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DIGITAL TRANSFORMATION OF ENERGY ENTREPRENEURSHIP: CHALLENGES AND OPPORTUNITIES FOR SUSTAINABLE DEVELOPMENT

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ABSTRACT

The rapid advancement of digital technologies is fundamentally reshaping the energy sector, giving rise to new forms of entrepreneurship and business models that extend well beyond conventional energy supply. This paper aims to systematically analyse the impact of digital transformation on energy entrepreneurship, identify the key drivers, challenges, and risks associated with this process, and develop conceptual recommendations for the formation of digital strategies in the Ukrainian context.

The study employs a combination of logical-theoretical synthesis, comparative analysis, and structural-functional analysis to examine the academic and policy literature on energy sector digitalisation, entrepreneurship, and sustainable development. Institutional analysis is applied to assess the role of regulatory frameworks and state support instruments.

The results demonstrate that digital transformation in energy entrepreneurship is driven by the convergence of the energy transition, technological innovation (AI, IoT, blockchain, cloud platforms), market liberalisation, and growing demands for transparency and efficiency. Four principal categories of digital business models are identified and characterised: energy-as-a-service, peer-to-peer energy trading, virtual power plants, and energy management platforms. These models share a common logic centred on data, service orientation, and network effects. The analysis also reveals that digitalisation entails significant challenges, including cybersecurity vulnerabilities, financial barriers for SMEs, regulatory uncertainty, and the risk of widening the digital divide between large corporations and smaller market participants.

For Ukraine, digital transformation offers particular opportunities within the context of post-war reconstruction and European integration, enabling a leapfrog transition to a decentralised and resilient energy system. Practical recommendations are formulated for Ukrainian energy entrepreneurs across six strategic directions.

The findings contribute to the theoretical understanding of digital energy entrepreneurship and provide a conceptual foundation for further empirical research and evidence-based policy design.

Keywords: digital transformation, energy entrepreneurship, business models, sustainable development, energy sector, Ukraine

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INTRODUCTION

The contemporary global economy is undergoing profound structural shifts, among which digitalisation occupies a central place. In the energy sector, these shifts are of particular significance: the convergence of the global energy transition, the decentralisation of generation, and the proliferation of digital technologies are creating fundamentally new conditions for conducting business and forming entrepreneurial initiatives. The traditional logic of energy markets – built around large vertically integrated companies and regulated tariffs – is being progressively transformed under pressure from new market participants, new forms of interaction, and evolving consumer expectations.

For Ukraine, the question of digital transformation in energy entrepreneurship carries special weight for several reasons. First, European integration processes require gradual convergence with the standards and requirements of the EU digital energy market. Second, war-related damage to infrastructure opens a window of opportunity for reconstruction on an entirely new technological basis, bypassing obsolete solutions. Third, the development of the domestic IT sector and the growing number of energy startups form an internal potential for innovative entrepreneurship.

Despite growing scholarly interest in individual aspects of digitalisation in the energy sector, the academic literature leaves unaddressed the question of a comprehensive understanding of digital transformation as an entrepreneurial phenomenon, from the perspective of business models, strategies, risks, and the conditions for sustainable development, particularly in the context of transition economies. Filling this gap is the objective of the present study.

LITERATURE REVIEW

In contemporary research, the digital transformation of energy enterprises is viewed as a strategic instrument for enhancing efficiency, competitiveness, and business sustainability through the deep integration of digital technologies into key business processes (Xue & Zhu, 2025). Analysis of energy companies shows that digital strategies significantly affect ESG performance and green total factor productivity, meaning that digitalisation not only optimises operational activities but also transforms the value creation model and the environmental performance of enterprises (Xue & Zhu, 2025).

A separate strand of the literature is devoted to the motivations and behaviour of energy enterprises during digital transformation. Drawing on game-theoretic models, researchers demonstrate that companies' decisions to invest in digital technologies are shaped by the balance of costs, regulatory incentives, and expected benefits in the form of improved market position and environmental efficiency (Li et al., 2023). It is emphasised that state policy and the institutional environment can both accelerate and impede digital transformation, influencing enterprises' readiness to adopt innovative solutions (Li et al., 2023).

Research on the impact of digital transformation on the financial and stock market behaviour of energy companies indicates that digital initiatives substantially alter investors' and capital markets' perceptions of businesses. Digitalisation can reduce information asymmetry, enhance transparency and predictability of operations, while simultaneously generating periods of heightened volatility associated with the market's assessment of new risks and opportunities (Sun et al., 2024). On this basis, the authors conclude that successful digital transformation requires not only technical changes but also a well-considered communication and investment strategy (Sun et al., 2024).

Mathematical models of digital transformation in energy enterprises reveal asymmetric behaviour among companies depending on their resources, technological capabilities, and market positions (Guo et al., 2025). It is shown that digital leaders are able to convert investments into green productivity and competitive advantages more rapidly, whereas less prepared enterprises face the risk of becoming 'stuck' at intermediate stages of transformation, thereby intensifying sectoral differentiation (Guo et al., 2025). This underscores the importance of developing adaptive digitalisation strategies tailored to the scale and specific characteristics of individual energy companies (Guo et al., 2025).

A significant portion of the international literature focuses on the transformation of business models in the energy sector under the influence of digitalisation. Research on digitalisation in energy proposes a systematic approach to developing new business models (understand – ideate – select – design – evaluate) and demonstrates how major energy companies, such as ENEL, employ digital tools to launch new services, platforms, and products (Römer et al., 2017). The authors emphasise that digitalisation opens space for service-oriented models (energy-as-a-service), platform solutions, and flexible tariff systems, which alter the role of traditional energy suppliers in the market (Römer et al., 2017).

