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Assessment of Priorities Model Representation of the Problem of Determining Investment Priorities of the Ukrainian Alternative Energy Industry: Theoretical and Applied Aspect

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ABSTRACT:
Ukraine's energy system is in a situation of crisis and development. The system needs stable operation in the face of war and crisis. This requires attracting investments, including foreign ones. To determine the priority areas for investment, it is necessary to model and analyze the benefits and effects of renewable energy types in Ukraine. The aim of the study was to assess the priorities of a model-based representation for determining investment priorities in Ukraine's alternative energy sector. The study employed methods such as analysis, synthesis, morphological analysis, elements of economic and mathematical modeling, and the "Fuzzy TOPSIS" method. The main results include the calculation of indicators for the normalized evaluation of alternatives (renewable energy stations) to select and rank these stations according to a strategy for prioritizing energy sectors for development in Ukraine. The economic effect of implementing the proposed model for establishing investment priorities in Ukraine's alternative energy sector lies in the fact that the use of scenario-based evaluation factors primarily encourages an increase in investment inflows, particularly from foreign investors. The transition of Ukraine's energy system to a carbon-neutral policy will accelerate the country's path toward sustainable and harmonious development, strengthening Ukraine's position among countries advancing alternative energy, even under temporary martial law conditions.

Keywords: energy, renewable energy, investment climate, threats, war, economic sustainability, energy system, energy strategy, investment, modeling

1. Introduction

The global energy sector (including the Ukrainian one) is based on non-renewable sources. And they have limited reserves and are exhaustible. As a result, these sources cannot clearly guarantee the harmonious, stable development of the global (including Ukrainian) energy sector in the long term. In addition, the use of these sources is a major factor leading to environmental degradation (pollution) and a crisis.
Therefore, a characteristic feature of the current energy sector is the transition from a fossil fuel-based system to systems operating on renewable energy sources.

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The speed of change, the effectiveness of government decision-making on the development, implementation (realization) of policies to ensure energy sustainability and independence depends on the level of economic growth of countries.

The World Energy Council supports these innovative changes in the energy sector. In the future, it is expected that the energy systems of each country (including Ukraine) will undergo significant changes. Moreover, distributed generation facilities will gradually replace fossil fuel power plants (Renewable capacity statistics, 2023).

However, it is well known that power plants running on renewable energy sources usually have an unstable electricity generation schedule. They are also distributed in different parts of the power grid. This somewhat complicates the control system (management, harmonization) of electricity flows in such systems (Matviychuk, et al. 2015, Rubanenko, 2016, Rubanenko, et al. 2019, Blinov, et al. 2019, Gunko, 2020).

In addition, as noted in (Sree Lakshmi, etc. 2020, Gunko, 2020), the demand for electric vehicles has also recently increased dramatically. Accordingly, the number and capacity of charging stations for these cars will increase in Ukraine. And this applies to the entire territory of the country. It is clear that this process is slow. In particular, the reason is the occupation of part of Ukraine's territories by the Russian occupiers. There are also active processes of urbanization of Ukrainian cities, development of new technologies, scientific and technical progress in production. All this leads to an increase in the complexity of power supply systems.

The Ukrainian energy sector is facing new challenges: ensuring the stability of the grid, maintaining and acceptable power quality indicators, taking into account bidirectional power flows in distribution networks with unstable generation schedules of available dispersed energy sources and unstable load schedules. Accordingly, there will be a need to study the processes occurring in power grids under new operating conditions by performing computer modeling (Gunko, 2020).

Relevance. The energy system of Ukraine is in a situation of crisis and development. The system requires stable operation in times of war and crisis and is centralized. From time to time, energy facilities are destroyed. Energy wars lead to instability in winter. Therefore, the main direction is to create a decentralized energy system that is difficult to destroy.

This issue is particularly relevant in the Ukrainian context. Decentralized energy is expected to become the backbone of the country's future energy independence. However, Ukrainian regions face vastly different conditions for decentralization. Below is a list of key mechanisms that can help ensure fair access and the resilience of decentralized energy in Ukrainian regions with varying levels of infrastructure, risk, and resources.

1. Ensuring systematic, differentiated state support.

Support should be prioritized for high-risk regions or those with destroyed infrastructure—for instance, through dedicated grant programs or subsidies for frontline areas, internally displaced persons (IDP) communities, or settlements with critically damaged grids.

Another priority is infrastructure equalization—funding for electricity grid restoration projects, smart grid implementation, or network redundancy in communities with limited access.

2. Establishing energy cooperatives and municipal platforms.

This involves developing shared use models. In communities where individual households cannot afford their own generation (due to poverty or living in apartment buildings), local energy cooperatives could jointly own solar PV systems or biogas plants. Another approach is the development of municipal microgrids -where energy is generated and consumed within a single locality and managed by a municipal utility. This ensures local energy autonomy.

3. Guaranteed access to financing.

Simple tools for small communities should be introduced—standardized financial products like typical grant applications or easy-to-access concessional loans for renewable energy (via state banks or donor funds). The Energy-as-a-Service model allows communities or consumers to obtain renewable energy solutions without upfront investment, paying gradually from the resulting savings.

4. Developing strategies based on risk-oriented planning.

Integrating wartime risks into energy planning is essential. In regions facing high shelling threats, the focus should be on mobile, autonomous solutions: solar panels with battery storage, diesel backup, microgrids for hospitals, shelters, and administrative centers. Also crucial is funding for infrastructure protection—including the fortification of transformers, dispersing generators, and safeguarding cable networks.

5. Providing educational and coordination support.

Regional energy hubs should be created—adapting global best practices to the Ukrainian context. These would be centers of competence in each region to support communities with technical documentation, project management, and donor engagement. A national education program on decentralized energy should be launched to train local professionals such as energy managers, installers, designers, and project administrators.

6. Ensuring transparency and continuous monitoring.

Platforms should be developed to clearly show which communities already have renewable energy solutions and which are in the queue or application process. This helps prevent an overconcentration of resources in already "strong" communities. Monitoring the social impact must be embedded in the resource allocation logic to ensure equitable development.

Fairness in the development of decentralized energy in Ukraine is only achievable through an inclusive approach, support for the most vulnerable, technical standardization, and regional equalization. This approach will ensure not only resilience but also the social legitimacy of the energy transformation process.

