that contribute to the industry's sustainable development. The components that guide the digitalization of processes related to the production, distribution, storage, and sale of electricity have been identified in the following areas: intelligent energy systems, Internet of Things networks and Big data systems, digital platforms, and marketplaces. The components that adjust the digital development of each individual or company engaged in business related to the production, distribution, storage, or sale of renewable energy have been identified in the following areas: 3D printing, robotics, and blockchain technology. It has been established that the digital foundations for the entrepreneurship development in the field of alternative energy are directed towards process optimization, increased efficiency, cost reduction, and the creation of new business models.

Keywords: intelligent energy systems, entrepreneurial projects, efficiency improvement, power system elements, digital technologies, virtual power plants.

Стаття присвячена конкретизації цифрових засад розвитку підприємництва у сфері альтернативної енергетики. Доведено, що ці технології є каталізатором інновацій, оптимізації базових бізнес-процесів та створення нових бізнес-моделей, що сприяють сталому розвитку діяльності з виробництва енергії з джерел, які є альтернативою традиційним викопним паливам. Виділено складові, що скеровують цифровізацію процесів пов'язаних з виробництвом, розподілом, зберіганням та продажем електроенергії, за напрямками: інтелектуальні енергетичні системи (що забезпечують ефективне управління енергетичними ресурсами, інтеграцію відновлюваних джерел енергії, підвищення енергоефективності), мережі інтернету речей та системи великих даних (що дозволяють оптимізувати роботу обладнання, спрогнозувати виробництво та споживання енергії), цифрові платформи та маркетплейси (які спрощують доступ до фінансування проєктів, допомагають підприємцям знаходити партнерів, постачальників, клієнтів). Виділено складові, що коригують цифровий розвиток кожного суб'єкта, який займається виробництвом, розподілом, зберіганням

або продажем енергії з відновлюваних джерел, за напрямками: 3D-друк та робототехніка (що знижують витрати на виробництво, дозволяють створювати індивідуальні рішення для клієнтів, адаптуватися до змін попиту), технологія блокчейн (що підвищує прозорість та довіру на ринку альтернативної енергетики, забезпечує чесну конкуренцію). Є очевидним, що цифрові засади розвитку підприємництва у сфері альтернативної енергетики спрямовують комплекс заходів зі створення сприятливого середовища для виникнення та зростання нових бізнесів, а також на підтримку осіб, які вже ініціювали та організовували свій бізнес. Перспективи подальших досліджень у сфері цифрових засад розвитку підприємництва в альтернативній енергетиці можуть бути зосереджені на створенні практичних рекомендацій для підприємців щодо вибору, впровадження та ефективного використання цифрових інструментів та платформ.

Ключові слова: інтелектуальні енергетичні системи, підприємницькі проєкти, підвищення ефективності, елементи енергосистеми, цифрові технології, віртуальні електростанції.

Problem statement. The fundamental digital principles of entrepreneurship in the alternative energy sector began to take shape in the late 20th and early 21st centuries with the development of information technologies and the growing interest in renewable energy sources. In particular, the 1990s became the foundation, marked by the emergence of the first digital monitoring and control systems for energy systems, which allowed for tracking the production and consumption of electricity. The 2000s saw the development of Internet of Things (IoT) and sensor technologies, which enabled the collection and analysis of data on the operation of alternative energy equipment. The 2010s saw the emergence of Smart Grids (intelligent energy systems) concepts, which combined digital technologies with traditional energy systems, enhancing the efficiency and reliability of generating, developing, managing, producing, and selling energy from renewable sources.

Currently, there is an active implementation of blockchain technologies to ensure transparency and trust in alternative energy markets, as well as the development of platforms for peer-to-peer (P2P) energy trading.

Therefore, it is evident that the relevance and significance of research in this area are increasingly growing, and digital technologies themselves are playing an ever-increasing role in transforming entrepreneurship in the field of alternative energy. In particular, these technologies open up new opportunities for optimizing processes, increasing efficiency, and ensuring sustainable development of activities aimed at creating, developing, and remotely managing businesses engaged in the production, distribution, storage, and sale of energy from renewable sources

The analysis of recent researches and publications. The issue of developing entrepreneurship in the field of alternative energy in general and its specific types is somewhat presented in the scientific literature.

So, research on specific aspects of entrepreneurship in the field of solar and wind energy has been conducted by Narayevsky S. V., Usachov A. M., and Shemyakina O. M.

General principles of entrepreneurship in the field of alternative energy and some aspects of its digitalization have been highlighted by Kasych A. O., Lytvynenko Ya. O., and Melnychuk P. S.

According to the data you provided, research in the field of alternative energy entrepreneurship in Ukraine is focused on specific aspects, such as solar and wind energy, as well as general principles and digitalization. However, the practical implementation of digital development in this area is still a challenge that requires further research and elaboration.

