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Review

ECONOMIC AND MATHEMATICAL EVALUATION OF UKRAINE'S RENEWABLE ENERGY DEVELOPMENT WITH CONSIDERATION OF MILITARY RISKS

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Abstract. This article explores the renewable energy development in Ukraine, taking into account military risks through an economic-mathematical assessment of its investment attractiveness. To evaluate the investment priorities of renewable energy in Ukraine, two strategies have been considered – traditional and the one taking into account ESG factors. Using the Fuzzy TOPSIS approach, the main priorities of renewable energy in Ukraine have been determined: solar power plants for the traditional strategy, and for the ESG strategy – biomass power plants. For further evaluation of the investment attractiveness of the identified priorities, a multifactor model for assessing investment attractiveness using the method of integral assessment was constructed. The model is based on four primary indicators: development prospects, return on equity of enterprises, level of inflation stability in industry prices, and industry-specific risks.

Keywords: renewable energy, sustainable development, investment attractiveness, econometric modeling, scenario modeling, substitution elasticity.

JEL Classification: C32, E22, Q42, Q43, D81.

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1. Introduction

One of the factors contributing to the development of renewable energy in Ukraine is the attraction of investments. Investors make decisions regarding the necessity and appropriateness of engaging in investment activities for a particular project by assessing its investment attractiveness. Methods of assessment have been studied for a long time. For example, Pidlisna and Chepizhko (2023) evaluated investment attractiveness across various renewable energy technologies, identifying optimal approaches for capital attraction based on profitability and efficiency metrics. Building on this foundation, Trofymenko (2021) explored how innovative energy sector development intersects with fourth industrial revolution paradigms within national economic frameworks. Ukrainian researchers have simultaneously advanced economic and mathematical modeling approaches to investment analysis. Chala et al. (2021) developed statistical models for energy market evolution, while Vostriakova (2021) quantified renewable energy potential through systematic assessment methodologies.

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However, the search for new approaches remains relevant. When attracting investments, it is necessary to consider various indicators, justify their effectiveness, and determine the investment attractiveness indicator. Therefore, defining these elements correctly is crucial for making effective decisions.

Attracting investments in the renewable energy sector increases the country's competitiveness on the global stage, ensures social protection and prosperity for the population, and characterizes the development of scientific and technological progress (Boiarynova & Stepanchuk, 2023a).

To analyze the relevance of the research, we examined works that investigated the development of energy consumption from renewable sources in European Union countries regarding investments and using economic-mathematical assessment. In particular, Soava et al. (2018) studied the causal relationship between economic growth and renewable energy consumption based on data from European Union countries. The results of their research indicate the feasibility of EU countries' policy decisions to increase renewable energy consumption.

A study examining China's renewable energy sector from 1990–2020 found bidirectional causality between renewable energy investment and electricity output, with economic growth driving investment in renewables, which in turn influences green finance, though these relationships vary across different time periods (M. Li et al., 2021).

Kwilinski (2024) presents a bibliometric analysis of research on green energy and green investment connections, identifying key countries, authors, and three main scientific clusters focusing on renewable energy and sustainable development, government's role in green energy, and green investment as a catalyst for green energy expansion, ultimately highlighting new research avenues in this field.

Y. Li et al. (2022) examines China's carbon emissions from 1995–2020, finding that green energy investment and renewable energy consumption reduce emissions while economic growth and non-renewable energy increase them, with renewable energy contributing more significantly to carbon reduction than green investments due to investment lag effects, suggesting China should prioritize both renewable energy adoption and green investments to achieve carbon neutrality.

Alharbi et al. (2023) provided evidence that green finance (green bonds) significantly fosters renewable energy production. The article by Poszwa (2021) highlights that while sustainable development requires commitment from all global economic participants, enterprises can simultaneously achieve business goals and environmental protection through energy investments.

Aceleanu et al. (2018) examined the economic effect of implementing renewable energy sources in Romania, specifically investigating the untapped potential of renewable energy in rural areas.