Ukraine's energy infrastructure has been and remains a target for the enemy. By the beginning of summer 2024, the Ukrainian power system had lost 9 GW of generating capacity, mainly thermal and hydroelectric power plants, which are shunting generation facilities. It was these types of generation that mostly kept the system in balance. It will take years to restore them, even with timely and sufficient funding. At the same time, the feasibility of restoring centralized thermal generation facilities to the levels that preceded the full-scale invasion is problematic in the context of the threat of new attacks. At the same time, Ukrainians need electricity right now, and there is also the issue of providing cities with heat in winter. And although imports of up to 1.7 MW are partially covering the electricity needs today, this is much less than the full replacement of lost generating capacity. Therefore, electricity consumption curtailment schedules in the face of generation deficits cannot be avoided in the long term. Especially if nothing is done to increase the existing capacities in the power system.

Decentralized or distributed generation is a system of energy production and transmission involving a large number of consumers who produce electricity and heat for their own needs and, at the same time, have the ability to transfer excess energy to the general grid. Distributed energy resources include three components: distributed generation facilities; demand response mechanisms; and energy storage.

The main feature of the decentralized model is to bring energy production as close as possible to the consumer. Decentralization implies the emergence of a large number of small generation facilities and cogeneration units, as well as the active participation of consumers in energy production and balancing. All this, according to experts, will contribute not only to more efficient use of energy but also to achieving decarbonization goals and combating climate change.

Decentralization reduces technical costs in power transmission lines and increases the flexibility of demand response planning, simplifying the electrification of rural areas and facilities that are geographically remote from power centers. In addition, the efficiency of cogeneration units is increasing.

The decision to develop decentralized energy has long been declared at the highest level of the country's political leadership. In particular, by the end of this year, the power system should have up to 1 GW of maneuvering capacity based on a large number of cogeneration units. In the coming years, it is planned to build an additional 4 GW of gas generation. These plans were announced by President Zelenskyy at the URC 2024 recovery conference in Berlin. While the details of the implementation of such plans have not been disclosed, communities should already be looking for effective solutions and resources to address the problem of electricity and heat shortages for the needs of local critical infrastructure. This need is explained by the realization that the most difficult winter, starting in 2022, is still ahead. The experience of Kharkiv and Khmelnytskyi, which suffered the most from the shelling on 22 March 2024 and actually experienced forced or emergency blackouts, leaving residents without electricity for a long time, has once again shown the demand for decentralized generating capacities in municipal systems as the main or backup power supply system of the city, depending on the operating modes and relevant circumstances.

Ideas are spreading to build local systems capable of operating in an “island” mode, using various combinations of electricity and heat generation technologies. The example of the city of Khmelnytskyi, where distributed generation is already in place, consisting of cogeneration units powered by natural gas, has received both positive feedback and criticism in the comments. It is difficult to objectively evaluate such cases without clarifying technical and other important details. But the general conclusion is that it is necessary to prioritize local energy supply projects. Technical solutions and models for creating decentralized systems in cities will depend on the agreed goals and priorities.

Other examples of distributed generation include a number of already implemented hybrid solar power plant projects to meet the needs of hospitals, water utilities, and other critical and social infrastructure facilities. It is worth noting that we are talking about the installation of stand-alone and hybrid stations, which necessarily include technologies that allow energy to be accumulated and consumed during hours when there is no external power supply, i.e. during the blackout. At the same time, certain peculiarities should be taken into account. Installing such stations to meet absolutely all the needs of the institution is impractical in most cases, especially for large facilities, due to the natural limitations of solar generation and the relatively high cost of battery storage. In each case, the composition of the system is determined by comparing the cost, payback period, efficiency of equipment use, etc. For example, to meet the individual needs of a hospital, the capacity of a typical rooftop solar station can be up to 50 kW, with battery systems up to 50 kWh, respectively. At the same time, the permitted capacity of such a hospital as a consumer can be 100 kW or more.

To promote the development of decentralized energy within communities, the Eco Fortress project initiative was created. The main objectives of the project are to study the regulatory, technical, and economic challenges to creating decentralized systems in communities. Depending on the goals and objectives, possible models of such systems are being explored in terms of organizational structure, functions, etc. If necessary, amendments to the existing legislation are proposed to remove barriers that hinder the development of municipal energy systems. At the same time, the main task is to strengthen the level of energy security primarily at the local level.

The analytical assessment of Ukrainian municipalities' capacity to manage decentralized energy systems under the conditions of decentralization, war, and the energy transition has made it possible to identify the following principles and opportunities for development:

1. Context: the role of municipalities in decentralized energy.

Following Ukraine's decentralization reform, local communities were granted broader powers in resource management, including in the energy sector. During wartime, this role has become even more critical, as local authorities are often responsible for: maintaining critical infrastructure (hospitals, water utilities, schools), coordinating humanitarian projects, initiating local energy efficiency and renewable energy initiatives.

2. Current capacity of municipalities. Strengths in Ukraine include: Experience in energy management: some amalgamated territorial communities (ATCs) have already implemented energy monitoring and Sustainable Energy and Climate Action Plans (SECAPs) within the framework of the Covenant of Mayors. International Support: Thanks to projects by GIZ, USAID, NEFCO, and UNDP, communities have received equipment, training, and expert assistance in energy efficiency and renewable energy. Local Initiative: Certain municipalities have become pioneers in installing solar rooftops, biomass mini-CHPs, and heat pumps in schools and Administrative Service Centers (ASCs). Key current challenges include: Limited Administrative Capacity: There is a shortage of specialists in energy planning, engineers, and project managers. Lack of Funding: Communities' own revenues are limited, and state subsidies often cover only basic operational needs. Complexity of Managing Microgeneration: Municipalities rarely have experience in managing microgrids, load balancing, or integrating renewables into local distribution systems. Uncertain Regulatory Environment: Legislation often lags behind technological developments—for example, the regulatory framework for energy cooperatives, shared generation, or energy storage remains underdeveloped.

