INNOVATION AND SUSTAINABILITY
Volume 5, No. 4. 2025
ISSN 2786-5940, e-ISSN 2786-5959
Received: 08.07.2025 Revised: 06.11.2025
Accepted: 23.12.2025 Published: 06.01.2026
Journal homepage: https://inns.com.ua/en

UDC 620.9:004:330.5
DOI: 10.31649/vis/4.2025.97

Digital transformation of energy allocation: From data transparency to socio-economic justice

Viktor Zamlynskyi*
Doctor of Economic Sciences, Professor
Odesa National University of Technology
65039, 112 Kanatna Str., Odesa, Ukraine
https://orcid.org/0000-0001-7642-2443

Stanislav Gorodnichenko
Postgraduate Student
Odesa National University of Technology
65039, 112 Kanatna Str., Odesa, Ukraine
https://orcid.org/0009-0002-6159-284X

Abstract. The relevance stems from the fact that, under the conditions of war and post-war recovery in Ukraine, the digital transformation of energy governance is becoming a key instrument for overcoming energy poverty, regional disparities, and a crisis of trust in energy policy. The organisation of digital energy allocation determines the social legitimacy of the energy transition and the recovery model. The purpose of the article was to substantiate the concept of digitally fair energy allocation and to develop a methodological framework for assessing the impact of digital tools on social justice and economic efficiency in distribution systems. The study systematised contemporary approaches to energy justice, analysed digital technologies in the energy sector, and applied comparative and systems analysis methods. On this basis, a conceptual "data-trust-justice" framework was developed, and a quasi-experimental design for evaluating digital allocation policies at the feeder level was formulated. The research established that the traditional centralised model of energy allocation, built on fragmented data and low transparency, reproduces regional disparities, energy poverty, and distrust towards regulatory decisions. Within the study, a new concept of "digitally fair energy allocation" was developed, combining economic efficiency and transparency with guaranteed access to basic energy services for vulnerable groups. The role of intelligent metering systems, big data analytics, artificial intelligence methods, and blockchain-based registries in forming an integrated "data-trust-justice" chain was analysed. A structure of digital allocation scenarios based on different principles of distributive justice was proposed, and measurable targets of implementation for distribution system operators were defined. The results showed that integrating justice criteria into digital allocation models helps to avoid socially regressive outcomes and strengthens the legitimacy of energy policy. The findings can be used by regulators, distribution system operators, central and local authorities, and energy and infrastructure project managers to design, monitor, and evaluate digital reforms in energy allocation, while considering principles of social equality and economic security

Keywords: economic efficiency; energy poverty; artificial intelligence; blockchain; energy ecosystem; concept of fair distribution

Introduction

The transformation of energy systems became one of the central dimensions of global economic modernisation in the 2010s and early 2020s. Between 2010 and 2024, reforms aimed at decarbonisation, decentralisation, and digitalisation of the energy sector were launched in many countries, and digital technologies played a critical role by enabling real-time monitoring of energy flows, automated network control, and new forms of interaction between producers and consumers. The energy transition raised questions of social justice regarding the distribution of energy

Suggested Citation:
Zamlynskyi, V., & Gorodnichenko, S. (2025). Digital transformation of energy allocation: From data transparency to socio-economic justice. *Innovation and Sustainability*, 5(4), 97-107. doi: 10.31649/vis/4.2025.97.

*Corresponding author

Copyright © The Author(s). This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/)

resources, the protection of vulnerable consumers, and spatial equity across regions.

Ukraine inherited a highly centralised energy infrastructure, significant asset depreciation, and institutional fragmentation in the governance of energy markets, which contributed to uneven access to reliable and affordable energy services across urban and rural areas, industrial centres, and peripheral territories, as well as across different income groups. After the full-scale Russian invasion in 2022, significant damage to generation, transmission, and distribution infrastructure occurred, supply interruptions became more frequent, and the need for emergency rationing increased. Under these conditions, digital transformation was considered not merely the introduction of modern information technologies into existing energy processes, but a systemic redesign of energy governance intended to reconcile efficiency, resilience, and social equity through advanced metering infrastructure, cloud-based data platforms, big data analytics, and artificial intelligence (AI) tools.

In the Ukrainian context, I.O. Pavlova (2025) formulated a paradigm of inclusive rural-urban development as a theoretical and applied model for post-war recovery and demonstrated that territorial disparities in infrastructure and access to basic services, including energy, constrained inclusive growth; the author concluded that reconstruction policies had to combine physical rebuilding with institutional and social reforms so that rural communities and secondary cities did not remain structurally disadvantaged. I. Rojek *et al.* (2025) investigated novel AI methods for energy-intensive industries and concluded that predictive maintenance, demand forecasting, and process optimisation significantly increased energy productivity and supported industrial transformation.

Additionally, researchers focused on blockchain and distributed ledger technologies (DLT) as elements of the digital energy and financial infrastructure. O.V. Sikorska *et al.* (2024) explored blockchain applications in the Ukrainian energy sector and argued that tamper-resistant registries and automated settlements could enhance transparency and reduce opportunistic behaviour in energy trading. O. Nakonechna & S. Gorodnichenko (2025) analysed DLT as a methodological foundation for control and accounting-analytical support in the digital economy. The researchers demonstrated that distributed ledgers enabled a shift towards triple-entry accounting and continuous auditing by ensuring immutability, cryptographic security, and real-time transaction verification, but also identified systemic challenges, such as shortages of DLT-competent staff, integration problems with legacy IT systems, and regulatory uncertainty. The authors' conclusions indicated that DLT-based registries could serve as a trusted digital infrastructure for recording and allocating economic resources, directly relevant to the design of digital energy-allocation mechanisms.

A substantial part of the research addressed renewable energy, circularity, and cooperative models, particularly in the agro-industrial complex (AIC). V. Brych *et al.* (2025) quantified the economic potential of renewable energy for business in Ukraine and Europe. The authors argued that the deployment of renewables was economically rational and strategically necessary for climate neutrality, energy security, and post-war recovery. The authors' work explicitly linked renewable investments to circular-economy principles, including resource efficiency and new value chains. N.I. Horbal & I.V. Plish (2021) examined circular business models for Ukrainian enterprises. The researchers showed that repeated use of materials, energy recovery from residues, and cooperative ownership structures increased resilience and reduced dependence on imported resources.