Works on digitalisation and new business models note that the emergence of digital platforms, peer-to-peer trading, virtual power plants, and services for prosumers is fundamentally reshaping energy market structures and enabling the development of new forms of energy entrepreneurship (Küfeoğlu et al., 2019). It is highlighted that digital technologies reduce entry barriers for startups and SMEs, enabling them to offer innovative products and services integrated into local and regional energy ecosystems (Küfeoğlu et al., 2019).

Policy documents from European expert platforms additionally focus on the role of digitalisation in engaging consumers and creating new market and business models. The ETIP SNET report emphasises that digital energy systems enable the transition from passive to active consumers, the development of local energy communities and cooperative models, in which digital platforms serve as the key infrastructure for market participation (ETIP SNET, 2020). This creates new opportunities for energy entrepreneurship based on decentralised generation, demand flexibility, and energy consumption management services (ETIP SNET, 2020).

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A separate strand of the literature focuses on digital entrepreneurship in the green economy and energy sector. Research on the digital transformation of clean energy startups (Odunaiya et al., 2024) demonstrates that the integration of IoT, artificial intelligence, big data, blockchain, and cloud services enables these companies to enhance operational efficiency, scalability, and market entry speed, as well as to develop innovative business models oriented towards personalised energy services. Studies on the digital foundations of entrepreneurship in renewable and alternative energy stress that digital platforms, marketplaces, and crowdfunding instruments facilitate entrepreneurs' access to financing, partners, and markets, acting as catalysts for new business initiatives in the green energy sector (Maslyhan et al., 2024).

An important contribution to the understanding of digital energy entrepreneurship is made by research on the emergence of digital platforms and X-as-a-Service models in the energy sector of developed countries. Analysis of 240 German energy startups indicates that the majority of innovative companies are early adopters of modern digital technologies (AI, blockchain, digital twins) and are oriented towards a platform-based economy; they offer multi-sided platforms and X-as-a-Service models that 'unbundle' the traditional linear energy value chain and shift the focus to the end consumer (Singh et al., 2021). In this context, digital startups are regarded as key actors in the transformation of energy markets, filling the 'gap' between technological capabilities and the ability of traditional energy companies to monetise digital innovations (Singh et al., 2021; Al-Ababneh et al., 2026).

Ukrainian research supplements the international discourse by emphasising the specificities of digital energy transformation in national conditions. Timchenko et al. (2019) examine digital energy as a new stage in the development of the energy industry, grounded in the convergence of ICT and energy technologies, the formation of intelligent energy systems, and digital management platforms. The authors propose a model of the technological platform 'Intelligent Energy System of Ukraine' and identify the organisational and economic determinants of digital energy transformation, which provides a theoretical foundation for analysing digital business models in the national context (Timchenko et al., 2019).

In the research of Bykonia (2021), digital energy transformation is examined through the lens of organisational and economic mechanisms and changes in the business processes of energy enterprises. The study emphasises the necessity of developing digital transformation roadmaps, transitioning to intelligent energy systems, and strengthening the role of new actors in the energy market. Derhachova et al. (2025) analyse how the introduction of blockchain, drones, smart meters, AI systems, and other digital tools is transforming the operational logic of energy companies, their organisational structure, and their regulatory environment.

The analytical report by Sukhodolia (2022) addresses the application of artificial intelligence in Ukraine's energy sector, covering load forecasting, optimisation of energy system operation, energy efficiency enhancement, and security. The author emphasises that the implementation of AI solutions in domestic energy is closely linked to business model transformation and the emergence of new service products, but is simultaneously accompanied by challenges in the areas of cybersecurity, regulatory compliance, and critical infrastructure protection (Sukhodolia, 2022).

Thus, contemporary academic literature demonstrates that the digital transformation of energy enterprises extends beyond purely technological innovation and encompasses changes in business models, organisational mechanisms, and interactions with investors and consumers. International research provides a general framework for understanding digital business models and entrepreneurial opportunities in the energy sector, while Ukrainian scholarship details the specificities of these processes in the context of digital energy development, institutional constraints, and the post-war transformation of Ukraine's energy market. At the same time, the existing literature leaves unresolved a number of questions concerning digital energy entrepreneurship that can be grouped around several key gaps.

First, it remains insufficiently understood how specific digital technologies (artificial intelligence, IoT, blockchain, cloud platforms) actually transform the logic of business model formation and monetisation in the energy sector, particularly at the level of small enterprises and startups. Most research focuses on technological capabilities and operational efficiency improvements, while the mechanisms for converting digital innovations into sustainable sources of entrepreneurial value are described only fragmentarily.

Second, the question of balancing the effects of digitalisation remains open: on the one hand, it creates new opportunities for the development of green products and services; on the other, it generates new risks associated with investment volatility, cybersecurity, digital inequality, and dependence on large platforms. Insufficient attention has been paid to the conditions under which digital transformation genuinely contributes to sustainable development, as opposed to merely amplifying existing imbalances between different groups of energy market participants.

Third, there is a lack of an integrated understanding of the interactions among large energy corporations, digital startups, regulators, and local energy communities. Strategies of corporations, startup ecosystems, and regulatory reforms are

analysed in isolation, but an integrated model showing how the ecosystem of digital energy entrepreneurship actually forms and how benefits and risks are distributed within it is practically absent.

Fourth, the national and regional specificities of digital energy entrepreneurship transformation have been insufficiently studied, particularly in transition economies and in the context of post-war reconstruction. The question of how differences in institutional environments, access to capital, and digital infrastructure affect the opportunities and barriers to sustainable energy business development requires further theoretical and empirical elaboration.