3. Development potential. Key areas for strengthening municipal capacity include: Personnel training: training of municipal energy managers, renewable energy engineers, and energy project administrators? creation of Energy Agencies or Municipal Utilities: These structures can professionally manage local energy systems, attract investment, and

implement pilot projects. Partnerships with business and research institutions: public-private projects, such as municipal solar power stations or biomass-based heating. Greater Participation in International Programs: Communities can secure funding for "green" reconstruction and ensuring energy independence for critical infrastructure.
Ukrainian municipalities have the potential to become local hubs of energy transformation. However, this requires systematic support from the state, donors, and the private sector. In particular, it is crucial to: ensure long-term financing, provide technical and methodological support, develop and maintain a favorable regulatory environment that is aligned with European and global standards.
This will allow communities to transition from passive energy consumption to active energy management, which is essential for energy security during the war and in the post-war recovery period.
The directions of modernization should be assessed using modern economic and mathematical models.

2. Theoretical Background

Analyzing the literature, it should be noted that the issue is relatively new for the Ukrainian energy sector. After all, Ukraine's true independence also lies in its energy component.
As the literature review and analysis shows, the issue of investment attractiveness of alternative energy attracts the attention of a significant number of scientists and practitioners who are engaged in a detailed analysis of this issue. After all, the rapid development of the industry requires addressing important energy challenges that are emerging and will arise in the future. Among the main specialists studying the subject, it is worth noting the following: Al-Dahidi S. (2024), Al-Ghussain L. (2024), Alhussan A. (2023), Alrbai M. (2024), Bhattacharya A. (2022), Blinov I. (2019), Boulakhbar M. (2025), Chala T. (2021), Chepeliev M. (2022), Chepizhko L. (2023), Conti S. (2024), Coronado C. (2021), De-León Almaraz S. (2024), Diachuk O. (2022), El-Amary N. (2025), Ettouhami M. (2025), Gerneho Y. (2021), Gonta A. (2022), Greskov D. (2020), Grigorak M. (2022), Gunko I. (2019), Gunko I. (2020), Hassan M. (2025), Hunko I. (2020), Kryl Y. (2024), Kudria S. (2020), Kuo P.-C. C. (2024), Lee J. (2023), Lee, P. (2024), Leszczyński G. (2024), Liashenko V. (2025), Lu, Z. (2024), Lyakhova O. (2021), Mahmoud M. (2023), Maréchal F. (2024), Matviychuk V. (2015), Miroshnyk V. (2019), Moura, C. (2024), Osadcha N. (2024, 2025), Özdemir F. (2024), Pidlisna O. (2023), Pinto G. (2021), Podolets R. (2022), Pryadko Y. (2021), Rubanenko O. (2015, 2016, 2020), Saeidi S. (2024), Salama S. (2023), Sebbani I. (2025), Semeniuk A. (2022), Shymaniuk P. (2019), Silveira J. (2021), Silveira J. (2024), Slavuta O. (2021), Sotnyk I. (2019), Souza de T. (2021), Stepanchuk K. (2023), Sree Lakshmi G. (2020), Trokhimenko O. (2021), Volovyk O. (2022), Vostriakova V. (2021), Wen D. (2024), Yanovych V. (2019), Zaverbnyj A. (2018, 2024, 2025), and many others.
It is also worth noting the specialists who study this issue in the context of war and post-war conditions. Among them are the following: Belousova K. (2022), Chepeliev M. (2022), Diachuk O. (2022), Greskov D. (2020), Gunko I. (2020), Konechenkov A. (2022), Osadcha N. (2024), Podolets R. (2022), Rubanenko O. (2020), Semeniuk A. (2022), Stepanchuk K. (2023), Zaverbnyj A. (2024) and others.

Scientists Pidlisna O.A. and Chepizhko L.M. analyzed investment attractiveness by type of renewable energy source in their studies (Bhattacharya, etc. 2022, Hayer, 2023). The authors also noted possible approaches to attracting investment in terms of profitability and efficiency (Pidlisna, etc. 2023).

The process of formation and implementation of innovative development of the energy sector of the Ukrainian economy in the context of the fourth industrial revolution is considered by Trokhimenko O. (2021). Scientists have also worked out aspects of economic and mathematical modeling of investment attractiveness (Davydova, 2014, Gunko, etc. 2020). Chala T.G., Pryadko Y.V., Slavuta O.I. (2021) carried out statistical modeling of the development of the domestic energy market. Vostriakova V.I. assessed the potential of renewable energy (Vostriakova, 2021). However, the issue of prioritizing the investment attractiveness of Ukraine's alternative energy sector in the face of uncertainty, in particular in the context of a full-scale invasion, remains relevant.

According to scientific research, the investment needs for the energy transition to carbon neutrality are very high (International Energy Agency, 2025). There is a need to develop infrastructure, research, and development to improve their efficiency. According to the International Energy Agency (International Energy Agency, 2025), the International Renewable Energy Agency (Renewable Capacity Statistics, 2023), total investments are closely linked to the Paris Climate Goals (Paris Agreement, 2015), amounting to more than 125 trillion US dollars. At the same time, annual investment needs until 2030 are estimated at USD 5 trillion (Renewable Capacity Statistics, 2023).

According to the analysis of statistical data, in 2022, hydropower had the largest capacity among renewable energy technologies in the world (Renewable Capacity Statistics, 2023). But the requirements for the use of water and land resources, high environmental and social costs significantly limit the future development of this type of energy in the energy transition to carbon neutrality.

As for the generalized global forecasts for the development of renewable energy technologies, taking into account Ukraine's unique geopolitical, economic, and infrastructural constraints, it is essential to focus in detail on the availability of resources in specific regions, the structure of investments (especially foreign ones) in Ukraine's renewable energy sector, and the trajectories of post-conflict recovery.