Most studies on energy justice and energy-system modelling added an explicit normative dimension to discussions of digitalisation and renewables. P. Lehmann *et al.* (2024) analysed spatial distributive justice in the siting of renewable-energy infrastructure. The authors showed that alternative justice principles led to different spatial distributions of generation capacity and burdens across regions. C. Lohr *et al.* (2024) integrated disamenity costs and equality considerations into energy-system optimisation models. The researchers demonstrated that fairness-aware formulations tended to reallocate generation and network investments away from already burdened territories.

However, earlier works rarely examined how feeder-level digital allocation mechanisms in a war-affected country could be explicitly designed and evaluated through a spectrum of justice perspectives, while simultaneously incorporating indicators of circularity and cooperation in the agri-food sector. In light of these gaps, this research aimed to elaborate a concept of digitally fair energy allocation for Ukraine and to construct a feeder-level evaluation framework that links digital allocation mechanisms with distributive-justice criteria and indicators of circular development in the agro-industrial complex.

Materials and Methods

The research adopted a theoretical-analytical and design-oriented approach that combined conceptual analysis, a structured literature review, comparative and systems analysis, and elements of quasi-experimental and scenario design. The overall aim of the methodological strategy was to construct a coherent framework for digitally fair energy allocation in Ukraine without relying on a single empirical dataset or econometric model. The conceptual analysis of energy allocation in Ukraine was carried out. For this purpose, national analytical reports (Ukraine energy market observatory…, 2025; National energy and climate…, 2025), regulatory documents, and sectoral statistics (State Statistics Service of Ukraine, 2023) were examined. These materials were used to identify typical patterns of regional disparities, infrastructure depreciation, institutional fragmentation, and social vulnerability that condition the operation of distribution systems in wartime and post-war contexts, and the patterns are presented in the results section on socio-economic problems.

A structured literature review was then conducted in order to systematise academic contributions. The search

was conducted for the period 2000-2025 using combinations of relevant keywords. The selection focused on international and Ukrainian publications that addressed digitalisation and inclusive development (Košovská *et al.*, 2022; Pavlova, 2025). The selection also included studies examining artificial intelligence and digital technologies in energy systems (Sukhodolia, 2022; Rojek *et al.*, 2025). Particular attention was given to publications analysing blockchain and distributed ledger technologies (Sikorska *et al.*, 2024; Nakonechna & Gorodnichenko, 2025). In addition, the selection covered research on circular and cooperative models in the agro-industrial complex (Dovgal, 2020; Dovgal & Potryvaieva, 2024; Brych *et al.*, 2025). Furthermore, the review incorporated studies addressing energy justice and fair allocation principles (Sovacool & Dworkin, 2015; Jenkins *et al.*, 2016; Lohr *et al.*, 2024). This provided the conceptual building blocks for the subsequent stages of the study. Based on these materials, comparative, and systems analysis were applied to map the relationships between data transparency, institutional trust, and social justice outcomes. This work resulted in the formulation of the "Data-Trust-Justice" analytical framework, in which digital energy data were treated as a foundational element for both managerial efficiency and equitable access to energy services.

The methodological design further included the development of a quasi-experimental evaluation scheme for digital allocation policies at the feeder level. Feeder-level units with advanced metering infrastructure and analytical tools were defined conceptually as "treated", while comparable feeders without such deployment were defined as "control". The design relied on staggered rollout, seasonal controls, and robustness checks against weather shocks and conflict-related disruptions. Although no empirical estimates were reported in this research, the scheme was formulated in a manner that allows implementation by distribution system operators and researchers.

Scenario design was used to incorporate distributive-justice regimes into the digital allocation model. Three perspectives were distinguished: a needs-based regime prioritising feeders and communities with the highest levels of energy poverty and infrastructure damage; a responsibility-based regime giving precedence to actors investing in low-carbon generation, demand-side flexibility, and energy efficiency; and a capacity-based regime favouring consumers and territories with greater fiscal and institutional capacity to co-finance infrastructure. For each regime, the conceptual model specified how changes in the spatial distribution of generating and network assets could be evaluated, with particular attention to feeders supplying the agro-industrial complex and to indicators of circularity and resilience in local food systems. The study's limitations should be acknowledged. The framework and scenarios remain conceptual and design-oriented and have not yet been tested empirically on real feeders. The magnitude of economic effects, such as reductions in losses, improvements in reliability, or changes in energy-poverty rates under different justice regimes, remains to be quantified.

Results

Socio-economic problems of energy resource allocation in Ukraine

The study systematised the main socio-economic problems of energy resource allocation in Ukraine under conditions of digital transformation, war, and post-war recovery (Table 1).

Table 1. Socio-economic problems of energy resource distribution in the context of digital transformation and the impact on the security and stability of the state's development

Socio-economic problem	Content of the problem / manifestation	Impact on the security and stability of the country's development
Uneven access to energy resources	Concentration of energy capacities in large cities, deficit in communities, energy poverty	Worsening regional disparities, increasing social tension, decreasing economic sustainability
Outdated energy infrastructure	High energy losses, worn-out networks, lack of modern control technologies	Increasing risks of man-made accidents, threat to energy security, increasing production costs
Lack of transparent energy accounting mechanisms	Insufficient digitalisation of data, duplication of regulatory functions, closed statistics	Corruption risks, loss of trust in energy policy, slowing down reforms
Low energy efficiency of industry and agro-industrial complex	Excessive energy consumption, lack of motivation to modernise	Overspending of resources, reduction in competitiveness, increasing dependence on energy imports
Energy poverty of the population	Inability of households and SMEs to invest in energy-saving technologies	Social stratification, growing dissatisfaction, risk of community destabilisation
Insufficient digital infrastructure for energy management	Lack of a single platform for data collection, analysis, and monitoring	Slow response to crises, ineffective state regulation
Human and technological deficit	Lack of specialists in the field of energy management, cybersecurity, data analysis	Decreased level of manageability of energy systems, vulnerability to external threats
Insufficient integration of socio-economic and technological reforms	Discontinuity between politics, business and science, weak intersectoral interaction	Loss of development synergy, risk of inefficient use of investments

Source: prepared by the authors

These problems were grouped into four interrelated clusters: spatial inequalities, infrastructural constraints, governance deficits, and social vulnerability. Spatial inequalities were manifested in the concentration of generation capacity and high-quality network infrastructure in large industrial agglomerations. At the same time, many rural and peripheral communities relied on weak feeders with high outage rates. Such disparities translated into differences in production costs, investment attractiveness, and quality of life across territories, contradicting the principles of inclusive rural-urban development. Enterprises located on vulnerable feeders faced higher implicit costs for backup solutions and lost output, whereas firms in more robust grids operated under more predictable conditions.