In their article, Chatterjee and Kar (2018) applied a fuzzy numbers approach to decision-making and investigated the issue of substituting traditional energy sources with renewable sources. The authors advocate for the use of multi-criteria assessment considering subjective and objective judgments in the context of ecological, social, technical, and economic diversity.

Since 2011, Ukraine has been a member of the Energy Community (The Institute for Economic Research and Policy Consulting, n.d.), committing to support the development of

renewable energy. To achieve energy efficiency goals, Ukraine is developing and implementing effective legislative mechanisms to stimulate the creation of new projects in renewable energy sources (Ministry of Energy of Ukraine, 2022; Cabinet of Ministers of Ukraine, 2017). The rapid growth of the sector before the war necessitated scientific research into the development of renewable energy in Ukraine and issues such as "green" financing. For instance, researchers at the Ukrainian Institute of Cybernetics studied investment attraction methods different from traditional ones to align with the UN Sustainable Development Goals (Hryhorak et al., 2022). Scientists at the Ukrainian Institute for Economics and Forecasting, Diachuk et al. (2019), with the support of the Ukrainian-Danish Energy Center, developed reports on scenario energy modeling and forecasting to implement Ukraine's Energy Strategy.

In wartime conditions, it is necessary to respond quickly to changes resulting from increased risk conditions, regulatory changes, etc. Within the framework of research on the development of the renewable energy sector, Ukrainian authors conducted a series of studies. For example, Boiarynova and Stepanchuk (2023b) highlighted the prospects and significance of investment attractiveness in alternative energy. Based on the results of this research, the authors presented an economic-mathematical model of investment attractiveness for alternative energy, considering traditional approaches to its evaluation. Chernousova and Stepanchuk (2022) investigated the transition of Ukraine's energy system to the European ENTSO-E. Investment in the renewable energy sector in Ukraine through insurance against military risks was studied by Shpynta (2023), and optimal portfolio structure modeling of investment projects in the renewable energy sector was presented in collaboration with Chernousova and Shpynta (2023).

The object of the study is the investment attractiveness of renewable energy. The subject of the study encompasses theoretical and methodological provisions, methods, and models of scenario modeling for investment priorities in Ukraine's alternative energy under conditions of uncertainty, as well as practical recommendations for making economic decisions based on these models.

Research methods used during the scientific research and development of the economic-mathematical model include statistical analysis, observation, and economic-mathematical modeling.

The scientific novelty of the results consists in the further development of a multifactorial economic-mathematical model that examines the influence of factors on the choice of investment priorities for alternative energy, taking into account military risks; and improvement of methodological provisions for scenario modeling of investment priority choices for alternative energy under conditions of uncertainty.

2. Methodology and theoretical framework

The need for investments in the renewable energy sector arises not only in developed countries but also in developing ones. Investments in energy are required not only for transition but also for ensuring access to sustainable and affordable energy for all. Investment requirements extend beyond the production of "green" energy alone. Consideration should be given to the entire range of environmental factors, such as building energy efficiency, industrial and

transportation sector greening, development of energy infrastructure with storage capacity, clean fuels with low emissions, supply chain control for renewable energy, scientific research, management of mineral extraction, and production of solar panels, wind turbines, or other "green" stations (Chernousova & Stepanchuk, 2022).

Furthermore, it should be noted that investments in fossil fuel-based power stations are ongoing (Ecodiia, 2021). Investments in such assets will remain necessary for some time to provide additional capacity. Additionally, investments will be needed to improve efficiency and mitigate the emissions impact of such stations, and ultimately to decommission them.

It's important to note that besides the fact that the renewable energy market is still evolving worldwide, which may be considered inherently unstable and variable, there are also internal economic and political threats affecting investment decisions (Blank, 2000), e.g., the COVID-19 pandemic in 2020 or the full-scale invasion of Ukraine in 2022. Such uncertainty has both negative effects due to increased risks and positive effects as the economy faces significant challenges. Hence, it is necessary to present scenarios of possible development with calculated risks and outcomes under different development scenarios. Scenario modeling is utilized to address this issue (Gaspars-Wieloch, 2023).

