УДК 330.13.009.12
DOI: https://doi.org/10.32782/business-navigator.76-13

Holovachko Vasyl
PhD in Economic, Associate Professor
Mukachevo State University
ORCID: https://orcid.org/0000-0002-5993-0873
Taranenko Sergiy
Applicants for Higher Education PhD
Odesa National Maritime University
ORCID: https://orcid.org/0009-0007-1872-5818
Zaborskyi Leonid
PhD in Engineering, Doctoral Student
Odesa National Maritime University
*ORCID: https://orcid.org/*0009-0009-7923-3475

Головачко В.М.
кандидат економічних наук, доцент
Мукачівський державний університет
Тараненко С.О.
здобувачі вищої освіти PhD
Одеський національний морський університет
Заборський Л.О.
кандидат технічних наук, докторант
Одеський національний морський університет

NEW CONCEPTS FOR THE DEVELOPMENT OF ALTERNATIVE ENERGY HUBS IN THE DIGITAL ECONOMY

НОВІ КОНЦЕПЦІЇ РОЗВИТКУ ХАБІВ АЛЬТЕРНАТИВНОЇ ЕНЕРГЕТИКИ В ЦИФРОВІЙ ЕКОНОМІЦІ

The development of alternative energy in the digital economy should currently be considered through the prism of the development of energy hubs, taking into account the current situation with energy security and the need to decentralize the energy system. The article aims to identify and analyze new concepts for developing alternative energy hubs in the digital economy. Considering the importance of integrated development of alternative energy in the digital economy, these aspects should be based on concepts aimed at ensuring an innovative approach to the production, distribution, and consumption of energy, which unites various renewable energy sources into a single macro, meso (regional), or microsystem, specifically through the concepts of intelligent energy hubs, decentralized energy hubs, community energy hubs**.** Given the outlined concepts and their potential impact on energy security, future research prospects include assessing the economic efficiency of different energy hub concepts and their impact on the development of the local economy.

Key words: renewable energy sources, entrepreneurial projects, energy systems, entrepreneurs, digital technologies, digitalization.

Стаття спрямована на аналіз нових концепцій розвитку хабів альтернативної енергетики в цифровій економіці. Зважаючи на важливість інтегрованого розвитку альтернативної енергетики у цифровій економіці, ці аспекти слід базувати на концепціях, здатних забезпечити інноваційний підхід до виробництва, розподілу та споживання енергії, який об'єднує різні джерела відновлюваної енергії в єдину макро-, мезо- чи мікросистему. Зокрема, це стосується концепцій інтелектуальних енергетичних хабів, децентралізованих енергетичних хабів та громадських енергетичних хабів. Доведено, що концепція інтелектуальних енергетичних хабів є інноваційним підходом до виробництва, розподілу та споживання енергії через використання їх суб'єктами передових технологій. Важливими є трансформації централізованого виробництва енергії у гібридне, гібридизація розподілу та інтеграція віртуальних електростанцій у системи споживання енергії. Враховуючи окреслені аспекти, формуються утворення, здатні справити значний позитивний вплив на енергетичну безпеку на національному рівні, підвищуючи стійкість та надійність енергосистеми і зменшуючи залежність від імпорту енергоресурсів. Доведено, що концепція децентралізованих енергетичних хабів базується на

розвитку об'єктів альтернативної енергетики, виходячи з принципу розподіленого виробництва та споживання енергії. Враховуючи ці аспекти, формуються утворення, здатні справити значний позитивний вплив на енергетичну безпеку на локальному рівні завдяки поступовому зниженню залежності від централізованих постачальників та підвищенню стійкості окремих груп "виробник-споживач" до зовнішніх впливів. Доведено, що концепція громадських енергетичних хабів базується на об'єктах генерації, що включають різні джерела відновлюваної енергії, системи зберігання енергії та інфраструктуру для зарядки електромобілів. Враховуючи ці аспекти, формуються утворення, здатні справити значний позитивний вплив на енергетичну безпеку на рівні окремої громади, зокрема завдяки підвищенню її енергетичної автономії та зниженню витрат на енергоносії.

Ключові слова: джерела відновлювальної енергії, підприємницькі проєкти, енергетичні системи, підприємці, цифрові технології, цифровізація.

Statement of the problem. Alternative energy development in the digital economy should currently be considered through the lens of energy hub development, taking into account the current situation with energy security and the need for decentralization of the energy system. The effectiveness of energy hub development is driven by several reasons. At the core lies the role of hubs in activating the integration processes of various renewable energy sources (solar, wind, hydro, biomass) and ensuring their efficient interaction. Digital technologies (such as artificial intelligence and the Internet of Things) optimize energy production, distribution, and consumption, enhancing efficiency and reducing costs.