Infrastructural constraints arose from the ageing of generation, transmission, and distribution assets, high technical losses, and limited integration of renewable energy sources. Outdated equipment and damage from military actions contributed to frequent supply interruptions, voltage fluctuations, and an increased risk of large-scale failures. For industrial and agri-food producers, these constraints increased operating costs, disrupted cold chains, and reduced competitiveness in domestic and export markets.

Governance deficits were associated with fragmented institutional responsibilities, incomplete or non-transparent data, and insufficient digitalisation of operational processes. The absence of unified, high-quality statistics on outages, losses, and consumption hampered effective regulation, complicated public oversight, and weakened trust in tariff and investment decisions. Fragmented information systems prevented the construction of an integrated energy balance and limited the ability to provide targeted support to vulnerable regions and consumer groups. Social vulnerability was reflected in energy poverty, the inability of households and small businesses to secure adequate energy services without sacrificing other basic needs. Energy poverty was particularly acute in communities characterised by low incomes, degraded housing, and unreliable supply. In combination, spatial inequalities, infrastructural constraints, governance deficits, and social vulnerability produced a pattern of a socially unjust energy system, in which the burdens of unreliability, high tariffs, and wartime disruptions fell disproportionately on low-income households, rural communities, and small agri-food producers.

These diagnostic conclusions are consistent with official statistical and policy documents. The statistical compendium "Ukraine in Figures 2022" documented persistent regional differences in income levels, infrastructure quality, and electricity consumption, confirming that rural and war-affected regions face higher risks of energy poverty and service interruptions (State Statistics Service of Ukraine, 2023). The report National energy and climate plan of Ukraine 2025-2030 (2025) identified ageing networks, high distribution losses, and uneven integration of renewables as key constraints for the energy transition and emphasised the need to modernise distribution infrastructure and improve data transparency. The report Ukraine energy market observatory: Quarterly report Q2 2025 (2025) further recorded increased losses, deteriorating reliability indicators, and severe damage to distribution assets in frontline and de-occupied regions. These findings provided the empirical background against which the problem clusters summarised in Table 1 were formulated.

In the contemporary Ukrainian context, these problems acquire a precise justice dimension. Energy systems and transition policies can be considered socially unjust where war-affected regions, low-income households, rural communities, and critical agri-food producers bear a disproportionate share of outages, losses, and tariff burdens, while benefiting least from modernisation. International research on energy justice (Sovacool & Dworkin, 2015; Jenkins *et al*., 2016) highlighted that the choice between distributional, recognition-based, and procedural perspectives substantially alters the diagnosis of who is "vulnerable" and what constitutes a fair allocation of energy services. When these perspectives are absent from planning and modelling, the analytical horizon narrows to purely techno-economic indicators, risking recommendations that are misaligned with the lived experiences and values of different Ukrainian communities and stakeholders.

Digital technologies and artificial intelligence as drivers of transformation

The analysis of the latest practice and literature showed that digital technologies, including artificial intelligence, have the potential to reshape energy-allocation mechanisms at system and feeder levels. Advanced metering infrastructure, automated monitoring, and AI-based analytics increased the accuracy of demand forecasts, enabled predictive maintenance, and supported real-time optimisation of flows and network configurations. In distribution networks, this translated into reduced technical and non-technical losses, improved reliability indicators, and greater flexibility for integrating distributed renewable generation.

In the agri-food sector, digital tools and AI-supported simulations enabled more precise management of energy-intensive operations, such as irrigation, storage, and processing. Optimised load profiles and better coordination between energy and production cycles created opportunities to lower costs per unit of output, reduce spoilage, and strengthen resilience to climate variability and wartime supply disruptions. At the regional level, feeders with higher levels of digitalisation and analytical capacity could become platforms for concentrating investment in processing, logistics, and storage. In contrast, feeders without such development risked further marginalisation.

At the same time, the study confirmed that artificial intelligence is not neutral with respect to social outcomes. The design of algorithms, the availability of representative data, and the choice of optimisation criteria critically influence how burdens and benefits are allocated. If vulnerable groups are under-represented in datasets or if only

cost-minimisation objectives are used, automated decision systems for tariffs, outage management, or eligibility for support may unintentionally disadvantage those groups. This observation motivated the incorporation of explicit justice regimes and transparency requirements into the proposed digital allocation framework.

The "Data-Trust-Justice" framework

The third contribution of the article was the development of the "Data-Trust-Justice" conceptual framework (Fig. 1). The framework is built on the assumption that digital energy data, when collected and used appropriately, can become a key asset for both efficient management and social justice.

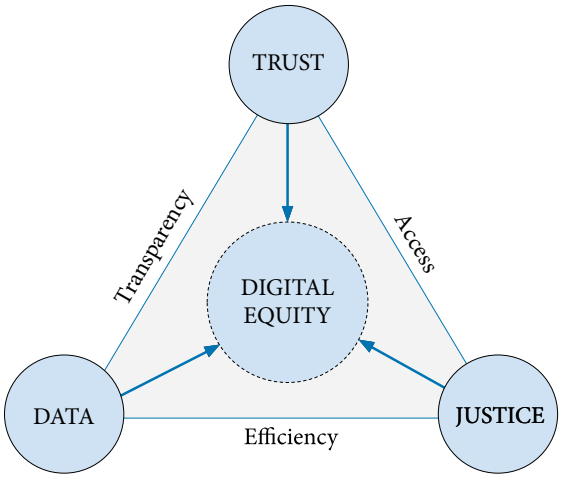

Figure 1. "Data-Trust-Justice" conceptual framework with edge labels Efficiency, Transparency, and Access, plus a centre "Digital Equity" (balance point)

Source: prepared by the authors

The vertex "Data" represents the availability, quality, and accessibility of information on generation, flows, losses, outages, tariffs, and the coverage of vulnerable groups. The vertex "Trust" captures the confidence of consumers, regulators, and market participants in the integrity of energy institutions, the fairness of allocation rules, and the reliability of technological solutions. The concept of "Justice" embodies the normative goal of ensuring that all citizens, particularly vulnerable households, have access to basic energy services and that the costs and benefits of energy transformation are distributed fairly.