Ukraine faces unique challenges and opportunities, including:

1. Geopolitical constraints. The risk of attacks on energy infrastructure by the Russian Federation makes centralized expansion of renewables impossible without considering security. The priority shifts toward decentralization and mobility — autonomous systems, microgrids, and energy storage solutions.
2. Infrastructure challenges. There is a pressing need to modernize the grid to enable the integration of renewables (flexibility, digitalization). The current system has limited capacity to balance energy flows without advanced storage infrastructure.
3. Economic constraints. Both the state and households operate under tight budgetary restrictions. However, international partners (the EU, World Bank, USAID) are willing to finance recovery and decarbonization through grants and concessional loans.
4. Growth potential. Ukraine has vast natural potential (solar, wind, biomass). There is an opportunity to transform destroyed infrastructure into “green recovery zones.” Moreover,

Ukraine's integration into ENTSO-E opens up export opportunities for green energy after the war.
Therefore, a significant part of the demand for renewable energy sources will have to be met by solar, wind, and hydrogen energy (Belousova, 2022, Chepeliev, 2022, Gerneho, et al. 2021, Konechenkov, 2022, Leszczyński, 2024, Osadcha, etc. 2025, Vostriakova, 2021).
Declining costs due to technological advances, high rates of learning, government support policies for renewable energy, and innovative financing models are making solar energy the leading technology for electricity generation (Renewable Capacity Statistics, 2023). It is worth noting that solar power is leading the way in adding renewable energy capacity, while hydropower is leading the way in total renewable energy capacity stock.
The projected growth of wind power worldwide is expected to increase from 899 GW to 3337 GW (Rebuilding Ukraine, 2023). Capacity in other renewable energy technologies, including biomass, geothermal, waste-to-energy, and marine energy, will also need to increase rapidly. The total capacity requirement for these other technologies is 749 GW in 2030 (Rebuilding Ukraine, 2023). Annual investment needs depend on the type of source and the cost of the technology. For example, solar power plants in the world require annual investments of more than $330 billion, and wind power plants, respectively, $400 billion (Rebuilding Ukraine, 2023).
Global international investment project financing for renewable energy sources is heavily dependent on private foreign investment. In general, foreign investors finance more than 50% of investments in renewable energy sources (Rebuilding Ukraine, 2023).
International alternative energy investment projects often require partnerships between the state and private sponsors, as renewable energy technologies are expensive.
In Ukraine, the public sector is much more involved in the development of alternative energy than in developed countries (both domestic and international projects). The high level of public capital involvement in renewable energy development acts as a guarantor and incentive for foreign private enterprises. It helps reduce uncertainty about risks. This is especially true for Ukraine, as it is at war, experiencing political and economic crises, etc.
The Ukrainian electricity and heat production sector will undergo priority transformation for decarbonization (as distribution generation of electricity, heat, smart grids, etc. will be intensively developed), as well as industry (widespread use of robotics, technologies that use electricity to produce products) and transport (gradual abandonment of oil products in favor of electricity, hydrogen (Al-Ghussain, etc. 2024, Alhussan, etc. 2024, Hassan, etc. 2025, Kryl, 2024, Lee, etc. 2023, Leszczyński, et al. 2024, Mahmoud, et al. 2023, Moura, et al. 2024, Salama, et al. 2023, Sebbani, et al. 2025), biofuels, etc.)
As indicated by the International Energy Agency (IEA) in its latest World Energy Outlook 2024: if countries adhere to their commitments made in the framework of the preparation, ratification of the Paris Agreement (Nationally Determined Contributions), then by 2040 (World Energy Outlook, 2024):
- electricity generation from renewable energy sources will reach 37% of the total electricity generation structure, compared to 23% now;
- almost 60% of all new capacities will use renewable energy sources, and most renewable energy facilities will be competitive without any additional grants and subsidies;
- the number of electric cars will increase from 1.3 to 150 million units;
- demand for gas will increase by 50%, replacing coal in the global energy balance, etc.

In Ukraine, investment policy measures to support the energy transition are consistent with development measures in other sectors (Rebuilding Ukraine, 2023). Investment policy measures for the energy transition operate within the regulatory framework for the energy sector, which provides government incentives for investment in alternative energy (fiscal incentives, including tax breaks (exemption from indirect taxes, production-based tax credits), etc. and in developed economies these are tools for attracting investment, usually including preferential tariffs, auctions), curbing the production of fossil fuels that lead to intensive carbon emissions in sectors (Rebuilding Ukraine, 2023).

Ukraine's current alternative energy sector is attractive to investors, even in the face of uncertainty (primarily the war with Russia). Increased attention to energy from alternative sources in Ukraine is related to international trends in the development of the concept of sustainable development, rising costs of natural resources, environmental pollution, etc.

The issue of transition to the use of alternative energy sources is important for Ukraine today, especially in the context of war, when the issue of sustainable development of domestic energy needs (Stepanchuk, 2023) arises to gain energy independence and economic independence through this.

The phase-out of fossil fuels is one of the most important energy decisions on the way to greening the energy mix (Stepanchuk, 2023) of Ukraine.

Fossil fuels, such as natural gas and coal, take many years to replenish, while renewable energy sources are naturally renewable (Stepanchuk, 2023, 2024).Other advantages include minimal impact on natural ecosystems. Energy production from renewable sources does not require mechanical intervention in nature.

3. Methods

To establish investment priorities for alternative energy under conditions of uncertainty, we used the Fuzzy TOPSIS method, which takes into account the complexity and ambiguity of decision-making, helping to find optimal solutions under conditions of uncertainty in Ukraine, with unclear data (Stepanchuk, 2023, 2024). After all, in times of war, much of the statistical data (primarily in the energy sector, as one of those that is constantly under attack by the occupiers) is classified from the Russian occupier.

The proposed method will allow taking into account various criteria when making management decisions in the energy sector and finding compromises between them. This is important when it is impossible to single out a single best (optimal) alternative. The proposed method will create a realistic model for the process of making managerial decisions in the energy sector (Stepanchuk, 2024).

The further discussion should focus on evaluating how the model's assumptions influence the prioritization outcomes, and whether alternative multi-criteria methods could provide more reliable insights under conditions of information asymmetry caused by the war and the shortage of statistical data.

Building a model representation of the problem of setting investment priorities for Ukrainian alternative energy requires a scenario approach. The data have a pronounced heterogeneity with respect to the criterion and alternatives. Therefore, it is important to normalize the data when building the model (Investing in Ukraine's Renewable Energy,

2023, Stepanchuk, 2024). This will help neutralize significant outliers of heterogeneous data (by bringing them to a common scale).
It is advisable to use data normalization for the model. This should be done by the criterion by applying the "z-score" method (Stepanchuk, 2024). That is, we propose to use formula (1) (Stepanchuk, 2024):

$$NSC_{xmn} = \frac{x_{mn} - \bar{x}_{mn}}{\hat{x}_{mn}}, \quad (1)$$

where NSC_{xmn}–is the normalized score of alternative n according to criterion m;
xmn – is the evaluation of alternative n by criterion m;
$\bar{x}_{mn}$– is the average value of x;
$\hat{x}_{mn}$– standard deviation.