AIMS AND OBJECTIVES

The aim of the study is to formulate and theoretically substantiate the impact of digital transformation on energy entrepreneurship, to identify key challenges and opportunities for ensuring sustainable development, and to develop recommendations for the formation of digital business models and the institutional conditions for their implementation in Ukraine.

Research objectives:

1. To identify and systematise the principal factors and drivers of digital transformation in energy entrepreneurship, particularly in the context of the energy transition, decentralisation, and the digital economy.
2. To identify and classify contemporary digital business models in energy entrepreneurship.
3. To analyse the main challenges and risks of digitalisation in energy entrepreneurship.
4. To assess the opportunities offered by digital technologies for achieving sustainable development goals in energy entrepreneurship, taking into account Ukrainian realities.
5. To develop conceptual and practical recommendations for the formation and implementation of digital strategies for energy entrepreneurship in Ukraine, aimed at minimising the risks of digital transformation and maximising its contribution to sustainable development.

METHODS

The methodological foundation of the study consists of systemic, institutional, and innovation-based approaches, which make it possible to examine the digital transformation of energy entrepreneurship as a complex process of change in technological, organisational-economic, and institutional parameters. Within the systemic approach, energy entrepreneurship is analysed as an element of a broader energy and entrepreneurial ecosystem linked to market, regulatory, and social subsystems.

To achieve the stated aim, methods of logical-theoretical synthesis and comparative analysis were employed for the critical review of scholarly approaches to digitalisation, energy entrepreneurship, and sustainable development; methods of structural-functional analysis were applied for the identification and classification of the factors and drivers of digital transformation, as well as for the typology of digital business models in the energy sector. Elements of institutional analysis were used to assess the impact of the regulatory environment, state policy, and innovation support instruments on the development of digital energy entrepreneurship, particularly in Ukraine.

In addition, methods of systematisation and logical modelling were used to construct a conceptual model of the interrelationship between digital technologies, business models of energy enterprises, and sustainable development goals, as well as to formulate practical recommendations regarding digital strategies for energy entrepreneurship.

RESULTS

Digital transformation in energy entrepreneurship is understood as a profound reconceptualisation of the ways in which energy products and services are created, delivered, and monetised, based on the widespread adoption of digital technologies across the entire value chain – from generation and transmission to retail and end-consumer interaction (Verytechnology, n.d.; Rebbert, 2025). Such transformation differs from a narrow understanding of digitalisation as the digitisation of individual processes in that it presupposes changes in business models, organisational structures, and management practices, the integration of data into strategic decision-making, and the use of digital platforms as a new type of market

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infrastructure (Fuentes & Fattouh, 2026; Strategy&, n.d.). Contemporary approaches emphasise that in the energy industry, digital technologies perform a 'transversal' role, simultaneously influencing operational efficiency, asset management, customer engagement, and new product development (Fuentes & Fattouh, 2025; Panorama Consulting Group, n.d.).

Energy entrepreneurship may usefully be defined as a set of entrepreneurial initiatives, business models, and practices aimed at the creation, implementation, and scaling of innovations in the production, distribution, storage, and consumption of energy (Hamwi & Lizarralde, 2018; Hannon & Bolton, 2015). It encompasses both the activities of new entrepreneurial structures – startups, energy cooperatives, flexibility aggregators – and the transformation of existing energy companies that are changing their business logic under the influence of the energy transition and decentralisation (Hamwi & Lizarralde, 2018; Mazzucato & Semieniuk, 2017). The distinguishing features of energy entrepreneurship include an orientation towards decentralised small-scale assets, a service logic, the active participation of end users in value creation, and the use of flexible revenue models – pay-per-use, subscription, platform commissions, and the like (Hamwi & Lizarralde, 2018; Römer et al., 2017).

The essence of the digital transformation of energy entrepreneurship manifests itself above all in the emergence of new digital business models. Research underscores that the combination of renewable generation and digital technologies (IoT, cloud platforms, data analytics, blockchain) leads to the formation of service-oriented models such as energy-as-a-service, peer-to-peer energy trading, flexibility management platforms, and virtual power plants, which supplement or transform the traditional 'linear' models of vertically integrated companies (Römer et al., 2017; Fattouh & Fuentes, 2025). Digital platforms thus function as the basic infrastructure for coordinating numerous decentralised participants, while data becomes the key resource for creating and capturing value (Römer et al., 2017; Rebbert, 2025).

The scholarly approaches to studying digital transformation in the energy sector have developed at the intersection of systemic, innovation, and institutional analysis. The systemic approach regards the energy industry as a complex socio-technical system in which digital technologies are altering the interrelationships between generation, grid infrastructure, markets, regulation, and consumer behaviour (Llorca et al., 2024; European Commission, n.d.). The innovation approach focuses on digitalisation as a source of business model innovations: digital solutions are interpreted not merely as optimisation tools but as the basis for the emergence of new value propositions, distribution channels, pricing mechanisms, and market participant roles (Römer et al., 2017; Hamwi & Lizarralde, 2018). The institutional approach emphasises that the character and pace of digital transformation in energy entrepreneurship are determined not only by technological capabilities but also by the architecture of the rules of the game – regulatory frameworks, interoperability standards, data policies, innovation support instruments, and ownership structures in the energy sector (European Commission, n.d.; E.DSO, 2025). In European strategic documents, the digitalisation of the energy system is regarded as an element of a comprehensive policy designed to ensure the combination of market competition, supply security, data protection, and the development of digital energy service markets (European Commission, n.d.). Together, these approaches form the methodological foundation for analysing the digital transformation of energy entrepreneurship as a multi-level process that combines technological, entrepreneurial, and institutional change.