Furthermore, energy hubs stimulate the development of digital infrastructure (such as smart grids, energy storage systems, and digital platforms for managing energy flows). It contributes to the digitalization of the economy and enhances its competitiveness. Additionally, it is important to note the significant impact of energy hubs on the energy system flexibility, aimed at improving its ability to adapt to changes in energy demand and supply. Due to decentralization and the use of digital technologies, hubs enhance the resilience of the energy system to external influences such as accidents or cyberattacks. Energy hubs also actively engage communities and businesses in alternative energy development. They can invest in renewable energy sources, participate in energy production and consumption, and reap economic benefits from these activities.

Furthermore, energy hub development contributes to reducing greenhouse gas emissions and transitioning towards cleaner energy sources, which is crucial for achieving sustainable development goals and addressing climate change. Digital technologies play a key role in the development of alternative energy hubs, enabling more efficient management of energy flows, attracting investments, and ensuring transparency in the energy market.

The analysis of recent researches and publications. The question of developing alternative energy, both in general and specific types, within the context of innovative production aimed at integrating various renewable energy sources has been addressed in scientific literature.

In particular, research on specific issues of innovative production in alternative energy and the fundamental principles of their digitalization has been conducted by Narayevsky S.V., Bila S.O., and Shvayuk Yu.E.

The issue of enhancing energy security in Ukraine through digitalized innovative production in alternative energy has been explored in the works of Bilyavsky M., Heletukha H.H., Cherevatsky D., and Novak I.K.

Also noteworthy are the contributions of Pavliy O., who has focused on enhancing digitalization and integrating production processes in alternative energy.

While acknowledging the substantial contributions of researchers, it should be noted that the issue of innovative production concepts in alternative energy and their impact on Ukraine's energy security within the context of the digital economy requires further scientific investigation.

Formulation of the research task. The article aims to identify and analyze new concepts for developing alternative energy hubs in the digital economy.

Summary of the main research material. An energy hub is a modernized approach to energy production, distribution, and consumption, integrating various renewable sources such as solar, wind, hydro, and biomass into a unified system. Hubs can vary in scale from small local projects (clusters) to large regional centers. The main components of an alternative energy hub include:

1. Renewable energy sources (such as solar panels, wind turbines, hydroelectric stations, biogas installations, etc.).
2. Energy storage systems (battery storage, pumped hydroelectric storage, thermal storage systems, etc.).
3. Intelligent grids (energy management systems that optimize production, distribution, and consumption of energy).
4. Digital platforms (online platforms ensuring transparency and efficiency in managing energy hubs, facilitating investment attraction, and enabling transactions between participants).

The authors emphasize that due to the integrative features and variability of existence, alternative energy development through the prism of energy hubs should become a primary strategic direction for Ukraine. Such development will help restore national energy security, stimulate the country's energy development, and simultaneously achieve sustainable development goals. Hubs are already operational in various countries. Specifically, among such hubs are "Energiewende Bridge" in Germany (which uses blockchain technology to manage energy flows between different countries), "Brooklyn Microgrid" in New York (which integrates solar panels on rooftops, energy storage systems, and smart meters), "Schoonschip" in Amsterdam (which is an energy community where residents of floating houses collectively generate and consume energy), "The Green Deal Hub" in the Netherlands (which combines renewable energy production with innovative energy storage technologies and demand management), and others.

In Ukraine, before the onset of full-scale military aggression by Russia, some entrepreneurial projects began

to emerge aimed at creating energy hubs that integrated various renewable energy sources and utilized digital technologies to manage energy flows. One such project was the energy hub in the Chornobyl Exclusion Zone, which initially planned to create a large-scale energy hub integrating solar and wind power plants, energy storage systems, and infrastructure for producing "green" hydrogen. Due to its extensive area and high level of solar radiation, the Chornobyl Zone has significant potential for developing renewable energy. However, the project has currently been suspended.

