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Methodology for Assessing Financial Results of Implementation of Energy Innovations Depending on their Progressiveness

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ABSTRACT

The purpose of this article is to develop a methodology that can be used for an objective assessment of financial results and to support managerial decision-making regarding the implementation of energy innovations. The methodology is developed using an interdisciplinary approach and is based on the fuzzy logic theory and method, which allows converting expert judgments and qualitative assessments into final quantitative indicators with some degree of confidence. The methodology includes five input variables that form a fuzzy set "progressivity versus regressivity of energy innovations." The article considers the main criteria based on which an energy innovation can be classified as technologically progressive or regressive. The article demonstrates the efficiency of the developed methodology drawing on the example of two projects for the implementation of energy innovations. The data obtained have shown that one of the innovations can be considered conditionally technologically progressive only by 46%, while the second is certainly technologically progressive by 92%. The conducted correction of the basic financial results allows demonstrating that the implementation project of a conditionally technologically progressive innovation is not cost-effective and requires an increase in capital expenditures or a reduction in expected revenues since it requires a balanced assessment of the feasibility of implementing innovation.

Keywords: Energy Innovations, Financial Results, Fuzzy logic Algorithms, Decision-Making, Assessment Methodology, Project Management
JEL Classifications: D70, O13, Q40, O32

1. INTRODUCTION

One of the constant trends of the current century is the transition from fossil to renewable energy. And this is certainly one of the most important trends that will ensure the preservation of contemporary civilization since such a transition helps to reduce the carbon footprint left by human activities.

But the global energy system still faces a threefold task. Firstly, the energy sector should fully meet the needs of private and corporate consumers in energy resources (electricity, thermal energy, motor fuel, etc.). Secondly, energy resources should be available to consumers both physically and economically. Thirdly, an increase in the availability of energy resources that meet the corresponding needs of various actors simultaneously leads to an increase in the negative anthropogenic impact on the environment, and this sparks a natural political and economic interest in renewable energy (HSE, 2016; Deloitte, 2018).

The transition to renewable energy is only one of the necessary steps towards reducing the rate of global warming, and therefore energy innovations should be considered as a way, means, or tool to solve the problem of global warming and reduce the harmful anthropogenic impact on the environment. At the same time, it should be emphasized that not all innovative solutions in the energy sector will contribute to solving this problem since more and more scientific studies and data indicate that energy innovations can be both progressive, environmentally friendly, or, at least, conditionally friendly, and regressive, i.e. environmentally harmful. But this circumstance is not always reflected correctly in the decisions taken at the macro- and microeconomic level (Fri, and Savitz, 2014; Polzin, 2017). Over the past two decades, energy innovations designed to ensure the abandonment of the use of fossil fuels (primarily, hydrocarbons and produced corresponding fuel and energy resources) have demonstrated significant progress in their spread around the world. This is also due to the following (Fri and Savitz, 2014; Polzin, 2017; Alam and Murad, 2020):

1) Reducing the cost of renewable energy production, i.e. increasing its economic accessibility for consumers;
2) Subsidizing and supporting renewable energy at the level of national governments;
3) Diffusing technologies that make renewable energy also physically accessible to consumers in various regions of the world.

However, the problem of an objective assessment of the financial and environmental consequences of energy innovations that mediate the abandonment of fossil fuels and resources still persists. The reason is that there is still no consensus on two important issues:

(a) How to classify energy innovations in terms of their impact on the environment in the medium and long term;
(b) How to assess the feasibility of implementing certain energy innovations and, first of all, renewable energy technologies, considering both financial and environmental discounting of their usefulness.

This article attempts to present a theoretical classification of energy innovations in terms of medium- and long-term environmental and other consequences of their practical implementation. Moreover, the article attempts to develop a scalable methodology for financial and environmental assessment, designed to show the feasibility of implementing energy innovations, namely, the efficiency and environmental friendliness of current use, as well as the usefulness and harmlessness of use in the future.

Considering the research objective, the present article has the following structure, which specifies the particular research tasks:

(1) An introduction that justifies the relevance of the study and reflects the target orientation;
(2) A literature review, in which a theoretical classification of energy innovations is given;
(3) Data and methodology, reflecting the developed financial and environmental assessment method of energy innovations;
(4) Results and conclusion, which present the results of testing the methodology and conclusions regarding its further practical application.