The digital transformation of energy entrepreneurship is taking place against the backdrop of broader global shifts associated with the energy transition, the decentralisation of generation, and the formation of the digital economy. High shares of renewable sources, the emergence of distributed energy resources, the development of electric mobility, and energy storage systems are complicating the management of energy systems while simultaneously creating demand for new digital solutions for monitoring, balancing, and coordinating large numbers of participants (Llorca et al., 2024). In such conditions, digital technologies become the key instrument for integrating the technical, market, and organisational elements of the energy system, opening space for the emergence of new entrepreneurial models (DNV, n.d.; Rebbert, 2025).

An important group of drivers comprises technological innovations – artificial intelligence, the Internet of Things, big data analytics, cloud computing, blockchain, and digital twins (Römer et al., 2017; Fuentes & Fattouh, 2026). The Internet of Things enables the continuous collection of data from meters, grid equipment, generation and consumption facilities, providing the foundation for operational management and forecasting (DNV, n.d.). Artificial intelligence and machine learning enable the optimisation of grid and generation operations, anomaly detection, demand and supply forecasting – functions that are critically important for dynamic electricity markets (Fuentes & Fattouh, 2026). Blockchain and other distributed ledger technologies are used to ensure transaction transparency, facilitate peer-to-peer trading, and verify the origin of green energy, while digital twins enable the modelling of complex energy systems and the testing of new business models without risk to real infrastructure (Römer et al., 2017; DNV, n.d.).

Institutional and regulatory factors exert a substantial influence on the development of digital transformation. The liberalisation of energy markets, the introduction of competitive retail segments, balancing services, and ancillary services create

new niches for digital services related to flexibility management, demand aggregation, and distributed generation (European Commission, n.d.; Llorca et al., 2024). Regulatory initiatives regarding the opening of energy data, the introduction of interoperability and cybersecurity standards, form the basis for the development of platform solutions and analytical services (European Commission, n.d.; E.DSO, 2025). At the same time, stringent requirements for the reliability and security of critical infrastructure, the slow pace of approval procedures for innovative projects, and uncertainty regarding data use regimes can significantly impede the adoption of digital technologies, particularly for small enterprises and startups (E.DSO, 2025).

Market and financial drivers are equally important. Growing competition in energy markets, the emergence of new players, and changing consumer behaviour – with customers expecting transparency, customised services, and digital interaction channels – are compelling companies to reconsider their business models and seek new sources of revenue (Strategy&, n.d.; Rebbert, 2025). Investors and financial institutions are increasingly assessing companies in terms of their digital maturity, data management capability, and ability to implement innovative projects, which creates additional incentives for digital transformation (Strategy&, n.d.). For energy entrepreneurs, this means that digital solutions are becoming not only an efficiency tool but also a prerequisite for access to capital and participation in new market segments.

An additional group of factors consists of organisational, managerial, and human capital conditions. Successful digital transformation requires not only IT infrastructure investment but also changes in corporate culture, the development of digital competencies among staff, and the formation of interdisciplinary teams at the intersection of energy, IT, and finance (Rebbert, 2025; Strategy&, n.d.). The presence of internal digital leaders capable of initiating pilot projects, working with data, and building partnerships with technology providers and startups significantly increases an enterprise's chances of successfully implementing new models. The absence of such competencies, conversely, becomes a barrier that allows only the formal digitisation of existing processes without substantive change to the entrepreneurial logic (Rebbert, 2025).

Table 1 below presents a systematisation of the factors influencing the digital transformation of energy enterprises.

Table 1. Factors of digital transformation of energy entrepreneurship.

Factor Group	Specific Drivers	Nature of Impact on Energy Entrepreneurship
Global Trends	Energy transition, decentralisation of generation, growing share of renewables	Increase the complexity of system management; create demand for digital solutions for monitoring, balancing, and coordinating multiple participants
	Formation of the digital economy	Raises expectations for digital services; opens opportunities for new data-driven value creation models
Technological Innovations	Internet of Things	Enables continuous data collection on consumption, grid status, and equipment; creates the foundation for operational management
	Artificial intelligence/machine learning	Optimise grid and generation operations; enable demand and supply forecasting; support new digital services
	Big data analytics, cloud computing	Enable processing of large volumes of energy data; support scalable platforms and service models
	Blockchain and distributed ledgers	Ensure transaction transparency; support peer-to-peer trading and verification of green energy origin
	Digital twins	Enable modelling of energy systems and testing of new business models without risk to real infrastructure
Institutional & Regulatory	Cybersecurity and data protection regulation	Defines requirements for digital solutions; can both foster trust and raise entry costs for SMEs
	Liberalisation of energy markets	Creates competitive segments (retail, balancing services); opens niches for digital services
	Open energy data policies, interoperability standards	Form the basis for platform development, analytical services, and new data-driven business models
	Cybersecurity and data protection regulation	Defines requirements for digital solutions; can both foster trust and raise entry costs for SMEs
Market & Financial	Innovation and startup support instruments	Facilitate testing and scaling of digital solutions; accelerate the formation of energy startup ecosystems
	Increased competition, emergence of new players	Incentivises companies to seek new revenue sources and transition to digital business models
	Changing consumer expectations (transparency, customisation, digital channels)	Drives development of digital services, self-service platforms, and personalised energy products
Organisational & Managerial	Investors focus on digital maturity	Makes digital transformation a prerequisite for accessing capital and attracting strategic partners
	Digital staff competencies, interdisciplinary teams	Determine the company's ability to implement and scale digital solutions and convert them into new business models

The combination of global trends, technological innovations, regulatory changes, and new market demands creates not only the conditions for digital transformation but also a demand for qualitatively new forms of energy business organisation.