Goal setting (formulation of goals of the article). The purpose of the article is to elaborate on the digital foundations for the development of entrepreneurship in the field of alternative energy.

The paper main body with full reasoning of academic results. The development of alternative energy in Ukraine since the early 2000s has occurred in parallel with the development of digital technologies, thus forming unique, largely digitalized foundations for entrepreneurship in this field. Considering the outlined evolutionary symbiosis, we interpret the digital foundations of entrepreneurship development in alternative energy as a set of digital technologies, tools, and approaches that are integral elements for creating, developing, and managing businesses in renewable energy sources.

These defined principles allow for the optimization of processes related to the production, distribution, storage, and sale of electricity (as a specific energy commodity), increase the efficiency of each of these processes, and create new business models (energy cooperatives and communities, virtual power plants (VPPs), energy service companies, flexibility aggregators, and peer-to-peer partnerships).

Considering the above, we can identify the following main components of the development of digital foundations for entrepreneurship in the field of alternative energy (which guide the digitalization of processes related to the production, distribution, storage, and sale of electricity) [1; 3-4]:

1. Digital technologies, tools, and approaches that enable the formation and evolution of Smart Grids, which are modernized electrical grids that simultaneously serve as a means of two-way communication between electricity suppliers and consumers.

2. Digital technologies, tools, and approaches that enable the development of the Internet of Things (IoT) and Big Data, which ensure the functioning of energy systems.

3. Digital platforms and marketplaces that simplify access to financing for projects in alternative energy help entrepreneurs find partners for project implementation, equipment, and service providers, as well as customers for the sale of electricity.

Entrepreneurs who actively implement digital technologies in the energy sector gain a significant competitive advantage and contribute to sustainable development in several key ways [1; 3; 5; 7]:

– through the optimization of energy production and distribution; through the enhancement of energy consumption efficiency;

– through the development of new business models and services;

– through the reduction of the environmental impact of their activities;

– through an increase in transparency and speed of consumer engagement.

So, smart grids are a key element of the digital transformation of the energy sector, and their development is ensured by the evolution of communication functions for monitoring and managing energy production, the integration of various generating plants that produce energy from renewable sources, and the adjustment of energy efficiency of equipment. This connectivity enables more efficient management of

Table 1

Characteristics and action focus of main Smart grid components used by entrepreneurs in the alternative energy sector

Main components	Focus of action of components	Advantages of forming a component in the field of alternative energy	General benefits of synthesized action of components
Smart meters	Collect real-time data on electricity consumption and transmit it to the supplier	Allows consumers to track their energy consumption, and suppliers to manage the load on the network	Optimization of electricity production and consumption, reduction of network losses. Rapid detection and elimination of malfunctions, automatic switching to backup power sources. Efficient integration of solar and wind power plants into the power system, taking into account their variability. Reduction of energy costs through optimization of consumption and use of energy-efficient technologies.
Sensors and remote monitoring systems	Are installed on various elements of the power system to enhance data collection functions on equipment condition, voltage, current, and other parameters	Help detect malfunctions, predict failures, and quickly respond to changes in the network.	
Control and automation systems	Analyze data received from meters and sensors, and make decisions to manage electricity flows, switch to backup power sources, regulate voltage, etc	Enable optimization of the power system operation and ensure its stability	
Communication technologies	Provide data exchange between all components of Smart Grids. This can be either wired or wireless communication (Wi-Fi, cellular communication, etc.)	Stable and reliable data exchange, less prone to interference and interruptions	

Note

*These elements include substations, transmission lines, and transformers

Source: formulated by the author based on [1–2; 6]

electricity flows, optimization of production and consumption, and enhancement of the reliability and resilience of the power system [1]. The main components of Smart Grids currently include smart meters, sensors and remote monitoring systems, control and automation systems, and communication technologies that function according to the specifications outlined in Table 1.

Note that in Ukraine, the deployment of Smart Grids is still in its early stages. However, there are already pilot entrepreneurial projects in some cities (the "Smart Grids" project in Ivano-Frankivsk, the "Smart Grid" project in Lviv, and the "Smart Quarter" project in Kyiv), as well as plans to modernize the energy infrastructure using digital technologies.

Internet of Things (IoT) networks and Big Data systems that ensure the operation of energy facilities for entrepreneurs are a complex of interconnected digital technologies that collect, process, and analyze huge amounts of information from various devices and sensors located in the local energy system [1; 5].

This data is used to optimize the operation of the entrepreneur's energy facilities, increasing their efficiency, reliability, and safety. The main components of Internet of Things (IoT) networks are various sensors installed on elements of the energy infrastructure, sensors and devices connected to the Internet, and specialized software platforms that function according to the specifications outlined in Table 2.