With the deterioration of energy security in western regions of Ukraine, initiatives have been launched to develop local energy hubs that integrate various renewable energy sources (solar, wind, biogas) to provide energy for local communities and businesses. Examples include the energy cluster in Yavorivskyi district of Lviv region (involving construction of solar and wind power plants, biogas facilities, and energy storage systems), the "Green" energy hub project in Lviv (establishing infrastructure for production and consumption of energy from renewable sources within the city), the "Smart" energy hub project in Ivano-Frankivsk (creating an intelligent energy network to efficiently manage energy flows and ensure stable energy supply), and the energy cluster project in Vinogradivskyi district (construction of a solar power plant and small hydroelectric power plant), among others. These are just some examples of projects being implemented in western regions of Ukraine. It's worth noting that the number of such initiatives is constantly increasing, indicating the active development of hubs for alternative energy and a desire for energy independence in the region.

Considering the importance of integrated development of alternative energy in the digital economy, these aspects should be based on concepts aimed at ensuring an innovative approach to energy production, distribution, and consumption, which integrates various renewable energy sources into a unified macro, meso, or microsystem. In particular, to achieve this goal, concepts such as intelligent energy hubs (as seen in projects like "Energiewende Bridge" in Germany and the macro hub "The Green Deal" in the Netherlands), decentralized energy hubs (as seen in projects like "Brooklyn Microgrid" in New York, the energy community "Schoonschip" in Amsterdam), and community energy hubs (as exemplified by projects like the energy cooperative "Ecopower" in Belgium, the community solar power station "BürgerEnergie Berlin" in Germany) are applied.

So, the concept of intelligent energy hubs relies on the adoption of advanced technologies (such as artificial intelligence, machine learning, and the Internet of Things) by their stakeholders to transform centralized energy production into hybrid systems, hybridize distribution, and integrate virtual power plants into energy consumption systems (which are provided to the overall grid). The development of this concept is implemented according to the specifics outlined in Table 1.

Due to this, energy systems of such formations gain the ability to integrate various renewable energy sources (solar, wind, hydro, biomass) and ensure flexible management of energy flows, resulting in the following advantages:

1. Optimization of energy production, distribution, and consumption reduces losses and enhances the overall flexibility and efficiency of the energy system.

2. Effective integration of various renewable energy sources contributes to reducing dependence on fossil fuels and lowering greenhouse gas emissions.

3. Ability to rapidly adjust to changing conditions such as fluctuations in energy demand or weather, ensuring stability and reliability of energy supply.

4. Optimizing the operation of the energy system to reduce production and distribution costs, potentially leading to lower tariffs for consumers.

Considering these aspects, formations capable of significant positive impact on national energy security are formed, taking into account their influence on enhancing the resilience and reliability of the energy system and the potential to reduce dependence on energy imports.

In Ukraine, there are already examples of implementing intelligent energy solutions (such as smart grids and energy management systems integrating energy producers). The development of intelligent energy hubs is a promising direction for Ukraine, which can contribute to modernizing the energy system, enhancing its efficiency, and integrating renewable energy.

The concept of decentralized energy hubs is based on developing alternative energy facilities, following distributed energy production and consumption principles. It means that instead of relying on large centralized

Table 1

Implementation specifics of the concept of intelligent energy hubs

Elements of the concept	Implementation specifics of the concept	Specifics of hub development	Features of the concept
Hybrid production	Integration of centralized and distributed energy production	Allowing to leverage the advantages of both approaches, ensuring stability of electricity supply and utilizing renewable energy sources	Requires a comprehensive approach, taking into account national specifics and needs, as well as cooperation among various stakeholders (government, businesses, civil society).
Hybridization of alternative energy distribution	Integration of various renewable energy sources (solar, wind, biomass, etc.) into a unified system	Increasing the efficiency of renewable energy utilization, ensuring uninterrupted electricity supply even under adverse weather conditions.	
Integration of virtual power plants into energy consumption systems	Unification of distributed energy sources into a single management system	Optimization of distributed resource utilization, increasing flexibility and efficiency of the energy system, enabling consumer participation in energy system balancing.	

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

power plants, energy is produced and consumed locally (by individual businesses and households), as outlined in Table 2.

These hubs should include small-scale solar and wind power plants, energy storage systems, and smart grids that facilitate energy exchange among different participants, thereby offering the following advantages:

1. Reducing reliance on centralized energy providers and improving the resilience of the energy system against external factors.

2. Transitioning towards local energy production and consumption, thereby reducing losses in transmitting electricity over long distances.

3. Enabling residents and businesses to actively participate in energy production and consumption, as well as reap economic benefits from these activities.

Considering these aspects, formations capable of significantly impacting energy security at the local level are being shaped, particularly through the gradual reduction of dependence on centralized suppliers and the enhancement of resilience among individual "producer-consumer" groups against external influences.