The modern renewable energy sector in Ukraine is attractive to investors, even under uncertain conditions. The growing focus on renewable energy sources stems from two convergent global forces: the international sustainable development agenda and escalating natural resource costs.

For making investment decisions, investors assess companies on various aspects and carefully analyze indicators. Using profitability potential, investors evaluate the potential return on investment, including expected profits and the possibility of capital growth in the future. Liquidity is crucial as it impacts an investor's ability to quickly convert an investment into cash. Macroeconomic factors such as inflation, unemployment, and other macroeconomic indicators are also considered as they influence the value of investments and the overall financial climate (Soava et al., 2018).

Today, investors are not limited to standard indicators alone. Evaluating investment projects and companies based on environmental (E), social (S), and governance (G) factors has become important (Hryhorak et al., 2022). In other words, investors demand a more comprehensive approach to assessing projects and companies that takes into account their impact on the environment, compliance with corporate responsibility standards, and management practices. Consequently, a project or company should align with commitments to improve social welfare.

Russia's full-scale invasion of Ukraine has had a significant impact on the rapid development of Ukraine's renewable energy potential. According to initial estimates, the war caused the destruction of installed generating capacity and, consequently, a significant decrease in the share of renewable energy in electricity production in Ukraine. 47% of the installed capacity of renewable energy power plants is located in regions where active hostilities are or have been conducted. The vast majority of wind and solar power plants in Ukraine were built in the southern regions of the country – Zaporizhzhia, Kherson, Mykolaiv, and Odesa (Guaranteed Buyer State Enterprise [GPEE], n.d.-b). In addition, many renewable energy plants are located in areas adjacent to zones where active hostilities are taking place. The war in Ukraine has also once again raised the problematic issue of paying off the Feed-in-tariff

debt to renewable energy producers. In 2022, electricity payments were limited due to the introduction of martial law (GPEE, n.d.-a). All these factors have placed the renewable energy market in a state of uncertainty. There is no clear understanding of which area of renewable energy to invest in and continue development under the constant threat of destruction and lack of support from the state.

To establish investment priorities in renewable energy amidst uncertainty, the Fuzzy TOPSIS method has been applied. This method considers the complexity and ambiguity of decision-making, helping to find optimal solutions in conditions of uncertainty and data fuzziness. Fuzzy TOPSIS allows for the consideration of various criteria in decision-making and finding compromises among them when it is impossible to identify a single best alternative (Madi et al., 2011). This method creates a more realistic model for the decision-making process. The method involves experts evaluating criteria and alternatives using linguistic terms. By using a predefined table of term definitions, linguistic evaluations are transformed into numerical ones in the form of fuzzy triangular numbers.

3. Results of the research

During the model experiment on establishing investment priorities in Ukraine's renewable energy sector, two strategies were considered: the first strategy was traditional, while the second strategy was an ESG (Environmental, Social, and Governance) strategy.

The first, traditional strategy involves evaluating alternatives based on traditional project evaluation criteria in the renewable energy sector: installed capacity (MW), total investment (million euros), electricity purchase/sale tariff (cents/kWh), and electricity generated (million kWh).

The second, ESG strategy evaluates alternatives not only based on the mentioned criteria but also takes into account social, environmental, and governance factors. In this model, ESG criteria such as reduction of CO_2 emissions per unit of installed capacity, region security assessment, and capital investments for the continuation of existing stations' operation are considered.

Determining the investment priorities of renewable energy is based on ranking alternatives. The best alternative is considered to be the closest to the ideal solution. Thus, the higher the proximity coefficient a renewable energy station has, the higher its ranking among the alternatives (Madi et al., 2011).