We will begin modeling experiments to establish investment priorities for alternative energy in Ukraine by normalizing the assessments of alternatives (using MS Excel to determine the average values and standard deviations for the assessments of alternatives for each criterion) (Investing in Ukraine's Renewable Energy, 2023, Stepanchuk, 2023, 2024).

4. Results and discussion

Let's make calculations for the traditional strategy of alternative energy development in Ukraine (Stepanchuk, 2024). An example of the first calculation is solar power plants. We calculate their normalized assessment according to the criterion of investment volume (Table 1) using formula (1).

NSCx11= (147,9-106,01) / 158,63= 0,261

Table 1. Calculated indicators of normalized assessment of alternatives (renewable energy plants)

Group	Solar power plants	Small hydro power plants	Wind power plants	Biogas power plants	Biomass power plants
Commissioned capacity (MW)	0.815	-0.734	1,348	-0,724	-0,704
Investment volume (EUR million)	0.261	-0.664	1.659	-0.644	-0.613
Electricity volume, mln kWh	1.518	-0.744	0.553	-0.694	-0.634
Weighted average tariff kopecks/kWh	1.559	-0.714	0.483	-0.694	-0.623
The amount of the "green" tariff, kopecks.	0.613	1.217	1.378	0.392	0.392

Source: based on (Stepanchuk, 2023, Stepanchuk, 2024, Website of the State Statistics Service of Ukraine, 2025)

Similarly (Table 1), estimates of solar and other types of stations are calculated according to other criteria. Determination of investment priorities in the domestic alternative energy sector is based on the ranking of alternatives. The best alternative is the one that is closest to the ideal solution. The higher the proximity coefficient (k) for a renewable energy plant, the higher the ranking of alternatives (Table 2). The calculation of the proximity coefficient (k) is based on formula (2) (Stepanchuk, 2023, Stepanchuk, 2024):

$$k_n = \frac{\sum_n R^-{}_{x_{mn}}}{\sum_n R^-{}_{x_{mn}} + R^+{}_{x_{mn}}} \tag{2}$$

where $R^+{}_{x_{mn}}$ is the distance to the positive ideal (optimal) solution according to criterion m;

$R^-{}_{x_{mn}}$ is the distance to the positive/negative ideal solution according to criterion m. Having calculated the coefficient of proximity of the weighted assessment of the alternative (k) to the ideal positive/negative decision, we can rank all the alternatives.

We have ranked the possible alternatives for Ukraine by (k) (see Table 2).

That is, the first place in the ranking was obtained for solar power plants (see Table 2).It is advisable to present two scenarios for the development of the alternative energy sector in Ukraine: pessimistic/optimistic.

The pessimistic scenario assumes an increase in the inflation index, a decrease in GDP, and a decrease in investment inflows into the industry. The optimistic one assumes a decrease in inflation, an increase in GDP, and an increase in investment inflows to the industry (Stepanchuk, 2023, Stepanchuk, 2024).

Table 2. Calculated proximity coefficients and ranking of renewable energy plants according to the sectoral ranking strategy

Renewable energy sectors	Proximity factor	Place
Solar power plants	0.701	1
Wind power plants	0.695	2
Biomass power plants	0.590	3
Biogas power plants	0.444	4
Small hydropower plants	0.338	5

Source: based on (Stepanchuk, 2023, Stepanchuk, 2024):

Table 3 shows the dynamism of factors under the pessimistic scenario for solar power plants for the forecast period from May 2025 to April 2026.

The purchase/sale price decreases, which is a negative phenomenon for renewable electricity producers from an economic point of view. After all, in an economic crisis (in which Ukraine is currently experiencing due to Russia), a decrease in energy payments makes it impossible to maintain the necessary development of these plants (Stepanchuk, 2023)

The pessimistic scenario emphasizes significant economic turmoil (including lower purchase prices, falling GDP, etc.). Accordingly, it is necessary to hold a discussion at the state level, including the Ministry of Energy of Ukraine, on the formation and provision of economic guarantees for renewable energy producers (especially for foreign investors). Ukraine faces unique challenges in wartime: it must simultaneously ensure an acceptable level of energy security, maintaining the confidence of investors (primarily foreign ones, as domestic financial resources are limited and insufficient), while making energy affordable for a population suffering from inflation, declining incomes, constant shelling, etc.

It is possible to balance these interests through the development and implementation of a comprehensive strategy, which should include the following steps:

1. Transparent, predictable policy for investors. Long-term guarantees: Providing guarantees to protect investments (especially in the green sector and renewable energy), even during war. Cooperation with international donors and insurance agencies: Involvement of war risk insurance mechanisms (e.g., through MIGA or DFC). Step-by-step increase of tariffs for business:A fair, predictable schedule of tariff revisions allows investors to plan for profitability.
2. Social justice, protection of producers and consumers. Targeted assistance: instead of fixed low tariffs for everyone, the state can provide subsidies to the most vulnerable groups (pensioners, large families, internally displaced persons). Energy saving: encouraging home insulation and the installation of energy-efficient equipment with support from international funds. Partial tariff regulation: temporary price freeze for households on a basic level of consumption (e.g., up to 200 kWh), with excess consumption priced at market rates.
3. Liberalization and modernization of the domestic energy market. Launch of a bilateral contracts market for large consumers to reduce pressure on state-owned generation. Deregulation of competitive segments where feasible (for example, in alternative energy). Reform of the "Green" Tariff: Gradual replacement with a system of auctions or contracts for difference, to maintain investment attractiveness and reduce the fiscal burden.
4. Public communication and trust. Clear and transparent communication of tariff policy, sources of deficit, and recovery plans. Dialogue with business and the public through open consultations to enhance the legitimacy of decisions.
5. Cooperation with international partners, primarily the EU. Access to preferential loans and grants for energy modernization. Electricity imports during peak periods — when possible, from European ENTSO-E markets.