The community energy hubs concept is based on generation facilities created and managed by local communities. It means that these facilities can include various renewable energy sources, energy storage systems, and infrastructure for electric vehicle charging, with the generated energy consumed by the community according to the specifics outlined in Table 3.

Thus, these hubs are developed taking into account the needs and development features of each element, considering local conditions and needs aimed at reducing costs, creating jobs, and increasing energy independence, due to which the following advantages are formed:

1. Reduction of energy costs and creation of jobs in renewable energy.

2. Optimizing the use of generated energy and reducing the load on the power grid.

3. Reducing electricity costs, increasing the energy independence of the community

Considering these aspects, formations are established that can have a significant positive impact on energy security at the community level due to increased energy autonomy, energy awareness, and reduced energy costs.

Conclusions. Given the importance of integrated development of alternative energy in the digital economy, these aspects should be based on concepts that ensure an innovative approach to production, distribution, and energy consumption, combining different renewable energy sources into a single macro, meso, or microsystem. Specifically through the concepts of intelligent energy hubs, decentralized energy hubs, and community energy

Table 2

The specifics of implementing the concept of decentralized energy hubs

Elements of the concept	Implementation specifics of the concept	Specifics of hub development	Features of the concept
Decentralized production	Energy is generated using small-scale renewable energy installations such as solar panels on rooftops of buildings, wind turbines on farms, biogas plants at enterprises, etc	The generating units should be integrated into microgrids that power local communities.	Requires a comprehensive approach, consideration of local specificities and needs, as well as collaboration among various stakeholders (local businesses, the community)
Decentralized consumption	Locally generated energy is consumed directly at the site, reducing losses from transmitting electricity over long distances	Excess energy should be stored in battery storage systems or fed back into the grid	
Smart grids	Decentralized energy hubs utilize smart grids.	The ability to locally manage energy flows, balance supply and demand, and integrate various energy sources	
Digital technologies	Focus on proprietary digital platforms and applications	The ability to manage energy production and consumption from own sources and participate in energy markets	

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

Table 3

The specifics of implementing the concept of public energy hubs

Elements of the concept	Implementation specifics of the concept	Specifics of hub development
Use of local natural resources (sun, wind, water, biomass) for electricity generation	Community-based energy generation to satisfy local energy demands	Generation facilities are created and located in places with the highest potential for renewable energy sources
Community energy storage systems (public energy bank)	Utilization of diverse energy storage solutions (batteries, pumped hydro storage) for maintaining reliable power delivery during peak demand periods	The selection of energy storage technology is determined by regional characteristics and the type of power generation
Digital solutions for community energy management	Public energy hubs employ smart grid technologies (Smart Grid) tailored to the specific requirements of the community	Capability to control community energy flows, optimizing the balance between energy supply and demand

Source: formulated by the author based on [1–2; 5–6]

hubs. Considering the outlined aspects, we can highlight several general conclusions regarding each of the concepts that can become the basis for the integrated development of alternative energy in the digital economy:

1. The intelligent energy hubs concept is an innovative approach to the production, distribution, and consumption of energy through the use of advanced technologies by their subjects. Important are the transformations of centralized energy production into hybrid, the hybridization of distribution, and the integration of virtual power plants into energy consumption systems. Considering the outlined aspects, formations can have a significant positive impact on energy security at the national level, given their impact on increasing the stability and reliability of the energy system and the possibility of reducing dependence on energy imports.

2. The decentralized energy hubs concept is based on the development of alternative energy facilities based on the principle of distributed energy production and consumption. It means that energy is produced and consumed locally. Thus, these hubs include small solar and wind power plants, energy storage systems, as well as intelligent networks that allow the exchange of energy between different participants. Considering these aspects, formations can have a significant positive impact on energy security at the local level due to the gradual reduction of dependence on centralized suppliers and increased resilience of individual "producer-consumer" groups to external influences.

3. The community energy hubs concept is based on generation facilities created and managed by local communities. It means that these facilities can include various sources of renewable energy, energy storage systems, and infrastructure for charging electric vehicles, and the generated energy is consumed by the community according to its specifics. Considering these aspects, formations can have a significant positive impact on energy security at the community level through increased energy autonomy, awareness, and reduced costs.

Given the presented concepts and their potential impact on energy security, the prospects for further research are to assess the economic efficiency of various concepts of energy hubs and their impact on the development of the local economy.