We present the assessment of the criteria based on the average expert scores in Table 1. The data presented in the Table 1 represents normalized expert evaluations (0–1 scale) of energy project indicators, compiled through a multifaceted approach. The assessments were conducted by a diverse panel of specialists including industry analysts, academic researchers, technical engineers, and environmental impact assessment experts (Belousova, 2022; Energy Map, n.d.; Ministry of Energy of Ukraine, 2023; Razumkov Center, 2022; Razom We Stand, 2023). The evaluation methodology incorporated analysis of published technical reports and/or articles, review of operational data from comparable projects, examination of financial performance indicators, etc. Evaluation of alternatives under the first strategy is presented in Table 2, and the evaluation of alternatives under the second strategy is presented in Table 3 (Ecodiia, 2021; GPEE, n.d.-a; NPC UKRENERGO, 2021).

Table 1. Average expert scores (source: compiled on the basis of the author's own research)

Group	Score
Installed capacity, MW	0.50
Total investments, EUR million	0.50
Weighted average tariff kopecks/kWh	0.09
Electricity generated, mln kWh	0.5
Feed-in tariff, kopecks	0.41
Reduction of CO2 emissions (E)	0.6
Regional security assessment (S)	0.7
Capital investments for continued operation (G), million euros	0.2

Table 2. Evaluation of alternatives under the first strategy (source: compiled on the basis of the author's own research)

Group	SPP	WPP	mHPP	Biomass	Biogas
Commissioned capacity, MW	222	299.00	1.00	6.00	3.00
Total investments, EUR million	147.90	367.24	1.68	9.33	3.91
Weighted average tariff kopecks/kWh	259.06	141.03	9.73	20.34	11.94
Electricity generated, mln kWh	6429.68	3804.17	267.32	553.25	387.98
Feed-in tariff, kopecks	1.95	1.68	2.59	2.30	2.30

Table 3. Evaluation of alternatives under the second strategy (source: compiled on the basis of the author's own research)

Group	SPP	WPP	mHPP	Biomass	Biogas
Commissioned capacity, MW	222	299.00	1.00	6.00	3.00
Total investments, EUR million	147.90	367.24	1.68	9.33	3.91
Weighted average tariff kopecks/kWh	259.06	141.03	9.73	20.34	11.94
Electricity generated, mln kWh	6429.68	3804.17	267.32	553.25	387.98
Feed-in tariff, kopecks	1.95	1.68	2.59	2.30	2.30
Reduction of CO_2 emissions (E)	106	200	104	230	203
Regional security assessment (S)	1	1	3	2	2
Capital investments for continued operation (G), million euros	5.3	10.2	1.3	7.8	3.4

The data are highly heterogeneous both in relation to the criteria and to the alternatives, so an important step in building the model is to normalize the data. This normalization process mitigates the influence of extreme outliers within heterogeneous datasets while establishing a uniform measurement scale ($N_{a_{ij}}$). To represent the evaluation of alternatives in a fuzzy triangular form, let's create a table of linguistic terms that will be determined by the critical values of the evaluation of alternatives for each criterion (Table 4).

Table 4. Linguistic terms (source: compiled on the basis of the author's own research)

Very poor			Poor			Acceptable			Good			Very good		
0	0.1	0.3	0.1	0.3	0.5	0.3	0.5	0.7	0.5	0.7	0.9	0.7	0.9	1

In the model built, it should be assumed that the values of the criteria for both the first and second strategies should tend to the maximum. To determine the critical values of the evaluation of alternatives for each criterion, the normalized sample should be conditionally divided into five segments. If the score falls into one of the segments, it will be evaluated by the corresponding linguistic term, which can then be translated into a numerical representation in the form of fuzzy triangular numbers.

After averaging, normalizing, and converting the scores of alternatives and criteria into fuzzy triangular numbers, it is necessary to construct a matrix of weighted scores of alternatives $\left(W_{a_{ij}}\right)$. In order to determine the investment priorities of renewable energy in Ukraine, i.e., to determine the rank of each type of RES power plant under study, it is necessary to find an ideal fuzzy positive $\left(W_{a_i}^{+}\right)$ and negative $\left(W_{a_i}^{-}\right)$ solutions for each criterion. The next step is to calculate the distance to the ideal solution. This can be done by calculating the Euclidean distance $\left(d_{a_{ij}}^{+} / d_{a_{ij}}^{-}\right)$.