The edges connecting the vertices are labelled "Efficiency", "Transparency", and "Access". Efficiency refers to the ability of digital systems to enhance the technical and economic performance of energy networks, including through loss reduction and improved investment planning. Transparency refers to open access to non-sensitive energy data and clear communication of allocation rules, which support public accountability and evidence-based policy debates. Access highlights the guarantee of minimum energy services and the targeted support necessary to protect households facing energy poverty. At the intersection of these relationships lies the notion of "Digital equity": a state in which digital transformation does not deepen existing inequalities but instead mitigates these inequalities by empowering consumers, enabling more precise targeting of support, and reducing information asymmetries. The framework emphasises that digitalisation is not inherently equitable; instead, equity results from deliberate design choices and governance arrangements.

The proposed "Data-Trust-Justice" triangle can be further specified by explicitly integrating circular-economy and food-system-resilience considerations. At the "Data" vertex, this includes disaggregated information on rural feeders, agricultural processors, storage facilities, and irrigation loads, as well as on distributed renewables and waste-to-energy projects in the AIC. At the "Trust" vertex, meaningful participation of farmers' organisations, cooperatives, and local communities in the design of allocation rules strengthens recognition and procedural justice. Finally, at the "Justice" vertex, distributive criteria can be extended beyond standard welfare or cost metrics to include indicators of food security, employment in rural areas, and circular resource use, aligning with broader water-energy-food (WEF) nexus and sustainable food-ecosystem approaches.

Quasi-experimental design for evaluating digital allocation policies.

The fourth result concerned the design of a quasi-experimental evaluation methodology for digital allocation policies. Studies predominantly described technological architectures, pilots, and platform-level case evidence rather than rigorous causal evaluation of distributional and social outcomes. For example, F.M. Enescu *et al.* (2025) and V. Valsan *et al.* (2025) discussed AI- and blockchain-enabled micro market and IoT-based solutions for local balancing and consumer participation. However, these contributions provided limited guidance on quasi-experimental designs that would quantify the impact of feeder-level

digital interventions on both technical indicators and equity-related outcomes.

The proposed evaluation design used a feeder (a distribution line serving a defined group of consumers) as the unit of analysis (Fig. 2). Feeders that introduced advanced metering infrastructure and analytical tools formed the treatment group. Feeders with similar pre-treatment characteristics that did not receive the intervention constituted the control group. Matching criteria included baseline loss levels, load profiles, customer composition, and climatic conditions. Key outcome indicators include: changes in feeder-level losses, measured as percentage points of energy input; changes in reliability indices, such as System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI); changes in the share of households in the service area that meet a defined criterion of energy poverty; coverage of vulnerable households by targeted tariffs or benefits linked to the digital system.

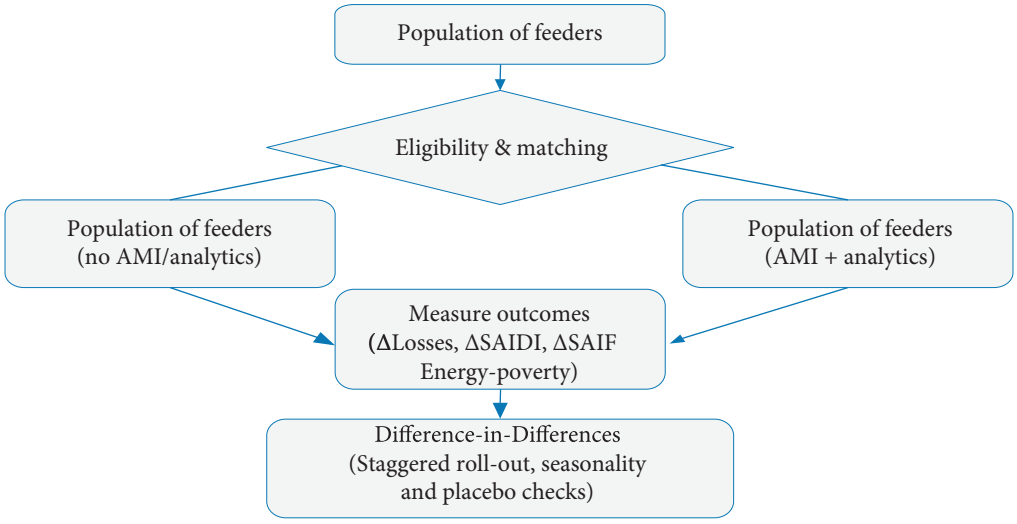

Figure 2. The design of the quasi-experimental evaluation

Source: prepared by the authors

The design relies on a staggered rollout of digital solutions across feeders, enabling difference-in-differences estimation with seasonality controls. Weather data and information on conflict-related damage are incorporated as covariates to control for confounding. Placebo periods, in which no treatment occurred, are used to test parallel trends assumptions. At the same time, the methodology acknowledges potential data-quality issues, including incomplete activation of metering points and inconsistencies in outage logging, and recommends sensitivity analyses. This design approach reflects international best practices in policy evaluation but is adapted to Ukraine's specific institutional and infrastructural context. It offers a pragmatic way for regulators and distribution system operators to assess whether digital interventions deliver promised improvements in efficiency, reliability, and social outcomes. At the same time, it draws on established evaluation techniques used in infrastructure and energy reform studies, particularly staggered rollouts and difference-in-differences methods (Lehmann *et al.*, 2024; Lohr *et al.*, 2024).