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In response to these drivers, energy companies and startups are transitioning from infrastructure-oriented models to digital business models centred on data, services, and platforms (Römer et al., 2017; Strategy&, n.d.; Rebbert, 2025).

Digital business models in energy entrepreneurship are forming around the idea of transforming energy from a 'commodity' into a complex of services and digital offerings based on the use of real-time data, platform logic, and flexible pricing mechanisms (Fuentes & Fattouh, 2026; Rebbert, 2025). Unlike the traditional model of selling kilowatt-hours at regulated tariffs, digital models are oriented towards delivering added value – consumption optimisation, flexibility management, integration of distributed resources, and personalised solutions for different user groups (Römer et al., 2017; Llorca et al., 2024).

One of the most prevalent digital models is the energy-as-a-service concept, under which the client pays not for the volume of electricity consumed but for a guaranteed level of comfort, energy efficiency, or uninterrupted equipment operation (Römer et al., 2017; DNV, n.d.). In this case, the provider enterprise assumes responsibility for energy consumption management, relying on IoT sensors, data analytics, and software platforms, and derives revenue in the form of a subscription or service fee (DNV, n.d.). For energy entrepreneurs, this model opens the possibility of moving beyond traditional energy retail and positioning themselves as providers of integrated technical-service solutions (Rebbert, 2025).

A second important direction comprises peer-to-peer energy trading models and local energy communities based on digital platforms and smart metering (ETIP SNET, 2018; Llorca et al., 2024). Through platforms, owners of small generation facilities – households with solar panels, small enterprises – can sell surplus energy directly to other consumers within a microgrid or energy cooperative (Römer et al., 2017). Such platforms combine the functions of a marketplace, billing system, and energy origin tracking, with their operators becoming new entrepreneurial actors – aggregators and platform providers (ETIP SNET, 2018).

A third group consists of models associated with virtual power plants and flexibility management, in which digital platforms aggregate distributed generation sources, storage facilities, and controllable loads into a unified 'virtual' portfolio (Fuentes & Fattouh, 2026). Using forecasting and optimisation algorithms, aggregator companies sell consolidated flexibility in wholesale, balancing, and ancillary markets, and also offer clients services for participation in these markets (Llorca et al., 2024). For small and medium-sized consumers, this opens access to additional sources of income that were previously available only to large generation companies (ETIP SNET, 2018).

A distinct segment of digital business models is associated with energy management platforms and analytical services that provide monitoring, visualisation, forecasting, and consumption optimisation tools for industrial consumers, municipalities, and building managers (DNV, n.d.; Rebbert, 2025). Revenue in such models is generated through licensing schemes, subscription, or pay-per-use, and the key competence of entrepreneurs becomes the ability to work with data and interfaces for different user groups (Strategy&, 2023). This creates a broad space for startups specialising in niche solutions – energy management for small businesses, municipal infrastructure, or electric vehicle charging stations (Llorca et al., 2024).

All of the aforementioned models share several common features:

1. They are data-centric: the source of competitive advantage becomes the ability to collect, process, and interpret energy data (Fuentes & Fattouh, 2026).
2. They have a service character and are oriented towards long-term client relationships rather than one-off transactions (Römer et al., 2017).
3. They embody a network logic, in which the value of a platform grows with the number of participants, and success depends on the entrepreneur's ability to build partnership ecosystems and integrate into existing market and regulatory infrastructure (Strategy&, n.d.; ETIP SNET, 2018).

For energy entrepreneurship, this signifies a shift from ownership of large material assets to the management of digital assets, data, and stakeholder relationships.

Despite the significant potential of digital technologies, the process of digital transformation in energy entrepreneurship is accompanied by a range of challenges and risks. Above all, the complexity of technically integrating new solutions into existing energy infrastructure creates high demands for equipment compatibility, data quality, and cybersecurity (Kummerow et al., 2023). The combination of traditional control systems – originally designed as relatively closed – with open digital platforms and cloud services increases the risks of unauthorised access, cyberattacks, and disruptions to critical infrastructure, requiring significant investment in protection, redundancy, and vulnerability management (European Commission, 2025; Eurelectric, 2025).

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In addition, digitalisation intensifies financial and organisational risks for energy entrepreneurs, particularly for small and medium-sized companies and startups. The high upfront cost of implementing digital solutions, uncertainty regarding return on investment, and limited access to capital and competencies are frequently cited as the key barriers to digitalisation for SMEs in the energy transition (Király, 2023; Casorati & Verbeek, 2020). This is compounded by the fact that regulatory frameworks and market rules often change more slowly than technology, creating a 'regulatory lag': entrepreneurs bear risks associated with the unpredictability of future rules of the game, tariffs, or requirements for market participation (ETIP SNET, 2021).

At the same time, digital transformation may deepen the digital divide between large energy corporations and small entrepreneurs. Large companies have more resources to invest in infrastructure, data analytics, proprietary platforms, and specialist teams, whereas SMEs are often limited to standard services or dependent on external platform providers (Casorati & Verbeek, 2020). This creates a risk of market power concentration in the hands of a few large players or platforms that control access to data and channels of interaction with end consumers, thereby complicating conditions of entry for new entrepreneurs (Chambers et al., 2022).