In other words, the key lies in a flexible combination of market mechanisms and social protection, along with a consistent state policy that aligns with the interests of both investors and consumers. In wartime conditions, it is crucial to maintain balance through clear planning, international support, and transparent policies.

Table 3. Example of calculation of factor scores for solar power plants under the pessimistic scenario (May 2025-April 2026)

Consumer price index	Price, UAH/ MWh	Demand, MWh	Capacity growth rate	Production, MWh	GDP, UAH million.	Investments, EUR million	Losses from war risks
1.01	1,813	3,365	0.93	62,817	1,547,025	0.58	433
1.01	1,527	1,895	0.93	61,189	1,516,085	0.58	390
0.99	1,167	1,330	0.93	59,541	1,485,763	0.58	352
0.99	990	1,122	0.93	57,902	1,456,048	0.58	318
1.01	1,248	1,173	0.93	56,303	1,426,927	0.58	287
1.01	1,392	1,464	0.93	54,754	1,398,388	0.58	259
1.01	1,357	1,471	0.93	53,234	1,370,420	0.58	234
1.01	1,461	1,733	0.93	51,763	1,343,012	0.58	211
1.01	1,423	1,547	0.93	50,314	1,316,152	0.58	190
1.01	1,430	1,507	0.93	48,897	1,289,829	0.58	172
1.01	1.523	1,731	0.93	47,528	1,264,032	0.58	155
1.01	1,593	1,894	0.93	46,204	1,238,751	0.58	140

Source: based on (Stepanchuk, 2023, Stepanchuk, 2024, Website of the State Statistics Service of Ukraine, 2025)

The consumer price index and GDP are mostly correlated (higher inflation leads to lower GDP and vice versa). In line with military risks, the growth rate of capacity and production is significantly reduced, which is also true for investment. This is due to a negative trend in the impact of shelling and hostilities on the development of new alternative capacity. Even the destruction of the existing one is possible. Clearly, this does not help improve the investment climate in Ukraine.

Losses from military risks are calculated based on the level of damage recorded to date, installed capacities, and security assessments (Stepanchuk, 2023, Stepanchuk, 2024, Website of the State Statistics Service of Ukraine, 2025).

According to the optimistic scenario for solar power plants and biomass power plants, the dynamics of indicators is obvious: an increase in the growth rate of capacity, investment, and electricity production from these types of plants. And the level of military threat remains, which is why, with the rapid growth of capacity, the share of capacity that can be lost (partially or completely) is also increasing. For solar power plants, this share is significant, as can be seen in the calculations in Table 4 (Stepanchuk, 2024, Website of the State Statistics Service of Ukraine, 2025).

It should also be noted that under the optimistic scenario, there is a decrease in demand. This is due to the oversaturation of the electricity market (Investing in Ukraine's Renewable Energy, 2023, Stepanchuk, 2024).According to the results of the assessment of the investment attractiveness of solar power plants (Table 4), we can see that under the optimistic scenario, the investment attractiveness assessment decreases. This is due to a negative change in the ratio characterising the security of the industry's development. The decline of this indicator over time means that foreign direct investment will not be enough for Ukraine to cover the needs of new Ukrainian capacities (Investing in Ukraine's Renewable Energy, 2023, Stepanchuk, 2024).

Table 4. Example of calculation of factor scores for solar power plants under the optimistic scenario (May 2025-April 2026)

Consumer price index	Price, UAH/ MWh	Demand, MWh	Capacity growth rate	Production, MWh	GDP, UAH million.	Inves-tments, million euros	Losses from war risks
1.01	1,444	2,753	1.26	342,119	1,815,490	0.66	69,399
1.01	1,883	2,300	1.25	412,972	1,851,799	0.67	83,864
0.99	1,262	1,402	1.24	497,626	1,888,835	0.68	100,235
0.99	1,027	1,145	1.22	597,544	1,926,612	0.68	118,454
1.01	1,310	1,213	1.21	713,982	1,965,144	0.69	138,356
1.01	1,297	1,389	1.20	847,842	2,004,447	0.69	159,665
1.01	1,341	1,458	1.18	999,608	2,044,536	0.70	181,974
1.00	1,329	1,613	1.17	1,169,222	2,085,427	0.71	204,747
1.00	1373	1,505	1.15	1,355,961	2,127,135	0.72	227,327
1.00	1,282	1,391	1.14	1,558,364	2,169,678	0.72	248,949
1.00	1,236	1,480	1.11	1,774,194	2,213,072	0.73	268,777
1.00	1,262	1,582	1.10	2,000,394	2.257,333	0.74	285,944

Source: based on (Stepanchuk, 2023, Stepanchuk, 2024, Website of the State Statistics Service of Ukraine, 2025)

In conclusion, the key problems of the model (1) include the lack of statistical data, analytics that would cover more military risks, the activities of individual renewable energy plants in Ukraine, social indicators at such plants, etc. There is a certain level of subjectivity in the model (the presence of expert opinion).

The economic effect of this model is that the use of factors for scenario-based assessment of investment priorities in alternative energy in Ukraine primarily involves an increase in investment from foreign investors. Accordingly, an increase in investment flows with the right investment priority will lead to an increase in capacity (Investing in Ukraine's Renewable Energy, 2023, Stepanchuk, 2024) and an improvement in the investment climate of Ukraine. In other words, it will no longer be just about the attractiveness of Ukraine's energy sector for foreign investment, but also other promising sectors.

After all, Ukraine is interested in developing its own capacity to produce alternative energy equipment. This is strategically important in the post-war reconstruction to create new jobs, reduce dependence on imported equipment and (as a result) reduce the cost of installing new plants, which is one of the biggest challenges for the development of domestic alternative energy (Dyachuk, et al. 2024, Osadcha, et al. 2024, Stepanchuk, 2024).Taking into account these recommendations and the forecast of consequences, Ukraine can develop alternative energy in an efficient and sustainable way, while contributing to the development of society and preserving the environment.

The future discourse should integrate social indicators: income equality, access to energy between urban and rural areas, and stakeholder involvement in investment models. All of this will ensure that Ukraine's transition strategy is not only green, but also equitable and inclusive.