The final step involves calculating proximity coefficients that measure how closely each alternative's weighted assessment aligns with ideal positive or negative solutions, thereby enabling comprehensive alternative ranking.

Thus, a model representation of the problem of setting investment priorities for renewable energy under conditions of uncertainty:

$$C_j = \frac{\sum_j d^{-}{}_{a_{ij}}}{\sum_j d^{-}{}_{a_{ij}} + d^{+}{}_{a_{ij}}}, d^{+}{}_{a_{ij}} = d\left(W_{a_i}^{+}, W_{a_{ij}}\right) = \sqrt{\frac{\left(W_{a_{ij}}{}^{k} - W_{a_i}^{+}\right)^2 + \left(W_{a_{ij}}{}^{l} - W_{a_i}^{+}\right)^2 + \left(W_{a_{ij}}{}^{m} - W_{a_i}^{+}\right)^2}{3}},$$

$$d^{-}{}_{a_{ij}} = d\left(W_{a_i}^{-}, W_{a_{ij}}\right) = \sqrt{\frac{\left(W_{a_{ij}}{}^{k} - W_{a_i}^{-}\right)^2 + \left(W_{a_{ij}}{}^{l} - W_{a_i}^{-}\right)^2 + \left(W_{a_{ij}}{}^{m} - W_{a_i}^{-}\right)^2}{3}},$$

$$W_{a_i}^{+} = \max_i\left(W_{a_{ij}}\right), W_{a_i}^{-} = \min_i\left(W_{a_{ij}}\right) W_{a_{ij}} = AV_{cr_i} \cdot N_{a_{ij}},\ N_{a_{ij}} = \frac{a_{ij} - \underline{a_{ij}}}{\widehat{a_{ij}}}. \quad (1)$$

For further evaluation of the investment attractiveness of the identified priorities, a multifactor model for assessing investment attractiveness using the method of integral assessment was constructed. This model is based on four main indicators: development prospects ($ratio_1$), return on equity of enterprises ($ratio_2$), level of inflation stability in industry prices ($ratio_3$), and industry-specific risks ($ratio_4$) (Boiarynova & Stepanchuk, 2023a).

The industry's development prospects are characterized by two indicators: the significance of the industry – the share of electricity production from stations operating on renewable energy sources ($Prodution_t$, MWh) in the country's GDP (GDP_t, million UAH), and the industry's provision – the volume of investments in renewable energy ($investments_t$, million euros) per unit of installed capacity ($capacity_t$, MW). The profitability of equity capital is characterized by the average profitability level of enterprises in the industry (ror_t). The level of inflation

stability shows the ratio of the purchase/sale price of electricity ($cost_t$, UAH/MWh) to the inflation index in Ukraine (inf_index_t). Industry-specific risks take into account the share of damage to installed capacity ($damage_j$) and an expert assessment of the region's security ($region_i$).

$$I_ratio_t = w_0 \left(\frac{ratio_1(t)}{ratio_1(t-1)}\right)^{w_1} \left(\frac{ratio_2(t)}{ratio_2(t-1)}\right)^{w_2} \left(\frac{ratio_3(t)}{ratio_3(t-1)}\right)^{w_3} \left(\frac{ratio_4(t)}{ratio_4(t-1)}\right)^{w_4} ratio_1(t) =$$

$$\frac{Production_t}{GDP_t} ratio_2(t) = \frac{Ind_c_t Capacity_{t-1}}{inv_t} ratio_3(t) = \frac{Cost_t}{Infl_t} ratio_4(t) = region_i Capacity_t damage_j. \quad (2)$$

4. Discussion and interpretation of results obtained

The modeling experiment to determine the investment priorities of alternative energy begins with the normalization of alternative assessments (Table 5). Mean values and standard deviations for alternative evaluations across each criterion were computed using MS Excel. The following calculations demonstrate implementation of the first strategy, representing the traditional approach.