Digitalisation also has important social and ethical dimensions. The automation of processes and the introduction of intelligent management systems can alter the employment structure in the energy industry, reducing demand for some traditional professions and imposing new requirements for digital competencies (Kummerow et al., 2023). Uneven access to digital infrastructure and services – across regions, consumer groups, and enterprise types – may reinforce existing economic and energy inequality, notably through the intensification of the 'digital divide', which complicates the alleviation of energy poverty (Qian et al., 2024; Chambers et al., 2022). Additional concerns arise from the use of large volumes of energy consumption data, related to privacy, user consent, and the potential use of such data for discriminatory pricing or consumer profiling (European Commission, 2025).

Finally, an important challenge is the alignment of the pace and scale of digital transformation with the actual needs and capabilities of energy markets. Excessive technological optimism, the absence of clear business objectives, and a weak link between digital initiatives and companies' long-term strategies can lead to fragmented, incompatible solutions that do not generate significant added value (ETIP SNET, 2021). For energy entrepreneurship, this implies the need to critically assess not only the potential benefits of digitalisation but also its associated risks, developing balanced approaches to the adoption of digital technologies, change management, and competency development (Casorati & Verbeek, 2020).

Table 2. Key challenges and risks of digitalisation in energy entrepreneurship.

Challenge / Risk Group	Specific Aspect	Summary
Technical & Cybersecurity	Integration of new digital solutions into existing IT/OT infrastructure	Complexity of combining traditional control systems with open platforms and cloud services; risks of failures and incompatibility
	Cyberthreats and protection of critical infrastructure	Growing risk of cyberattacks and unauthorised access; need for significant investment in cybersecurity and redundancy
Financial	High cost of implementing digital technologies	Substantial upfront investment in IT infrastructure, platforms, and data protection – particularly burdensome for SMEs and startups
	Uncertainty regarding return on investment and business impact	Difficulty in accurately forecasting financial outcomes of digital projects; risk of getting 'stuck' at the pilot stage without scaling
Regulatory	'Regulatory lag' and unpredictability of rules	Slow adaptation of the regulatory framework to new models (P2P trading, aggregators, platforms); uncertainty regarding tariffs and market participation conditions
	Requirements on data, interoperability, and cybersecurity	Stringent standards can raise entry costs for small players, while simultaneously serving as a prerequisite for trust in digital solutions
Structural (Market)	Digital divide between large companies and SMEs	Large companies have resources to build proprietary platforms and analytics; SMEs depend on external providers and have inferior access to data and markets
	Concentration of platform power	Risk of dominance by a few large platforms controlling interfaces with end consumers, disadvantaging smaller participants
Social	Changes in employment structure and competency requirements	Automation of routine tasks, reduction of traditional roles; growing need for digital and interdisciplinary competencies
Ethical & Data-Related	Digital inequality across regions and consumer groups	Uneven access to digital infrastructure and services may deepen economic and energy inequality
	Privacy and consumer data use	Mass collection of energy consumption data generates risks of privacy violations, opaque profiling, and discriminatory pricing
Strategic & Managerial	Absence of clear digitalisation objectives	Risk of fragmented, incompatible solutions and 'digitalisation for its own sake', disconnected from corporate strategy
	Lack of competent digital leadership	Difficulty managing change; staff resistance; orientation towards maintaining old processes rather than building new business models

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Despite the risks identified above, the digital transformation of energy entrepreneurship creates multidimensional opportunities (Table 3) that lie at the intersection of technological, economic, social, and environmental effects:

1. Digital technologies make it possible to significantly enhance the energy efficiency of both production and consumption. Smart meters, IoT sensors, and real-time monitoring and analytics systems enable the precise measurement and identification of inefficient operating modes, the optimisation of equipment performance, and the reduction of grid losses (IIASA, 2019; Llorca et al., 2024). For entrepreneurs, this opens a market for energy management services, data-driven energy auditing, and digital solutions for smart buildings and industrial facilities.
2. Digitalisation facilitates the integration of renewable energy sources and flexible resources into the energy system. Platforms for forecasting renewable generation, flexibility management, and virtual power plants enable the combination of distributed sources, storage facilities, and controllable loads into manageable portfolios that can participate in wholesale and balancing markets (Fuentes & Fattouh, 2026; EC, 2025). This opens opportunities for a new wave of energy startup aggregators and service companies specialising in flexibility and system balancing.
3. Digital platforms and mobile services broaden access to energy services for households, SMEs, and communities that were previously remote from traditional infrastructure. Pay-as-you-go business models, crowdfunding platforms for financing microgrids, and online marketplaces for local energy trading make small renewable energy projects economically viable and enable local communities to participate in investing in and managing energy assets (IIASA, 2019; OECD, n.d.). For entrepreneurs, this means the emergence of new niches in decentralised solutions and social energy entrepreneurship.
4. Digitalisation contributes to enhanced transparency and accountability in energy markets. Public data platforms, blockchain solutions for tracking the origin of green energy, and consumer digital accounts create conditions for more transparent pricing, fair competition, and better-informed consumers (Llorca et al., 2024; EC, 2025a). This, in turn, strengthens trust in new business models, reduces information asymmetry, and stimulates active consumer market participation.
5. Digital technologies can support the environmental and social responsibility of the energy business. Carbon footprint measurement tools, ESG reporting systems, and platforms for engaging the public in monitoring environmental and social impact enable entrepreneurs to integrate sustainability criteria into their business models (JRC, 2025; OECD, n.d.). This not only meets investor and regulatory expectations but also creates additional market advantages associated with green branding and access to specialised financing.

Table 3. Opportunities of digital transformation for sustainable development of energy entrepreneurship.