References:

1. Bilyavs′kyy M. (2020) Oriyentyry rozvytku al′ternatyvnoyi enerhetyky Ukrayiny do 2030 r. [Landmarks of the development of alternative energy of Ukraine until 2030]. *Razumkov tsentr – Razumkov Center.* Available at: https://razumkov.org.ua/statti/oriientyry-rozvytku-alternatyvnoi-energetyky-ukrainy-do-2030r

2. Bila S. O., Shvayuk Yu. E. (2016) Rol′ enerhetychnoho sektoru u zrostanni konkurentospromozhnosti natsional′noyi ekonomiky: svitovyy dosvid ta realiyi Ukrayiny [The role of the energy sector in the growth of the competitiveness of the national economy: world experience and realities of Ukraine]. *Naukovyy visnyk Uzhhorods'koho natsional'noho universytetu – Scientific Bulletin of the Uzhhorod National University,* vol. 10(1), pp. 30–35.

3. Heletukha H. H., Zhelyezna T. A., Kucheruk P. P., Oliynyk Ye. M. (2014) Suchasnyy stan ta perspektyvy rozvytku bioenerhetyky v Ukrayini [The current state and prospects for the development of bioenergy in Ukraine]. *Analitychna zapyska BAU – Analytical note of BAU*, vol. 9. Available at: http://uabio.org/img/files/docs/position-paper-uabio9-ua.pdf

4. Narayevs′kyy S. V. (2015) Porivnyal′nyy analiz efektyvnosti roboty sonyachnoyi enerhetyky u providnykh krayinakh svitu [Comparative analysis of the efficiency of solar energy in the leading countries of the world]. *Ekonomichnyy visnyk NTUU «KPI» – Economic bulletin of NTUU* "KPI", vol. 12, pp. 145–150.

5. Pavliy O. (2024) Vplyv stratehichnykh zmin na efektyvnist′ enerhetychnykh kompaniy ukrayiny [Impact of strategic changes on the efficiency of Ukrainian energy companies]. *Ekonomika ta suspil'stvo – Economy and society*, vol. 63. DOI: https://doi.org/10.32782/2524-0072/2024-63-39

6. Cherevat·s′kyy D., Novak I. (2022) Enerhetychni khaby y elektrostantsiyi zamist′ shakht – rishennya, na yake chekala Ukrayina [Energy hubs and power plants instead of mines – the solution Ukraine was waiting for]. *Hazeta "Svit" – "Svit" newspaper.* Available at: https://svit.kpi.ua/2022/02/08/стаття-економістів-данила-череватсь/

Список використаних джерел:

1. Білявський М. Орієнтири розвитку альтернативної енергетики України до 2030 р. Разумков центр. 22 грудня 2020. URL: https://razumkov.org.ua/statti/oriientyry-rozvytku-alternatyvnoi-energetyky-ukrainy-do-2030r

2. Біла С.О., Шваюк Ю.Е. Роль енергетичного сектору у зростанні конкурентоспроможності національної економіки: світовий досвід та реалії України. *Науковий вісник Ужгородського національного університету*. 2016. № 10(1). С. 30–35.

3. Гелетуха Г.Г., Желєзна Т.А., Кучерук П.П., Олійник Є.М. Сучасний стан та перспективи розвитку біоенергетики в Україні: Аналітична записка БАУ. 2014. № 9. URL: http://uabio.org/img/files/docs/position-paper-uabio9-ua.pdf

4. Нараєвський С.В. Порівняльний аналіз ефективності роботи сонячної енергетики у провідних країнах світу. *Економічний вісник НТУУ «КПІ».* 2015. № 12. С. 145–150.

5. Павлій О. Вплив стратегічних змін на ефективність енергетичних компаній україни *Економіка та суспільство*, 2024. № 63. DOI: https://doi.org/10.32782/2524-0072/2024-63-39

6. Череватський Д., Новак І. Енергетичні хаби й електростанції замість шахт – рішення, на яке чекала Україна. Газета "Світ", 2022. URL: https://svit.kpi.ua/2022/02/08/стаття-економістів-данила-череватсь/

МУКАЧІВСЬКИЙ ДЕРЖАВНИЙ УНІВЕРСИТЕТ

89600, м. Мукачево, вул. Ужгородська, 26
тел./факс +380-3131-21109
Веб-сайт університету: www.msu.edu.ua
E-mail: info@msu.edu.ua, pr@mail.msu.edu.ua
Веб-сайт Інституційного репозитарію Наукової бібліотеки МДУ: http://dspace.msu.edu.ua:8080
Веб-сайт Наукової бібліотеки МДУ: http://msu.edu.ua/library/