Within this quasi-experimental design, the evaluation also compares alternative justice regimes and circularity settings. For each treated feeder, outcome indicators (losses, SAIDI/SAIFI, tariff burdens, connection of renewables, stability of supply for critical agri-food loads) are estimated under three allocation logics: needs-based, responsibility-based, and capacity-based. Moreover, the spatial distribution of generating and network assets is mapped across urban, peri-urban, and rural territories, with particular attention to feeders that serve agro-industrial clusters, storage and processing facilities, and irrigation systems. This allows assessing how equality-oriented versus disamenity-sensitive or cost-minimising scenarios shift burdens and benefits between regions and social groups, as suggested by the latest work on integrating equality considerations and local disamenity costs into energy system optimisation (Lehmann *et al.*, 2024; Lohr *et al.*, 2024). In turn, this provides an empirical basis for designing digital allocation policies that support a climate-neutral energy transition in the AIC while remaining socially acceptable.

Policy implications and implementation priorities

The results of the analysis yield a set of policy implications and implementation priorities for Ukraine's digital energy transformation. Firstly, digital reforms should explicitly incorporate social objectives, such as reducing energy poverty and ensuring territorial equity, rather than focusing exclusively on efficiency. This requires setting measurable targets, for example: reducing technical and non-technical losses on treated feeders by at least two percentage points; achieving coverage of at least 80% of customers with advanced metering infrastructure on urban feeders and 50% on rural feeders; reducing interruption duration by at least ten per cent relative to matched controls; and ensuring that

no less than 90% of registered vulnerable households are covered by targeted tariff or benefit delivery.

Building trust requires a robust open-data strategy. Non-sensitive data on outages, losses, tariffs, and planned coverage should be made available in user-friendly formats, enabling civil society, local governments, and researchers to monitor progress and identify bottlenecks. This approach is consistent with broader trends in digital governance and enhances accountability. Regulatory frameworks must address questions of data governance, privacy, and algorithmic fairness. Clear rules are needed to define which actors can access which types of data, under what conditions, and how decisions supported by artificial intelligence may be contested or revised. Dedicated institutions or units within existing regulators may be required to oversee these processes. Digital transformation must be accompanied by investments in human capital, including training for engineers, data scientists, regulators, and local officials. Without such investments, the potential of advanced technologies cannot be fully realised, and the risk of misinterpretation or misuse of data increases. International partners can play a crucial role by supporting pilot projects, co-financing digital infrastructure, and facilitating knowledge exchange with other countries that have implemented similar reforms. Such cooperation can accelerate learning and help avoid common pitfalls.

Justice perspectives and net-zero electricity futures for Ukraine's agri-food sector

Research on energy-system optimisation demonstrated that the choice of distributive-justice principle has a first-order effect on the resulting design of net-zero power systems (Lehmann *et al.*, 2024; Lohr *et al.*, 2024). When models seek only to minimise total system costs, the models tend to favour spatial concentration of generation in locations with the cheapest resources and lowest connection costs, even if this entails higher local disamenities or neglects peripheral regions. By contrast, models that incorporated equality constraints, social-welfare functions, or fairness-aware allocation rules often redistributed generation and grid investments more evenly across territories, prioritising regions with higher historical underinvestment or higher vulnerability to energy poverty (Lehmann *et al.*, 2024; Lohr *et al.*, 2024). In other words, different justice logics, utilitarian, egalitarian, capability-based, responsibility-based, or opportunity-oriented, can generate markedly different maps of future energy systems, even when the overall technical and climate targets (such as net-zero emissions by 2050) are held constant.

For Ukraine, this has direct implications for the design of alternative, zero-emission electricity systems extending to 2050. A purely cost-optimal scenario could, for example, concentrate most new renewable capacity, storage, and digital control in a few industrial and metropolitan hubs, while leaving AIC-dominated regions dependent on ageing infrastructure and exposed to more frequent curtailments or outages. An egalitarian or capability-oriented scenario, by contrast, would explicitly treat reliable and affordable electricity for irrigation, storage, and primary processing as a critical capability for food security and rural livelihoods. This would justify greater investment in distributed renewables, storage, and digital control on feeders serving cooperatives, small- and medium-sized agri-food enterprises, and rural communities, even if such investments modestly increase aggregate system costs.

These justice-sensitive constructions directly influence the spatial distribution of generating infrastructure, the pattern of grid reinforcements, and the incidence of local externalities. When coupled with indicators of circularity, such as the utilisation of agricultural residues and biogas, waste-heat recovery in processing plants, or cooperative ownership structures in renewable projects, such approaches align energy system design with the broader objective of building a resilient, low-waste food-energy ecosystem as a pillar of Ukraine's post-war reconstruction model. In this sense, the "Data-Trust-Justice" framework, combined with justice-aware digital modelling, can help prevent the emergence of unjust or socially regressive designs for future energy systems, notably when models might otherwise implicitly encode normative assumptions without transparent justification. Making these justice perspectives explicit broadens the analytical horizon and increases the likelihood that model-based assessments will resonate with the values and lived experiences of diverse communities and stakeholders.

Economic, managerial, and regulatory implications of the proposed approach

The integrated analysis of socio-economic problems, digital tools, conceptual framework, and evaluation design led to several important implications for regional development, business decisions, and public policy. From an economic standpoint, a fair digital allocation at the feeder level can reduce technical and non-technical losses, shorten outages, and stabilise voltage quality, thereby lowering operating costs and investment risks for enterprises. For agri-food businesses, improved reliability and more predictable tariffs reduce spoilage of perishable products, facilitate long-term contracts, and support the development of higher-value-added processing and storage facilities in regions that previously suffered from chronic underinvestment. For territorial development, targeting digital and physical upgrades towards structurally weak feeders creates conditions for more balanced growth between urban centres and rural areas.

In managerial terms, the framework supports concrete decision-making processes. Distribution system operators can use feeder-level indicators within the "Data-Trust-Justice" framework to prioritise network reinforcement, transformer replacement, and the integration of distributed renewables, while balancing efficiency and justice criteria. Local governments and regional development agencies can identify where digital investments will yield the most significant combined impact on the business climate,

employment, and energy-poverty reduction. Agri-food cooperatives and energy communities can rely on the same information to design cooperative investment schemes and negotiate connection conditions for local generation and storage projects.