2. LITERATURE REVIEW

Many scientific works are devoted to various theoretical and methodological aspects of the study of the essence and content, as well as the value and significance of energy innovations. According to *Google Scholar* indexing, only for the period from the beginning of 2020 to the middle of 2021, more than 130 thousand scientific articles were published in English, in which significant problems are discussed, such as:

1) The impact of energy innovations on the quality of the environment and the significance of globalization processes in this context (Baloch et al., 2021; Pless et al., 2020);
2) The impact of energy innovations on the activities of farmers in particular and on food security in general (Avgoustaki and Xydis, 2020);
3) The state of innovation activity in the energy sector with regard to the political decisions taken in the field of public administration (Ali et al., 2020);
4) Assessment of the effectiveness of reducing various costs associated with the implementation of energy innovations in the field of renewable energy (Elia et al., 2020).

Despite the existence of a large scientific, theoretical and methodological base on the energy innovations issue, research in this area does not stop. At the same time, it is necessary to draw attention to the following main points.

First, energy innovations are not always and in all cases focused on reducing the consumption of fossil fuels, and also they are not always safe for the environment and future generations. For example, underground mining and the subsequent use of coal in the energy supply of private or corporate consumers is a serious environmental problem. At the same time, the proposed solutions in the field of mothballing already spent coal mines with various grouting solutions and waste rock cannot be considered an innovative and progressive solution, since the carbon footprint from the extraction and use of hard or brown coal in the energy sector is one of the largest. Therefore, it is advisable to completely abandon such an energy carrier, especially since the restoration of land and forests after the mothballing of coal mines is quite slow (relative to human life, on average about 60 years) (Buzylo et al., 2020; Motosugi et al., 2021).

A similar problem occurs with regard to the production of unconventional hydrocarbons (shale oil and gas, oil and gas of the northern shelves and the northern seas) (Shcherba et al., 2019; Crépin et al., 2017). But it is unlikely that the problems of climate change in the Arctic, as well as land, water, and air pollution in shale provinces, can be solved by improving extraction technologies of unconventional hydrocarbons, especially since, for example, the risks of Arctic production are associated not only with climate change in the region itself but also globally (Wieder et al., 2019). This problem lies in the fact that the Arctic, as the "climate laboratory" of the entire planet, retains methane accumulated in the bowels due to the ice cover. Global warming, which leads to the melting of ice, releases accumulated methane, which results in the strengthening of the greenhouse effect on the planet (Laufkötter et al., 2020). This leads not only to environmental but also to political, economic (Diffenbaugh and Burke, 2019), and even neurophysiological consequences (Ahima, 2020).

Another significant problem related to various long-term environmental consequences associated with energy innovations is associated with the nuclear power industry. Undoubtedly, using nuclear fission technologies will allow many countries that do not have other, including fossil sources of energy resources, to show significant economic growth and sustainable social development, in particular, countries such as Japan, China, South Korea, some European countries (France, Ukraine, Slovakia, and Hungary).

With the proper operation, nuclear power plants leave a smaller carbon footprint, do not increase the anthropogenic and technogenic load on the environment, and in the standard operating mode do not increase the usual economic risks in the field of energy supply, providing consumers with various types of energy (thermal and electric) (Prăvălie and Bandoc, 2018). At that, risks arise only in the case of:

(a) Violations of energy production technologies from nuclear fuel (in this case, the issue concerns the energy resulted from nuclear fission, i.e. nuclear fission);
(b) Physical destruction of the power units of nuclear power plants, due to various disasters;
(c) Violations of technologies for decontamination and disposal of spent nuclear fuel waste.

At that, the probability of radiation accidents is several orders of magnitude lower than the probability of a spill of oil and petroleum products, and large leaks of natural gas (methane). To date, only 23 radiation accidents, recorded by the IAEA, have occurred in the recent history of mankind (International Atomic Energy Agency, 2021), but thousands of man-made and technogenic accidents occur annually worldwide at the production sites of conventional and non-conventional hydrocarbons, not counting accidents that occur during their transportation or operation by the final consumer. But the degree and amount of damage from a single radiation accident are several orders of magnitude greater than the damage from accidents related to the operation of other energy sources, energy carriers, or final energy products. Therefore, firstly, it is advisable to change the management approaches to the operation of existing nuclear power plants, which necessitates (Velikhov et al., 2019):

(a) Further research in the field of creating barriers that would prevent the release of radioactivity from reactors damaged as a result of disasters or other events;
(b) Further research on creating technologies for the effective disposal or reuse of spent nuclear fuel extracted from reactors operating on nuclear fission.

Secondly, it is advisable to strengthen the financing of projects in which nuclear fission reactors will be replaced by controlled nuclear fusion reactors. Besides, it should be taken into account that the resource base of natural uranium, i.e. the main element of nuclear reactors is still limited, and, therefore, it is already advisable to think about abandoning large nuclear and centralized generation at nuclear power plants in favor of small and distributed generation, which can be based on both nuclear fission reactions and nuclear fusion reactions (Velikhov et al., 2019), as well as recycling or reuse of spent nuclear fuel (Antipin et al., 2018; Sadekin et al., 2019).