Table 5. Matrix of normalized scores of alternatives (RES power plants) under the first strategy

Group	SPP	WPP	mHPP	Biomass	Biogas
Commissioned capacity, MW	0.81	1.34	–0.73	–0.70	–0.72
Total investments, EUR million	0.26	1.65	–0.66	–0.61	–0.64
Weighted average tariff kopecks/kWh	1.55	0.48	–0.71	–0.62	–0.69
Electricity generated, mln kWh	1.51	0.55	–0.74	–0.63	–0.69
Feed-in tariff, kopecks	–0.61	–1.37	1.21	0.39	0.39

Investment prioritization in renewable energy employs alternative ranking methodologies where optimal solutions are identified through proximity analysis to ideal solutions. Renewable energy stations achieving higher proximity coefficients secure superior rankings, reflecting their closer alignment with optimal investment criteria. The proximity coefficient, calculated via Eq. (1), represents the ratio of distances from negative ideal solutions to the total distances across all RES. These indicators were used to rank the alternatives. The results under the first strategy are presented in Table 6.

Table 6. Proximity coefficient and ranking of renewable energy plants under the first strategy (source: compiled on the basis of the author's own research)

Ranking of RES stations		
RES stations	Proximity coefficient	Rank
Solar power plants	0.701	1
Wind power plants	0.695	2
Small hydroelectric power plants	0.338	5
Biomass power plants	0.590	3
Biogas power plants	0.444	4

Let's make calculations for the second, ESG strategy. The second strategy incorporates factors related to the environmental, social, or governance components of enterprises' activities (Table 7). The assessment of the CO_2 emissions reduction criterion was carried out using examples of specific plants of each type per 100 MW of installed capacity.

Solar power plants are mostly located in Dnipro, Mykolaiv, and Odesa regions, which indicates a high level of risk. Wind power plants are located in Kherson, Zaporizhzhia, and Mykolaiv regions, which also indicates a high risk (European-Ukrainian Energy Agency, 2021). For small hydropower plants, the regions include Kirovohrad, Vinnytsia, and Khmelnytskyi, which indicates low to medium risk. Biogas and biomass plants are located in Kirovohrad, Vinnytsia, and Dnipro regions, so they are at medium risk (Ukrainian Union of Industrialists and Entrepreneurs, n.d.).

The results under the second strategy are presented in Table 8.

Table 7. Matrix of normalized scores of RES power plants according to ESG criteria

Group	SPP	WPP	mHPP	Biomass	Biogas
Reduction of CO2 emissions (E)	–1.06	0.53	–1.09	1.04	0.58
Regional security assessment (S)	–0.96	–0.96	1.43	0.24	0.24
Capital investments for continued operation (G), million euros	–0.09	1.31	–1.22	0.63	–0.63

Table 8. Proximity coefficient and ranking of renewable energy plants under the second strategy (source: compiled on the basis of the author's own research)

Ranking of RES stations		
RES stations	Proximity coefficient	Rank
Solar power plants	0.594	3
Wind power plants	0.655	2
Small hydroelectric power plants	0.363	5
Biomass power plants	0.659	1
Biogas power plants	0.502	4

Based on the results of the conducted model experiment to determine investment priorities, it has been determined that under the traditional scenario, priority is given to solar power plants, while under the ESG (Environmental, Social, Governance) strategy, priority is given to biomass power plants.

Table 9 presents the dynamic of solar power plant factors changes throughout the forecast period from March 2022 to April 2024 (Stepanchuk, 2024). The declining purchase/sale price trajectory represents a critical economic challenge for renewable energy producers, as reduced energy payments during economic crises undermine the financial viability necessary for sustained plant development. Consumer price index and GDP demonstrate inverse correlation patterns, with inflationary pressures typically corresponding to GDP contraction, while deflationary periods coincide with economic growth. War-related risks have precipitated substantial declines in both capacity expansion and production levels, with investment flows

experiencing parallel deterioration. Military activities, including targeted shelling and ongoing hostilities, impede new capacity development while simultaneously destroying existing infrastructure, fundamentally undermining investor confidence (Ministry of Energy of Ukraine, 2023). War risk assessments incorporate documented destruction levels, existing installed capacity, and regional security evaluations to quantify associated losses.