5. Implications and further research

The challenges of modern energy security and the need to reduce dependence on fossil fuels set ambitious targets for the country in terms of using its unique natural resources. In addition to their key role in combating the climate crisis, renewable energy sources help people solve many other problems: they promote energy equality, ensure energy price stability, reduce income inequality and promote social justice by distributing the benefits of renewable energy production and use among different stakeholders, increase the reliability of energy supply, and develop energy independence, as they allow the country to become independent of energy and fuel imports, and help to reduce the dependence on fossil fuels.

References

17 Sustainable Development Goals. (2025). Global Compact Network Ukraine. Available online: https://globalcompact.org.ua/tsili-stijkogo-rozvytku/

Al-Ghussain, L., Alrbai, M., Al-Dahidi, S., Lu, Z., Lee, P. (2024). Techno-economic and environmental assessment of solar-based electrical vehicles charging stations integrated with hydrogen production. Journal of Cleaner Production. 434. 140219. Available online: https://www.scopus.com/record/display.uri?eid=2-s2.0-85181138144&origin=resultslist&sort=plf

Alhussan, A. et al. (2023). Economies of scale in green hydrogen production. Hydrogen Scaling J. 15(4). pp. 76–92.

Belousova, K. (2022). Half of Ukraine's renewable energy facilities are threatened with destruction because of the war. Infographics. Ecopolitics. Available online: https://ecopolitic.com.ua/ua/news/polovini-ukrainskih-ob-iektiv-vde-zagrozhuie-znishhennya-cherez-vijnu-uave-infografika/

Bhattacharya, A. et al. (2022). Financing a big investment push in emerging markets and developing economies for sustainable, resilient and inclusive recovery and growth. London: Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science, and Washington, DC. Brookings Institution. pp. 71. Available online: https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2022/05/Financing-the-big-investment-push-in-emerging-markets-and-developing-economies-for-sustainable-resilient-and-inclusive-recovery-and-growth-1.pdf.

Blinov, I.V., Miroshnyk, V.O., Shymaniuk, P.V. (2019). Short-term interval forecast of total electricity supply by producers from renewable energy sources. Proceedings of the Institute of Electrodynamics of the National Academy of Sciences of Ukraine. 54. pp. 5–12.

Chala, T.G., Pryadko, Y.V., Slavuta, O.I. (2021). Statistical modeling of energy market development in the regions of Ukraine. Business Inform.. 1. pp. 151–157. Available online: https://doi.org/10.32983/2222-4459-2021-1-151-157.

Chepeliev, M., Diachuk, O., Podolets, R. and Semeniuk, A. (2022). What is the Future of Nuclear Power in Ukraine? The Role of War, Techno-Economic Drivers and Safety Considerations. Available online: https://ssrn.com/abstract=4288067

Davydova, O.Y. (2014). Scenario modeling - an optimal approach to planning. 2, pp. 493-498. Available online: http://global-national.in.ua/archive/2-2014/99.pdf.

Dyachuk O. et al. (2024). Long-term Energy Modeling and Forecasting in Ukraine: Scenarios for the Action Plan for the Implementation of the Energy Strategy of Ukraine until 2035. Available online: https://ens.dk/sites/ens.dk/files/Globalcooperation/long-term_energy_modelling_and_forecasting_in_ukraine_ukrainian.pdf.

EU taxonomy for sustainable activities (2024). European Commission. Available online: https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en.

Gerneho, Y.O., Lyakhova, O.O. (2021). Financing the potential of alternative energy development in Ukraine. Efficient economy. 3. Available online: http://www.economy.nayka.com.ua/pdf/3_2021/5.pdf

Grigorak, M.Y., Gonta, A.A., Volovyk, O.I. (2022). Taxonomy of Objects for Sustainable Financing for Risk Management System Simulation. Cybernetics and computer technologies. Available online: http://cctech.org.ua/images/docs/Articles/2022/paper_22_3_2.pdf

Gunko, I.O., Rubanenko, O.O., Greskov, D.O. (2020). Analysis of software tools for modeling the operating modes of electrical systems. Bulletin of Khmelnytsky National University. 3. pp. 138-141.

Hassan, M.A., El-Amary, N.H. (2025). Economic and technical analysis of hydrogen production and transport: a case study of Egypt. Scientific Reports, 15(1), 9002. Available online: https://www.scopus.com/record/display.uri?eid=2-s2.0-105000176687&origin=resultslist&sort=plf

Hayer, A. (2023). Scenario Analysis: How It Works and Examples. Investopedia. Available online: https://www.investopedia.com/terms/s/scenario_analysis.asp

International Energy Agency: official web portal. (2025). Available online: https://www.iea.org/

Investing in Ukraine's Renewable Energy: The Key to Future Energy Security (2023). Razom We Stand. London. p. 28.

Investments in "green" generation capacities. Energy Map. (2023). Available online: https://map.ua-energy.org/uk/resources/02f06812-5ab4-49e0-8fa7-e70337f81988/

Konechenkov, A. (2022). Renewable Energy Sector of Ukraine before, during and after the war. Edited by V. Omelchenko. Razumkov Center.Available online: https://razumkov.org.ua/statti/sektor-vidnovlyuvanoyi-energetyky-ukrayiny-do-pid-chas-ta-pislya-viyny

Kryl, Y.M. (2024). Hydrogen energy in Ukraine: prerequisites, potential and prospects for European integration. Ekonomika Promyshlennosti. 4 (108). pp. 49-62.

Lee, J. et al. (2023). Economic evaluation of hydrogen production in Korea. Energy Perspect. 10(4). P. 325–338.

Leszczyński, G., De-León Almaraz, S. (2024). Sustainable energy supply transition: the value of hydrogen for business customers. Journal of Business and Industrial Marketing. 39(11). pp. 2478–2496. Available online: https://www.scopus.com/record/display.uri?eid=2-s2.0-85201152837&origin=resultslist&sort=plf

Levelized cost of energy by technology. (2025). Our World in Data. Available online: https://ourworldindata.org/grapher/levelized-cost-of-energy

Mahmoud, M. et al. (2023). Geothermal hydrogen production: Economic analysis. Geothermal Energy Studies 12(1). pp. 123–139

Matviychuk, V.A., Rubanenko, O.E., Rubanenko, O.O. (2015). Features of power supply of powerful agricultural enterprises with the use of neural networks and distributed sources of electricity. Collection of scientific works of VNAU. Series: technical sciences. № 2 (90). pp. 117–123.