The regulatory and institutional implications concern the need to define standards for digital data, establish open-data practices, and embed fairness criteria into tariff and allocation rules. Regulators are required to mandate the publication of anonymised feeder-level data, specify procedures for the use of AI-based tools, and provide mechanisms for contesting unjust allocation decisions. Coordination among energy regulators, ministries responsible for regional and agrarian policy, and local authorities is essential to ensure that digital energy allocation reforms align with broader post-war recovery priorities. Overall, the results show that digitally fair energy allocation should be understood as both an energy-sector reform and a lever for wider socio-economic reconstruction. When combined with circular and cooperative trajectories in the agro-industrial complex, the proposed approach contributes to the formation of a resilient, low-waste, and socially balanced food-energy ecosystem for post-war Ukraine.

Discussion

The results of this study are closely related to the latest work on inclusive development and digital transformation. I.O. Pavlova (2025) developed a paradigm of inclusive rural-urban development for post-war Ukraine and demonstrated that disparities in infrastructure and access to basic services that are prerequisites for reliable energy service provision constrained inclusive growth. The present research confirmed this diagnosis but moved from the strategic level to the operational level of energy allocation. In contrast to I.O. Pavlova (2025), who focused on general reconstruction policy, the digitally fair allocation framework specifies feeder-level indicators and justice-aware scenarios to target investments and tariff measures in precisely the territories I.O. Pavlova (2025) identified as structurally disadvantaged.

The findings also engage with studies of the digital economy and electronic information systems. I. Košovská *et al.* (2022) analysed the electronification of accounting processes in the Slovak Republic and showed that digitalisation strengthened transparency, standardisation, and transaction traceability, thereby improving the quality of managerial decisions. The "Data-Trust-Justice" framework extends this logic to the energy sector. While I. Košovská *et al.* (2022) focused on financial accounting, the current study argues that similar data-centric architectures support not only efficiency but also social legitimacy when applied to energy allocation, as these architectures provide auditable evidence of how outages, losses, and tariff burdens are distributed across different consumer groups.

Technological research on artificial intelligence in the energy sector has so far stressed mostly efficiency gains. I. Rojek *et al.* (2025) reported that AI-based predictive maintenance and optimisation tools improved energy productivity and supported industrial transformation. O.M. Sukhodolia (2022) examined the opportunities and risks of AI deployment in Ukraine's energy sector and highlighted the importance of robust data governance and consumer rights protection. The integration of justice regimes into allocation scenarios directly addresses O.M. Sukhodolia's (2022) concern about social risks. It illustrates how AI and advanced metering can be embedded in rules that consider needs, responsibility, or capacity rather than pure cost minimisation.

Another important strand of literature concerns blockchain and distributed ledger technologies. O.V. Sikorska *et al.* (2024) analysed blockchain-based applications for the Ukrainian energy sector and argued that tamper-resistant registries and smart contracts could enhance transparency in energy trading and settlements. O. Nakonechna & S. Gorodnichenko (2025) investigated distributed ledgers as a basis for control and accounting-analytical support in the digital economy. The authors demonstrated the feasibility of triple-entry accounting and continuous auditing, while also highlighting staffing shortages and institutional challenges. The present study builds on these insights by interpreting DLT-based registries as a component of the infrastructure for digitally fair energy allocation. Beyond recording transactions, such registries can track service levels and cost exposure across different categories of consumers, thereby enabling distributional analysis and monitoring of justice indicators within the energy system.

V. Valsan *et al.* (2025) proposed an AI-integrated blockchain micro market logic for local balancing and coordination and argued that automated verification and data-driven settlement can reduce transaction frictions and expand consumer participation in decentralised flexibility arrangements. This aligns with the present study's interpretation of digital allocation as an institutional mechanism, not merely a technical tool, because micro market architectures make allocation rules explicit, auditable, and comparable across feeders. The proposed approach also interacts with research on renewable energy, circular economy, and cooperative models, particularly in the agro-industrial complex. V. Brych *et al.* (2025) quantified the economic potential of renewable energy for business in Ukraine and Europe. The researchers argued that investments in renewables were both economically rational and strategically necessary for climate neutrality and post-war recovery.

N.I. Horbal & I.V. Plish (2021) and O. Dovgal & N. Potryvaieva (2024) showed that circular business models, repeated use of materials, bioenergy from agricultural residues, and cooperative ownership structures increased resilience and reduced dependence on imported resources in the AIC. Related evidence from the Ukrainian agrarian context indicated that alternative and renewable energy solutions can strengthen resource conservation and competitiveness in the agricultural sector, especially when linked to local biomass streams and decentralised generation options (Parkhomets *et al.*, 2020). The concept of a

sustainable food-energy ecosystem adopted in this article is consistent with these results. Still, it emphasises that realisation of the economic potential described by these authors depends on feeder-level allocation rules. These considerations are aligned with analyses of how enterprises adapted the financial strategies to wartime and post-war challenges, which highlighted the need to combine short-term liquidity and risk management with investment in resilience-enhancing assets and infrastructure (Zhigar & Petryniak, 2025). Without justice-aware digital tools, renewable and circular projects may continue to bypass rural communities and smaller agri-food enterprises. In contrast, the allocation framework proposed here directs digital and physical investments precisely to those feeders where such investments can generate combined effects on energy security, food security, and rural employment.

Insights from the water-energy-food nexus literature add another perspective. J.G. Segovia-Hernández *et al.* (2023) reviewed optimisation approaches to the WEF nexus and highlighted the need to evaluate synergies and trade-offs jointly rather than within isolated sectoral models. The present study converged with this view by embedding indicators of circularity and food-system resilience, such as the share of renewable and bioenergy in processing facilities or the stability of cold chains, into the evaluation of energy-allocation scenarios. At the same time, WEF-nexus models have typically focused on physical and environmental constraints, whereas the framework developed here centres on distributive justice and wartime vulnerability. In this sense, the study offers a complementary angle rather than a competing one.