Table 2

Characteristics and action focus of main components of IoT network and Big Data system used by entrepreneurs in the alternative energy sector

Main components	Focus of action of components	Advantages of forming a component in the field of alternative energy	General benefits of synthesized action of components
Main components of Internet of Things networks			Equipment condition monitoring, fault detection, and failure prediction. Electricity consumption forecasting, network load management, electricity production optimization. Forecasting electricity generation from renewable sources, balancing the power system, and managing energy storage systems. Analysis of electricity consumption data to identify energy saving opportunities. Creation of new services for consumers, such as household energy management, "smart" homes, and cities
Various sensors	Collect data on equipment condition, electricity parameters (voltage, current, frequency), electricity consumption, etc.	Formation of data on the operation of elements of the energy infrastructure	
Connectivity	Transmit data in real-time to centralized servers or cloud platforms. Sensors and devices connected to the Internet	Sensors and devices connected to the Internet	
Platforms and applications	Specialized software platforms collect, process, and analyze data from sensors	Providing energy system operators with information for decision-making and system management	
Main components of Big Data systems			
Data Volume	Energy systems generate massive volumes of data	Tools to store, process, and analyze data	
Speed of data processing and analysis	Synthesizes real-time data about the entrepreneur's energy system	Tools that facilitate fast processing and analysis for prompt response to changes in the system	
Variety of data	Synthesizes data of various formats (structured, unstructured, text, numerical).	Possibilities for applying special analysis methods	
Data analytics	Identification of hidden patterns, prediction of events, and optimization of the entrepreneur's energy system operation	Big data analysis capabilities, through methods of machine learning, artificial intelligence, and statistical analysis	

Note

* Are installed on elements of the energy infrastructure (power plants, substations, transmission lines, transformers, consumer meters).

Source: formulated by the author based on [1-2; 4; 6]

The main components of Big Data systems are data volumes, data processing and analysis speed, various data formats, and data analytics that function according to the specifications outlined in Table 2.

The application of IoT and Big Data in the energy sector is one of the key directions in Smart Grids development and the transition to a more sustainable, efficient, and environmentally friendly energy system. So, currently, DTEK has created an IoT network with "smart meters" connected to it in some regions of Ukraine and is collecting real-time data on electricity consumption. In some Ukrainian cities (for example, Lviv, Kyiv), entrepreneurs are implementing "smart city" projects, within which IoT technologies are used to manage street lighting or data collected on energy consumption by consumers.

Digital platforms and marketplaces in alternative energy are online platforms that connect project developers with potential investors and provide tools for project presentation, investment attractiveness assessment, fundraising, and investment management.

The main components of such platforms and marketplaces are crowdfunding platforms, P2P lending platforms, investment platforms, and specialized platforms for alternative energy (which function according to the specifications outlined in Table 3).

Digital platforms and marketplaces play a crucial role in the development of alternative energy by providing access to financing for projects that can make a significant contribution to the transition to a more sustainable energy system. Specifically, in Ukraine, the Greencubator platform (for supporting startups in the field of clean energy and sustainable development) and the BetterMe crowdfunding platform (for supporting social and environmental projects) are currently operating.

It's worth noting that additional components can be identified that contribute to the development of digital foundations for entrepreneurship in the alternative energy sector (which adjust the digital development of each individual or company engaged in business related to the production, distribution, storage, or sale of energy from renewable sources) in the following directions:

1. Blockchain technologies contribute to increasing transparency and trust in the alternative energy market through components such as transparency and immutability of data on electricity origin, smart contracts, and P2P energy trading, operating according to the specifications outlined in Table 4.

Due to data immutability and the ability to track the origin of electricity, blockchain helps ensure fair competition and stimulates the development of "green" tariffs and certificates of origin. The automation of contract execution through smart contracts reduces costs and

Table 3

Characteristics and action focus of main components of digital platforms and marketplaces used by entrepreneurs in the alternative energy sector

Main Components	Focus of action of components	Overall benefits from the synthesized information
Crowdfunding platforms	Allow raising funds from a large number of investors who contribute small amounts. Examples: Kickstarter, Indiegogo, Patreon	Project developers can raise funds without having to turn to traditional financial institutions, such as banks. Platforms allow attracting funds from investors around the world, which increases the chances of successful project financing. The process of raising funds for entrepreneurial projects in alternative energy becomes more transparent and efficient through the use of digital tools. Crowdfunding platforms allow raising funds from a large number of investors who contribute small amounts
P2P lending platforms	Connect borrowers (project developers) with investors who provide loans under certain conditions. Examples: Lending Club, Prosper.	
Investment platforms	Offer investors the opportunity to invest in stocks or bonds of companies operating in the alternative energy sector. Examples: Energize Ventures, Greenbacker Capital	
Specialized platforms for alternative energy	Focused on financing projects in the field of solar, wind, hydro, bioenergy, etc. Examples: Wunder Capital, Mosaic.	