Table 9. Assessment of factors for solar power plants, May 2023–April 2024 (source: compiled on the basis of the author's own research)

CPI	Price, UAH/mW	Demand, MWh	Capacity growth rate	Production, MWh	GDP, UAH million.	Investments, EUR million	Losses from war risks
1.01	1756.93	3261.12	0.90	60869.74	1499055.79	0.56	419.71
1.01	1480.25	1836.92	0.90	59291.87	1469074.68	0.56	378.82
0.99	1131.18	1289.62	0.90	57695.05	1439693.18	0.56	341.90
0.99	959.59	1087.52	0.90	56106.70	1410899.32	0.56	308.57
1.01	1210.15	1137.58	0.90	54557.65	1382681.33	0.56	278.48
1.01	1349.72	1419.13	0.90	53056.34	1355027.71	0.56	251.32
1.01	1315.25	1425.59	0.90	51583.81	1327927.15	0.56	226.80
1.01	1416.37	1680.17	0.90	50158.41	1301368.61	0.56	204.67
1.01	1379.38	1499.69	0.90	48754.34	1275341.24	0.56	184.70
1.01	1385.80	1460.88	0.90	47381.16	1249834.41	0.56	166.67
1.01	1476.04	1678.01	0.90	46054.97	1224837.72	0.56	150.39
1.01	1543.69	1836.06	0.90	44771.91	1200340.97	0.56	135.70

Table 10 shows the dynamics of changes in the factors for biomass power plants over the forecast period from March 2022 to April 2024 (Stepanchuk, 2024). Despite the decrease in capacity and demand, the table shows that the purchase/sale price is quite variable and seasonal. From an economic perspective, this variability may be attributed to biomass plants becoming an alternative to other types of power plants in the face of increased military threats. Consequently, prices have increased to meet demand. According to the modeling results, there is an increase in production from renewable energy plants, which can be explained similarly. Due to this increased production, the value of GDP has risen despite growing inflation (consumer price index), indicating a positive effect from utilizing biomass plants. However, in line with military risks, the volume of investment is decreasing.

Used the investment attractiveness model (3) to evaluate solar and biomass power plants on a monthly basis (Stepanchuk, 2024). The results are shown in Table 11.

$$I_ratio_t = 0.65\left(\frac{ratio_1(t)}{ratio_1(t-1)}\right)^{-0.02}\left(\frac{ratio_2(t)}{ratio_2(t-1)}\right)^{1.22}\left(\frac{ratio_3(t)}{ratio_3(t-1)}\right)^{0.08}\left(\frac{ratio_4(t)}{ratio_4(t-1)}\right)^{0.003}. \quad (3)$$

The assessment of investment attractiveness for solar power plants is more stable but also shows a downward trend. Due to high military risks for this type of plant, capacity tends to decrease, which is clearly a negative consequence, though the industry remains generally well-supplied. For biomass power plants, we observe a slight, seasonal decrease, primarily caused by reduced industry supply levels and increased military risks for these facilities.