The normative dimension of energy systems is treated explicitly in the energy-justice literature. B.K. Sovacool & M.H. Dworkin (2015) conceptualised energy justice through distributional, procedural, and recognition components. The authors argued that energy systems are socially unjust depending on who bears the costs and who receives the benefits of energy production and transition. K. Jenkins *et al.* (2016) synthesised this field and defined energy justice as a framework for identifying, analysing, and remedying energy-related inequalities. The latest modelling work, such as that of P. Lehmann *et al.* (2024) and C. Lohr *et al.* (2024), demonstrated that different justice principles, such as cost minimisation, equality of outcomes, equality of opportunities, or consideration of local disamenity costs, led to markedly different spatial configurations of net-zero energy systems. The present research is fully aligned with these conclusions and operationalises these findings by implementing justice regimes as alternative objective functions or constraints in feeder-level digital allocation models. The needs-based, responsibility-based, and capacity-based regimes proposed in this article can be seen as specific instantiations of the broader justice logics discussed in these works.

Taken together, these comparisons indicated that the concept of digitally fair energy allocation does not contradict existing evidence but reorganises it around the specific problem of justice in wartime and post-war conditions. Research on digitalisation, AI, and blockchain has tended to accentuate efficiency and security; this article adds a structured distributive-justice perspective and shows how efficiency-focused technologies can be embedded in rules that protect vulnerable households and agri-food producers. Studies on renewables and circular AIC models have documented substantial economic opportunities; the present work explains how allocation rules and digital data can either unlock or block these opportunities in practice. Energy-justice scholarship and fairness-aware modelling have demonstrated that justice principles shape system design; the framework developed here translates that insight into concrete feeder-level scenarios, linked to a quasi-experimental evaluation design and to agri-food-system indicators.

Conclusions

The study demonstrated that the digital transformation of energy allocation in Ukraine cannot be reduced to the technical introduction of new information technologies. Under wartime and post-war conditions, digital tools were shown to reshape the structure of socio-economic problems by influencing how shortages, losses, and reliability risks are distributed between regions, consumer groups, and sectors. The systematisation of spatial inequalities, infrastructural constraints, governance deficits, and social vulnerability revealed that existing allocation practices tend to reproduce energy poverty and territorial disparities, especially for rural communities and agri-food producers.

On this basis, the concept of digitally fair energy allocation was formulated. The "Data-Trust-Justice" framework clarified how energy data, institutional trust, and distributive outcomes are interconnected through efficiency, transparency, and access. Justice-aware regimes of allocation were specified, including needs-based, responsibility-based, and capacity-based approaches, and the conceptual embedding of these regimes into feeder-level scenarios was demonstrated. The corresponding quasi-experimental design provided a structured framework for evaluating digital allocation policies, using changes in losses, reliability, and energy-poverty indicators as outcome measures.

From an economic and managerial perspective, the proposed approach indicated that targeted digital investments at the feeder level can reduce losses, stabilise supply, and create more predictable conditions for business activity, particularly in the agro-industrial complex. At the same time, the framework highlighted that digitalisation must be accompanied by explicit fairness criteria, clear data-governance standards, and coordinated regulatory decisions if it is to support inclusive regional development and a sustainable food-energy ecosystem in the post-war recovery.

Future research should focus on empirical testing of the proposed evaluation scheme on real distribution feeders, including the estimation of actual economic gains and social effects under different justice regimes. Further

work is also needed to refine indicators of circularity and resilience for agri-food-dominated feeders, and to explore how cooperative and community-based energy projects respond to digitally fair allocation rules. In addition, comparative studies across regions and countries would help to determine the transferability of the framework and to identify institutional conditions under which digitally fair energy allocation can be most effective.

Acknowledgements
None.

Funding
None.

Conflict of Interest
None.

References
[1] Brych, V., Shuvar, A., Moroz, V., & Pankevych, V. (2025). Economic potential of renewable energy for business: Strategies of decarbonisation and climate adaptation in Ukraine and Europe. *Economic Analysis*, 35(3), 180-194. doi: 10.35774/econa2025.03.180.

[2] Dovgal, O. (2022). Organizational and economic principles of creation and implementation of a circular business model of development. *Ukrainian Black Sea Region Agrarian Science*, 26(4), 40-50. doi: 10.56407/2313-092X/2022-26(4)-4.

[3] Dovgal, O., & Potryvaieva, N. (2024). Practical study of the implementation of circular economy at agricultural enterprises of Ukraine. *Ukrainian Black Sea Region Agrarian Science*, 28(1), 9-18. doi: 10.56407/bs.agrarian/1.2024.09.

[4] Enescu, F.M., Drăguşin, S.-A., Boştinaru, R.-N., Marica, M.-C., Nicolăescu, C.-G., Frîncu, N.-C., & Bizon, N. (2025). Energy market: A review of current solutions, trends, issues, and future directions based on the blockchain, internet of things and artificial intelligence. *Results in Engineering*, 28, article number 107736. doi: 10.1016/j.rineng.2025.107736.

[5] Horbal, N.I., & Plish, I.V. (2021). Circular business models for sustainable development of Ukrainian enterprises. *Journal of Lviv Polytechnic National University. Series of Economics and Management Issues*, 5(1), 15-29. doi: 10.23939/semi2021.01.015.

[6] Jenkins, K., McCauley, D., Heffron, R., Stephan, H., & Rehner, R. (2016). Energy justice: A conceptual review. *Energy Research & Social Science*, 11, 174-182. doi: 10.1016/j.erss.2015.10.004.

[7] Košovská, I., Hallová, M., Váryová, I., Šilerová, E., Hennyeyová, K., & Cihelka, P. (2022). The digital economy in the context of digital transformation and their impact on the electronification of accounting processes in the Slovak Republic. *AGRIS on-line Papers in Economics and Informatics*, 14(4), 53-65. doi: 10.7160/aol.2022.140405.

[8] Lehmann, P., Gawel, E., Meier, J.-N., Reda, M.J., Reutter, F., & Sommer, S. (2024). Spatial distributive justice has many faces: The case of siting renewable energy infrastructures. *Energy Research & Social Science*, 118, article number 103769. doi: 10.1016/j.erss.2024.103769.

[9] Lohr, C., Peterssen, F., Schlemminger, M., Bensmann, A., Niepelt, R., Brendel, R., & Hanke-Rauschenbach, R. (2024). Integration of disamenity costs and equality considerations regarding onshore wind power expansion and distribution into energy system optimization models. *Energy, Sustainability and Society*, 14, article number 58. doi: 10.1186/s13705-024-00489-6.