Moura, C.H.S., Conti, S.A., Silveira, J.L. (2024). Thermodynamic, economic and environmental analyzes the compression and storage processes of green hydrogen involved in fueling station for vehicular use. Environment, Development and Sustainability. Available online: https://www.scopus.com/record/display.uri?eid=2-s2.0-85208125627&origin=resultslist&sort=plf

Osadcha, N., Zaverbnyj, A. (2024). Assessing the Role and Viability of Nuclear Power in Ukraine's Post-War Energy Strategy. European Journal of Sustainable Development. Vol. 13, No. 3.pp. 469-488.

Osadcha, N., Zaverbnyj, A. (2024). Assessment of the energy system of Ukraine: ways of recovery, cases of development // European Journal of Sustainable Development. Vol. 13, No. 1. pp. 185–204.

Osadcha, N., Zaverbnyj, A., Liashenko, V. (2025). Advancing Renewable Energy Transition for Economic Sustainability: Insights from Global Practices and Local Adaptation Strategies. European Journal of Sustainable Development. Vol. 14. No. 1. pp. 335-356

Paris Agreement. (2015). Available online: https://unfccc.int/sites/default/files/english_paris_agreement.pdf

Pidlisna, O.A., Chepizhko, L.M. (2023). Analysis of the investment attractiveness of alternative energy in Ukraine. Economic Bulletin of NTUU "KPI": a collection of scientific papers. 26. pp. 51-58. Available online: https://doi.org/10.32782/2307-5651.26.2023.8

Rebuilding Ukraine with a Resilient, Carbon-Neutral Energy System. United Nations Economic Commission for Europe. Geneva, 2023. Available online: https://unece.org/sites/default/files/2023-07/EN_Rebuilding%20Ukraine%20with%20a%20Resilient%20Carbon-Neutral%20Energy%20System_V8.pdf

Renewable capacity statistics 2023, International Renewable Energy Agency (IRENA), Abu Dhabi. Available online: https://www.irena.org/publications/2023/Mar/Renewable-CapacityStatistics-2019.

Renewable energy sources. Edited by Kudri, S.O. (2020). Kyiv: Institute of Renewable Energy of the National Academy of Sciences of Ukraine. 392 p.

Rubanenko, O.O. (2016). Microgrids as a means of increasing the reliability of power supply to enterprises in the agro-industrial complex. Bulletin of the Kharkiv Petro Vasylenko National Technical University of Agriculture. Technical sciences. "Problems of energy supply and energy saving in the agro-industrial complex of Ukraine". 175. pp. 43–45

Rubanenko, O.O., Yanovych, V.P., Gunko, I.O. (2019). Analysis of RES operation in distribution networks and ways to compensate for their instability. Bulletin of Khmelnytsky National University. 5. pp. 176–179.

Salama, S. et al. (2023). Control strategies for renewable hydrogen production. Renew. Control Syst. 21(2). pp. 310–324

Sebbani, I., Ettouhami, M.K., Boulakhbar, M. (2025). Fuel cells: A technical, environmental, and economic outlook. Cleaner Energy Systems. 10, 100168. Available online: https://www.scopus.com/record/display.uri?eid=2-s2.0-85214569273&origin=resultslist&sort=plf

Sotnyk, I.M. (2019). Energyefficiency and rewneable energy in Ukraine: problems of management. Monograph. Sumy. University book. 247 p.

Souza de, T.A.Z., Coronado, C.J.R., Silveira, J.L., Pinto, G.M. (2021). Economic assessment of hydrogen and electricity cogeneration through steam reforming-SOFC system in the Brazilian biodiesel industry. Journal of Cleaner Production, 279, 123814. Available online: https://www.sciencedirect.com/science/article/abs/pii/S0959652620338592

Sree Lakshmi, G., Rubanenko, O., Hunko, I. (2020). Renewable Energy Generation and Impacts on E-Mobility, Journal of Physics: Conference Series. J. Phys.: Conf. Ser.1457 012009. pp. 1–8

Stepanchuk, K.S. (2023). Assessment of investment attractiveness of an enterprise in the field of alternative energy in Ukraine: a course work. Kyiv: National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute". 36 p.

Stepanchuk, K.S. (2024). Scenario modeling of alternative energy investment priorities under uncertainty. Master's thesis for a master's degree in the educational and professional program "Economic Cybernetics", specialty 051 "Economics". 122 p.

Trokhimenko, O.O. (2021). Development of a mechanism for implementation of a national innovative policy in the energy sector based on Industry 4.0. Technology Audit and Production Reserves. 4(60). pp. 34–40. Available online: https://doi.org/10.15587/2706-5448.2021.238959

Ukraine's power system was attacked by more than 1000 missiles and shells - head of Ukrenergo. Interfax-Ukraine news agency (2022). Available online: https://interfax.com.ua/news/general/876970.html.

Vostriakova, V.I. (2021). Assessing the potential of renewable energy as a driver of economic growth. Business Inform. 7. pp. 146–152. Available online: https://doi.org/10.32983/2222-4459-2021-7-146-152

Website of the State Statistics Service of Ukraine (2025). Available online: https://www.ukrstat.gov.ua/

Wen, D., Kuo, P.-C., Saeidi, S., Özdemir, F., Maréchal, F. (2024). Renewable synthesis fuels for a circular economy: A life cycle assessment. Resources, Conservation and Recycling, 211. 107851. Available online: https://www.scopus.com/record/display.uri?eid=2-s2.0-85201603349&origin=resultslist&sort=plf

World Energy Outlook 2024. (2024). Executive summary. Internation Energy Agency. Available online: https://www.iea.org/reports/world-energy-outlook-2024

Zaverbnyj, A.S. (2018). Complementarity of Energy and Economic Policy of Ukraine in the Context of European Integration. Lviv Polytechnic National University, Lviv: Lviv Polytechnic Publishing House. 308 p.