Source: formulated by the author based on [1; 3–4; 6]

Table 4

Characteristics and action focus of main blockchain components used by entrepreneurs in the alternative energy sector

Main components	Focus of action of components	Advantages of forming a component in the field of alternative energy	General benefits of synthesized action of components
Transparency and trust	Blockchain ensures transparency and immutability of data on the origin of electricity	Transparency and trust are particularly important for the development of green energy markets and certificates of origin	Tracking the origin of electricity. Fair competition and stimulation of the development of "green" tariffs and certificates of origin. Automation of contract execution using smart contracts, reducing costs and increasing the efficiency of interaction between market participants.
Smart Contracts	Automation of the execution of contracts for the purchase and sale of electricity using smart contracts	Improved interaction between market participants	
P2P Energy Trading	Blockchain enables the creation of decentralized platforms for direct energy trading between producers and consumers, bypassing intermediaries	Facilitation and acceleration of interaction between market participants	

Source: formulated by the author based on [1–2; 5]

increases the efficiency of interaction between market participants.

2. 3D printing and robotics technologies make entrepreneurial projects in alternative energy more accessible through components such as reduced production costs and personalization and flexibility, operating according to the specifications outlined in Table 5.

These technologies allow for reduced production costs of components and equipment for alternative energy generation and provide the opportunity to create customized solutions for clients, taking into account their needs and the specifics of their facilities. This promotes the spread of alternative energy and its integration into various spheres of life.

Conclusions from this study and prospects for further exploration in this direction. Research confirms that digital technologies play a key role in transforming entrepreneurship in alternative energy. They act as a catalyst for innovation, process optimization, and the creation of new business models, contributing to the sustainable development of the industry. In conclusion, it can be stated that:

1. The main components of developing digital foundations for entrepreneurship in the field of alternative energy (which guide the digitalization of processes related to the production, distribution, storage, and sale of electricity) can be identified in the following areas:

– Smart Grids ensure efficient management of energy resources, integration of renewable energy sources, and increased energy efficiency.

– Internet of Things (IoT) and Big Data, allow optimizing equipment operation, predicting energy production and consumption, and creating intelligent solutions for energy management.

– Digital platforms and marketplaces, which simplify access to financing for projects in the field of alternative energy, help entrepreneurs find partners for project implementation, equipment, and service providers, as well as customers for electricity sales.

2. Additional components that can be identified to further develop the digital foundations of entrepreneurship in the alternative energy sector (which adjust the digital development of each individual or company engaged in business related to the production, distribution, storage, or sale of energy from renewable sources) in the following areas:

– 3D printing and robotics, which reduce production costs, allow for the creation of customized solutions for clients and enable quick adaptation to changes in demand.

– Blockchain technology, which increases transparency and trust in the alternative energy market, ensures fair competition and stimulates the development of "green" tariffs and certificates of origin.

Table 5

Characteristics and action focus of main 3D printing and robotics components used by entrepreneurs in the alternative energy sector

Main components	Focus of action of components	Advantages of forming a component in the field of alternative energy	General benefits of synthesized action of components
Reduction of production costs	3D printing allows for a reduction in the production costs of components for solar panels, wind turbines, and other equipment.	3D printing enables the on-site manufacturing of components for solar panels, wind turbines, and other devices, reducing transportation and storage costs. 3D printing also allows for the use of less material and shorter production times, further reducing costs	By reducing production costs, alternative energy becomes more affordable for a wider range of consumers and entrepreneurs. Personalization and flexibility enable the creation of more efficient and reliable solutions, increasing the attractiveness of alternative energy. The ability for rapid prototyping and experimentation fosters the development of new technologies and solutions in the field of alternative energy
	Robotics allows for the creation of customized solutions for clients and quick adaptation to changes in demand	Automation of production processes using robots allows for a reduction in labor costs and an increase in production efficiency.	
Personalization and flexibility	3D printing enables the creation of unique components tailored to the specific needs of the client and the characteristics of the project	Allows for optimizing the design and increasing the efficiency of equipment	
	Robotics can be programmed to perform various tasks	Allows for reconfiguring production to manufacture various components or modifications of equipment	

Source: formulated by the author based on [1; 4; 6]

Based on the presented research, it is evident that the digital foundations of entrepreneurship development in the alternative energy sector are driving process optimization, increased efficiency, cost reduction, and the creation of new business models. Considering the research findings, future research prospects in the field of digital foundations for entrepreneurship development in alternative energy could focus on creating practical recommendations for entrepreneurs regarding the selection, implementation, and effective use of digital tools and platforms.

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