[10] Nakonechna, O., & Gorodnichenko, S. (2025). Distributed ledger technologies for control and accounting-analytical support in the digital economy. *Ukrainian Journal of Applied Economics and Technology*, 4, 215-221. doi: 10.36887/2415-8453-2025-4-42.

[11] National energy and climate plan of Ukraine 2025-2030. (2025). Retrieved from https://www.energy-community.org/dam/jcr:9d144283-08ed-410b-a670-7fd15c7782f2/1_NECP_EnMachineTranslation.pdf.

[12] Parkhomets, M., Putsenteilo, P., & Uniiat, L. (2020). Intensification of the use of renewable energy sources – the objective need to improve resource conservation and increase the competitiveness of production of products of the agrarian sector of Ukraine. *Innovative Economy*, 5-6, 122-132. doi: 10.37332/2309-1533.2020.5-6.16

[13] Pavlova, I.O. (2025). The essence of inclusive development of rural-urban agglomerations. In *Theoretical and methodological foundations and practical aspects of inclusive development of rural-urban agglomerations in Ukraine* (pp. 39-65). Odesa: Astroprint.

[14] Rojek, I., Mikołajewski, D., & Prokopowicz, P. (2025). The impact of novel artificial intelligence methods on energy productivity, industrial transformation and digitalization within the framework of energy economics, efficiency and sustainability. *Energies*, 18(19), article number 5138. doi: 10.3390/en18195138.

[15] Segovia-Hernández, J.G., Contreras-Zarazúa, G., & Ramírez-Márquez, C. (2023). Sustainable design of the water-energy-food nexus: A literature review. *RSC Sustainability*, 1, 1332-1353. doi: 10.1039/d3su00110e.

[16] Sikorska, O.V., Samsoniuk, D.Yu., & Bohatova, A.S. (2024). The use of blockchain technologies in the energy sector. In *Materials of the LIII scientific and technical conference of VNTU departments*. Vinnytsia: Vinnytsia National Technical University.

[17] Sovacool, B.K., & Dworkin, M.H. (2015). Energy justice: Conceptual insights and practical applications. *Applied Energy*, 142, 435-444. doi: 10.1016/j.apenergy.2015.01.002.

[18] State Statistics Service of Ukraine. (2023). *Ukraine in figures, 2022*. Kyiv: State Statistics Service of Ukraine.
[19] Sukhodolia, O.M. (2022). *Artificial intelligence in the energy sector*. Kyiv: National Institute for Strategic Studies. doi: 10.53679/NISS-analytrep.2022.09.
[20] Ukraine energy market observatory: Quarterly report Q2 2025. (2025). Retrieved from https://euneighbourseast.eu/wp-content/uploads/2025/08/q2_2025_observatory-report.pdf .
[21] Valsan, V., Vuppala, N.S.K., Koganti, S.S.H., Kalla, L.S.E., Pappala, K.A., Kanakasabapathy, P., & Ramesh, M.V. (2025). Conceptual study – artificial intelligence-integrated blockchain micromarkets for sustainable energy. *Renewable and Sustainable Energy Reviews*, 214, article number 115482. doi: 10.1016/j.rser.2025.115482.
[22] Zhigar, N., & Petryniak, A. (2025). Adaptation of financial strategies of enterprises to the challenges of wartime and post-war recovery. *Economic journal of Lesya Ukrainka Volyn National University*, 2(42), 82-89. doi: 10.29038/2786-4618-2025-02-82-89.

Цифрова трансформація розподілу енергоресурсів: від прозорості даних до соціально-економічної справедливості

Віктор Замлинський
Доктор економічних наук, професор
Одеський національний технологічний університет
65039, вул. Канатна, 112, м. Одеса, Україна
https://orcid.org/0000-0001-7642-2443

Станіслав Городніченко
Аспірант
Одеський національний технологічний університет
65039, вул. Канатна, 112, м. Одеса, Україна
https://orcid.org/0009-0002-6159-284X

Анотація. Актуальність зумовлена тим, що в умовах війни та повоєнного відновлення України цифрова трансформація управління енергетикою стає ключовим інструментом подолання енергетичної бідності, регіональних диспропорцій та кризи довіри до енергетичної політики. Від організації цифрового розподілу енергії залежить соціальна легітимність енергетичного переходу та моделі відновлення. Метою статті було обґрунтувати концепцію справедливого розподілу енергії та розробити методологічні засади оцінювання впливу цифрових інструментів на соціальну справедливість і економічну ефективність систем розподілу. У дослідженні було систематизовано сучасні підходи до енергетичної справедливості, проаналізовано цифрові технології в енергетиці та застосовано методи порівняльного й системного аналізу. На цій основі було розроблено концептуальну рамку «дані-довіра-справедливість» і сформовано дизайн квазіекспериментального оцінювання політики цифрового розподілу енергії на рівні фідерів. Було встановлено, що традиційна централізована модель розподілу енергії, побудована на фрагментованих даних і низькій прозорості, відтворює регіональні диспропорції, енергетичну бідність і недовіру до рішень регулятора. У межах дослідження було розроблено концепт «цифрового справедливого розподілу енергії», який поєднує економічну ефективність, прозорість та гарантований доступ вразливих груп споживачів до базових енергетичних послуг. Було проаналізовано роль інтелектуальних систем обліку, аналітики великих даних, методів штучного інтелекту та блокчейн-реєстрів у формуванні цілісного ланцюга «дані-довіра-справедливість». Було запропоновано структуру сценаріїв цифрового розподілу, що ґрунтуються на різних принципах дистрибутивної справедливості, та сформульовано вимірювані цільові орієнтири на перші 24 місяці впровадження для операторів систем розподілу. Показано, що інтеграція критеріїв соціальної справедливості у цифрові моделі розподілу дає змогу уникати соціально регресивних рішень та посилює легітимність енергетичної політики. Отримані результати можуть бути використані регуляторами, операторами систем розподілу, органами державної влади та місцевого самоврядування, а також менеджерами енергетичних й інфраструктурних проєктів для проєктування, моніторингу та оцінювання цифрових реформ у сфері розподілу енергії з урахуванням принципів соціальної рівності та економічної безпеки

Ключові слова: економічна ефективність; енергетична бідність; штучний інтелект; блокчейн; енергетична екосистема; концепція справедливого розподілу