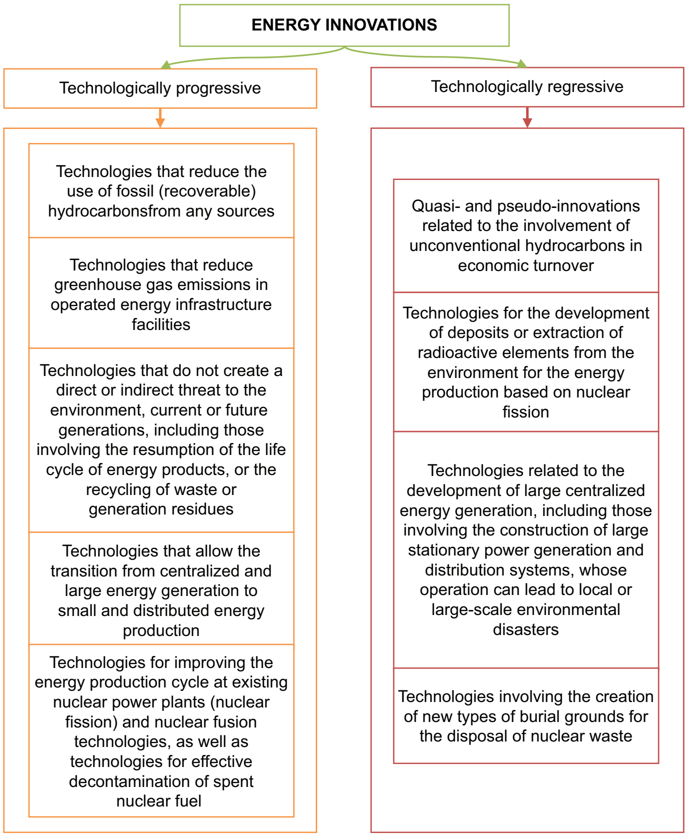
Considering the above, we believe that the theoretical classification scheme of energy innovations in terms of environmental harm, carbon footprint, and safety for current and future generations can be presented as shown in Figure 1.

3. MATERIALS AND METHODS

The methodological basis of the present article is an interdisciplinary approach that combines econometrics, statistics, financial mathematics, as well as analysis of innovations and investments. There are many options for the financial and environmental assessment of energy innovations, but at the same time, almost all of them are reduced to the analysis and probability of damage that will be caused (or, on the contrary, will be eliminated) using certain technologies (Lorente and Alvarez-Herranz, 2016; Balsalobre-Lorente et al., 2019; Baloch et al., 2021; Sinha et al., 2020; Dudin et al., 2020). The assessment of damage and the probability of occurrence or its elimination is certainly an important component of the methods of analysis, the effectiveness of the implementation of certain energy innovations. However, not in all cases, the indicators used for analysis and assessment can be expressed in the form of quantitative or cost values, and their ratios, especially since it is difficult to do this when it comes to the future value of energy innovations and their discounting over time.

In other words, clear econometric and financial-mathematical approaches cannot always give an adequate answer to the question of the future value of energy innovations, considering the economic factor. Therefore, it is advisable to use different assessment and analytical tools here, which are based on fuzzy logic, whose theory and methodology were outlined by Zadeh in the 1970s (Zadeh, 1988). The idea of fuzzy logical analysis algorithms consists in bringing the evaluative judgments of experts (i.e. expressed

Figure 1: Theoretical classification of energy innovations for financial and environmental assessment of the feasibility of their implementation [compiled by the authors]



linguistically, without using specific numerical values or variables) regarding specific absolute or relative indicators that will allow answering the question, provide support for making a certain decision, etc (McNeill and Thro, 1993).

The basics of the methodology of fuzzy logic algorithms are described not only in the early and later works of Zadeh (Yager and Zadeh, 2012) but also in other scientific studies on this topic (Kosko and Toms, 2014). Therefore, we will not dwell on this issue in detail, limiting ourselves only to the presentation of the fundamental formulas describing the methodological approach to the analysis of fuzzy sets, which are the research subject within the framework of the fuzzy logic theory.

So, a fuzzy set is a certain set of elements (*x*), with respect to which it is not known exactly whether they have any characteristic property described by the membership function (), to form a fuzzy set (*A*) and a subset (S_A), included in the universal set (*X*):

$$A = \frac{\mu_A x}{x} \tag{1}$$

$$S_A = \left(x|x \right) \grave{o} X \cap \mu_A x > 0 \tag{2}$$

Based on these aspects of the theory and practice of energy innovations, Table 1 describes the variables that, as we believe, it is correct to include in the fuzzy set “progressivity *vs* regressivity of energy innovations” for the financial and environmental assessment of the latter.