Direction	Nature of Opportunity	Key Instruments / Models	Potential Effect
Energy Efficiency Enhancement	Optimisation of energy consumption and production; reduction of losses in smart grids	Smart meters, IoT sensors, energy management systems, data analytics	Reduced costs, lower waste, emergence of energy management service businesses
Integration of Renewables and Flexibility	Managed integration of distributed generation, storage, and controllable loads	Virtual power plants, flexibility platforms, aggregators, renewable generation forecasting	Enhanced system resilience; new niches for aggregators and startups
Broadening Access to Energy Services	Providing energy to remote and vulnerable communities through decentralised solutions	Microgrids, pay-as-you-go models, mobile payments, crowdfunding	Reduction of energy poverty; development of local energy entrepreneurship
Transparency and Consumer Participation	Enhancing market transparency; engaging consumers as active participants	Open data, blockchain for energy origin tracking, P2P trading platforms, consumer portals	Reduced information asymmetry; increased trust; new prosumer roles
ESG and Green Responsibility	Integration of environmental and social indicators into business models	ESG dashboards, non-financial reporting systems, carbon footprint measurement tools	Strengthened reputation, compliance with investor requirements, access to green financing

Finally, in the context of Ukraine, digital transformation opens opportunities for 'leapfrogging' obsolete technological paradigms and building a modern, decentralised, and resilient energy system in the course of infrastructure reconstruction. The combination of reconstruction programmes, European integration requirements, and the development of digital infrastructure creates a window of opportunity for scaling local energy projects, enhancing the energy efficiency of industry and the municipal sector, and developing Ukrainian energy startups oriented towards global markets (UNDP, 2025; Bandura & Romanishyn, 2025).

In light of the development opportunities identified, the following recommendations may be offered to domestic energy enterprises:

1. Develop digital energy management services for businesses and communities (focus on solutions that combine smart metering, consumption visualisation, analytics, and energy cost optimisation recommendations for SMEs, residential building associations, and municipalities; use subscription or pay-per-use models to lower the entry barrier for clients and tie revenue to actually achieved savings).
2. Launch platforms for flexibility management and microgrids (work with local communities, industrial parks, and logistics hubs where renewable sources, storage, and variable loads are combined; build flexibility aggregation services and prepare for participation in balancing and ancillary markets as these are progressively liberalised).
3. Focus on digital solutions for decentralised and off-grid applications (develop pay-as-you-go models, mobile applications, and crowdfunding platforms for financing and servicing small renewable energy projects in communities; position such products as combining savings for households and SMEs with enhanced local energy security).
4. Utilise open data and blockchain for transparency and trust (create services that build on open energy data: tariff comparisons, supplier ratings, renewable energy benefit calculators; for green products – certificates of origin, local green energy – consider blockchain solutions that verify energy origin and consumption).
5. Integrate ESG and sustainability into digital products from the outset (embed carbon footprint accounting, energy savings, and social impact modules into platforms so that clients can generate ESG reporting 'out of the box'; use these modules as an argument for attracting green financing, grants, and partnerships with international donors).
6. Build partnerships with IT companies and communities (avoid attempting to create all technologies independently: it is more effective to combine domain expertise in energy with the competencies of Ukrainian IT companies; work with communities as co-founders or anchor clients of local energy platforms – this simplifies financing attraction and scaling).

DISCUSSION

The results of the study allow for several interpretations that extend beyond the immediate description of the data. First and foremost, the systematisation of the factors and drivers of digital transformation demonstrates that none of them is sufficient in isolation: technological capabilities are realised only in the presence of an appropriate institutional environment, market incentives, and organisational readiness on the part of enterprises. This observation resonates with the general direction of the contemporary literature (Li et al., 2023; Fuentes & Fattouh, 2025), which is increasingly moving away from technological determinism in favour of systemic and ecosystem-based explanations of digital transformation dynamics, particularly in studies of digital energy business models and start-up ecosystems (Römer et al., 2017; Singh et al., 2021; Küfeoğlu et al., 2019).

The common features identified across digital business models – data centricity, service character, and network logic – indicate that transformation in energy entrepreneurship is not only a technological but also a deeply organisational process. The transition from selling energy as a commodity to managing data and stakeholder relationships requires a different entrepreneurial logic, a different competency structure, and accordingly a different model of strategic management, as is partly confirmed by studies of energy platforms and X as a Service models in advanced economies (Römer et al., 2017; Singh et al., 2021). The findings of this paper complement these contributions by emphasising the specific situation of SMEs and startups, whereas most existing research focuses primarily on large energy companies.

The analysis of risks and challenges allows for a further important conclusion: 'regulatory lag' – the situation in which the regulatory framework lags behind the pace of technological change – is not merely an external constraint but an autonomous source of strategic uncertainty for entrepreneurs. It is precisely this uncertainty that complicates investment decision-making and explains why even technologically ready enterprises may delay the transition to new business models.

At the same time, the study has a number of characteristics that define promising directions for further work. Since the analysis is grounded in the theoretical and conceptual synthesis of the academic and analytical literature, the proposed typology of business models and the conceptual model of the interrelationship between digital technologies, entrepreneurship, and sustainable development require verification on the basis of primary data. A comparative case study of specific Ukrainian and Central European energy enterprises and startups would make it possible to determine the extent to which the identified opportunities and barriers are reproduced in different institutional contexts.

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Furthermore, the recommendations proposed for Ukrainian energy entrepreneurs are formulated at a conceptual level. Their operationalisation requires the development of quantitative indicators of digital maturity adapted to the conditions of transition economies, as well as their testing within the framework of specific pilot projects or innovation support programmes.