Table 10. Assessment of factors for biomass power plants, May 2023–April 2024

CPI	Price, UAH/mW	Demand, MWh	Capacity growth rate	Production, MWh	GDP, UAH million.	Investments, EUR million	Losses from war risks
1.01	1853.94	31663.27	0.84	17722.67	1499055.79	1.07	2.52
1.01	1831.04	39965.38	0.83	19285.35	1469074.68	1.06	2.14
0.99	1967.73	38660.18	0.83	20813.57	1439693.18	1.06	1.79
0.99	1409.26	41176.66	0.82	22443.23	1410899.32	1.05	1.49
1.01	2184.99	28980.52	0.81	23650.74	1382681.33	1.04	1.23
1.01	1893.87	27766.68	0.81	24824.27	1355027.71	1.03	1.01
1.01	1927.79	25599.94	0.80	25929.61	1327927.15	1.02	0.82
1.01	2156.61	26462.57	0.79	27074.27	1301368.61	1.01	0.66
1.01	1316.37	27401.77	0.79	28261.18	1275341.24	1.00	0.53
1.01	1669.09	28593.00	0.78	29499.78	1249834.41	0.99	0.42
1.01	2572.83	20970.31	0.77	30476.29	1224837.72	0.99	0.33
1.01	1102.24	32544.99	0.77	31872.87	1200340.97	0.98	0.25

Table 11. Assessment of investment attractiveness of solar and biomass power plants, May 2023–April 2024

SPP					Biomass				
Ratio 1	Ratio 2	Ratio 3	Ratio 4	**I_ratio**	Ratio 1	Ratio 2	Ratio 3	Ratio 4	**I_ratio**
1.00	0.83	1.30	0.90	**0.52**	1.11	0.85	0.36	0.86	**0.50**
0.99	0.83	0.84	0.90	**0.51**	1.10	0.85	1.94	0.85	**0.55**
0.99	0.83	0.77	0.90	**0.51**	1.11	0.84	0.98	0.85	**0.52**
0.99	0.83	0.86	0.90	**0.51**	1.10	0.83	1.09	0.84	**0.52**
0.99	0.83	1.24	0.90	**0.52**	1.10	0.83	0.72	0.83	**0.50**
0.99	0.83	1.11	0.90	**0.52**	1.08	0.82	1.52	0.83	**0.52**
0.99	0.83	0.98	0.90	**0.51**	1.07	0.81	0.86	0.82	**0.50**
0.99	0.83	1.08	0.90	**0.52**	1.07	0.81	1.02	0.81	**0.50**
0.99	0.83	0.97	0.90	**0.51**	1.07	0.80	1.12	0.81	**0.49**
0.99	0.83	1.00	0.90	**0.51**	1.07	0.79	0.61	0.80	**0.47**
0.99	0.83	1.06	0.90	**0.52**	1.07	0.79	1.27	0.79	**0.49**

5. Conclusions

In our research, we analyzed the development of renewable energy in Ukraine while accounting for military risks. We recognize that attracting investment contributes significantly to renewable energy development in Ukraine. Therefore, our article explores how to determine investment priorities using fuzzy logic and econometric methods to model the investment attractiveness of renewable energy in Ukraine.

To determine investment priorities, we applied two strategies: the traditional strategy and the ESG (Environmental, Social, Governance) strategy. The traditional strategy adopts a basic objective approach to evaluate different power plant types based on installed capacity, investment volume, weighted average tariff, and energy production volume. The ESG strategy

incorporates modern trends by including subjective, non-measurable indicators of social, environmental, and governance factors. Specifically, this approach considers CO_2 emissions reduction per unit of installed capacity, regional security assessment, and capital investments for extending the operation of existing stations.

Our evaluation of investment priorities revealed that under the traditional strategy, solar power plants are prioritized, while under the ESG strategy, biomass stations take precedence. In the context of increased risk due to military actions in Ukraine, these results can be explained by the geographical location of the stations. Solar power plants are predominantly located in southern Ukraine, increasing their exposure to combat consequences, whereas biomass stations are evenly distributed across the country. Another factor is Ukraine's high level of generation and utilization of agricultural residues. Consequently, Ukraine can meet its renewable energy demand, particularly for biomass, while potentially exporting surplus resources.

Based on our modeling of factors affecting production, assessment of subsector investment attractiveness, and evaluation of investment priorities, we conclude that biomass power plants represent the investment priority for Ukraine's alternative energy sector under conditions of uncertainty. Beyond production sustainability in changing market conditions and high integrated investment attractiveness scores, the biofuel subsector demonstrates environmental, social, and governance sustainability – key factors that foreign investors consider when evaluating investment projects.

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