Finally, the specifics of digital energy entrepreneurship transformation under conditions of war-related infrastructure damage and accelerated reconstruction constitute a phenomenon that is practically absent from the existing international literature. This opens a broad research space in which Ukrainian scholars have the opportunity to make an original contribution not only to regional but also to global academic discourse.

CONCLUSIONS

Digital transformation in energy entrepreneurship is not merely the introduction of individual IT solutions but a fundamental change in business logic: from the sale of energy as a commodity to service-oriented, platform-based, and data-centric models in which data, analytics, flexibility, and consumer participation play a central role. It is established that the driving forces of these changes are the convergence of the energy transition, technological progress, market liberalisation, and growing demands for transparency and efficiency, while the principal constraints are associated with high investment costs, cyber risks, institutional uncertainty, and the digital divide between large companies and small entrepreneurs. Digital business models – energy-as-a-service, peer-to-peer energy trading, virtual power plants, and energy management platforms – are shown to create significant potential for enhancing energy efficiency, integrating renewable sources, broadening access to energy services, and forming new market niches, but their sustainable development requires purposeful support policies and balanced risk management. For Ukraine, this opens additional opportunities in the context of post-war reconstruction and European integration, provided that digital, energy, and innovation policies are aligned and that energy startups and SMEs receive appropriate support.

A structured analysis of the main challenges and risks of digital transformation for energy firms has been carried out, highlighting vulnerabilities in the field of cybersecurity, financial and organisational barriers for SMEs and start-ups, and demonstrating that regulatory uncertainty and "regulatory lag" act as independent sources of strategic risk that can delay the transition to new digital business models even when companies are technologically ready. By combining international experience with the specific features of Ukraine's post-war energy transition, the study assesses how digital technologies can contribute to achieving sustainable development goals – improving the efficiency, flexibility, transparency and resilience of the energy system – while at the same time revealing context-specific constraints related to infrastructure damage, institutional instability and limited access to finance, which determine the real scope for realising these benefits. Building on the developed conceptual framework and the analysis of drivers, business models, risks and sustainable-development potential, the paper proposes a set of strategic recommendations for Ukrainian energy entrepreneurs and policy-makers, grouped around the development of digital platforms and services, partnerships with start-ups, data and cybersecurity management, innovation financing and consumer engagement, which together form a practical roadmap for designing and implementing digital strategies in Ukraine's energy sector.

Further research should focus on several directions. First, empirical studies are needed of specific cases of Ukrainian energy startups and companies implementing digital business models, with an assessment of their economic, social, and environmental impact. Second, it is relevant to develop quantitative methodologies for measuring the impact of digital services on the energy efficiency, competitiveness, and resilience of energy enterprises of various scales. Third, it is promising to analyse regulatory and institutional scenarios that would combine the stimulation of digital innovation with the minimisation of cyber, social, and environmental risks, including support mechanisms for SMEs and local energy communities. Fourth, the impact of digital transformation on vulnerable consumer groups and the instruments for ensuring equity and inclusivity in digital energy deserve separate attention.

ADDITIONAL INFORMATION

AUTHOR CONTRIBUTIONS

All authors have contributed equally.

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The Authors declare that there is no conflict of interest.

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ЦИФРОВА ТРАНСФОРМАЦІЯ ЕНЕРГЕТИЧНОГО ПІДПРИЄМНИЦТВА: ВИКЛИКИ ТА МОЖЛИВОСТІ СТАЛОГО РОЗВИТКУ

Швидкий розвиток цифрових технологій докорінно змінює енергетичний сектор, зумовлюючи появу нових форм підприємництва та бізнес-моделей, що виходять далеко за межі традиційного енергопостачання. У дослідженні

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здійснено спробу систематично проаналізувати вплив цифрової трансформації на енергетичне підприємництво, виявити ключові рушійні сили, виклики та ризики цього процесу, а також розробити концептуальні рекомендації щодо формування цифрових стратегій в українському контексті.

У дослідженні застосовано поєднання логіко-теоретичного синтезу, порівняльного аналізу й структурно-функціонального аналізу для вивчення наукової та політичної літератури з цифровізації енергетики, підприємництва й сталого розвитку. Для оцінки ролі регуляторних рамок і інструментів державної підтримки використано інституційний аналіз.

Результати показують, що цифрова трансформація в енергетичному підприємництві зумовлена поєднанням енергетичного переходу, технологічних інновацій (AI, IoT, блокчейн, хмарні платформи), лібералізації ринків і зростання вимог до прозорості й ефективності. Виокремлено й охарактеризовано чотири основні категорії цифрових бізнес-моделей: energy-as-a-service, peer-to-peer енерготоргівля, віртуальні електростанції та платформи енергоменеджменту – їх об’єднує спільна логіка, заснована на даних, сервісній орієнтації та мережевих ефектах. Аналіз також виявив, що цифровізація супроводжується суттєвими викликами, зокрема вразливістю до кібератак, фінансовими бар’єрами для МСП, регуляторною невизначеністю та ризиком поглиблення цифрового розриву між великими корпораціями й меншими учасниками ринку.

Для України цифрова трансформація відкриває особливі можливості в умовах післявоєнного відновлення та європейської інтеграції, дозволяючи здійснити «стрибок» до децентралізованої й стійкої енергетичної системи. Сформульовано практичні рекомендації для українських енергетичних підприємців за шістьма стратегічними напрямами.

Отримані результати поглиблюють теоретичне розуміння цифрового енергетичного підприємництва й створюють концептуальну основу для подальших емпіричних досліджень і розроблення політики, заснованої на доказах.

Ключові слова: цифрова трансформація, енергетичне підприємництво, бізнес-моделі, сталий розвиток, енергетичний сектор, Україна

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