Further, to avoid complex fuzzification and defuzzification procedures, we will determine the input values of the above variables, which can be calculated using formula-mathematical apparatus, specially created by the author.

For the variable x_1 or the environmental harmlessness (friendliness) indicator of energy innovation, we propose to use a modified carbon factor, i.e. the ratio of the volume of carbon dioxide emissions in tons (tons of CO_2 – tCO_2) to the volume of energy product generated based on the implemented innovation (tons of oil equivalent – *toe*):

$$x_1 = 1 - \frac{tCO_2}{toe} \tag{3}$$

In case, if the estimated value of the variable x_1 is negative, it will be assigned a null value $x_1=0$, and hence energy innovation is environmentally harmful, and respectively, technologically regressive. Therefore, it would make sense to give up its analysis and evaluation already at this stage.

Variable x_2 or energy innovation safety indicator for future generations is to be calculated as the ratio of the specific weight of recycling of waste or residue generation after the completion of the life cycle energy of the product (*r*), created based on innovation, to the magnitude of the threat to future generations, expressed in points (s_t), where:

- One point means that the threat does not exist, no burying waste or residue generation and constant monitoring of burial is required;

Table 1: Variables, included in the fuzzy set “progressivity *vs* regressivity of energy innovations” [compiled by the authors]

Name of the variable	Linguistic description of the variable
(1) Environmental harmlessness (friendliness, x1)	The technology created within the framework of energy innovation should be characterized by a small carbon footprint, should not create a greenhouse effect or the prerequisites for its occurrence
(2) Security for current and future generations (x2)	The technology, created within the framework of energy innovation should not increase environmental pollution and at the same time: (a) Should provide a possibility of full or maximum utilization/recycling of waste or generation residues after the end of the life cycle of the energy product; (b) Should allow abandoning the need to bury waste or generation residues, as well as to maintain burial grounds in proper condition after the completion of the life cycle of the energy product.
(3) Accessibility for private and corporate consumers (x3)	The technology created within the framework of energy innovation should be characterized by: (a) Physical accessibility for consumers, i.e., there should be an uninterrupted flow of energy goods produced based on technology to the places of their consumption in volumes sufficient to meet demand; (b) Economic accessibility for consumers, i.e., there should be an opportunity to purchase energy goods at market prices in the volumes that correspond to the rational norms of energy supply for the activities of a person or organization
(4) Benefits for generating companies (holdings or industries, x4)	The technology created within the framework of energy innovation should be characterized by sustainable financial and economic benefits for generating companies, i.e., using technology for commercial purposes should bring companies income, profit, value-added growth, and the state should increase tax revenues to the budget and/or extra-budgetary funds
(5) The potential for technological improvement (x5)	The technology created within the framework of energy innovation should be characterized by the ability to change and technological improvement. At that, such improvement should not require creating a new operational, distribution, or generating infrastructure

- Two points mean that there is a threat since it is necessary to bury waste or generation residues but there is no need for constant monitoring of burial grounds;
- Three points mean that the threat is significantly pronounced, since it is necessary to bury waste or generation residues, and at the same time constant monitoring of burial grounds is required.

Then the formula for calculating the variable x_2 takes the following form:

$$x_2 = \frac{r}{s_t} \tag{4}$$

The variable x_3 or the availability indicator of energy products created as a result of innovation for private and corporate consumers will be calculated as two integrated ratios.

The first ratio will reflect the physical supply of an energy commodity to its demand (*pa*). The second ratio will reflect the unit average price of energy goods, produced based on innovation, to the average price of the most popular or the most affordable energy product, already available on the market (*ea*):

$$x_3 = \sqrt{pa * ea} \tag{5}$$

In that case, if one of the ratios will have a basic value >1, then to calculate the variable x_3 it should be taken equal to unity, i.e., $pa\,(ea) \leq 1$.

The variable x_4 or the indicator of generating company benefit can be expressed by the usual discounted index of return on investment in energy innovations (the ratio of the discounted amount of capital invested in innovations to the net present income – *PI*). Or, if the assessment is carried out in favor of the state, then the budget efficiency index should be taken into account (the ratio of the volume of public expenditures on energy innovations to the discounted volume of expected tax revenues to the budget from the sale of energy goods created employing innovation – *BI*).

The variable x_5 or the indicator of the technological improvement potential of an energy product or the innovation underlying can be expressed as a natural logarithm of the quantity (1) or (2):

- ln_1 – If the potential for technological improvement is implicit, absent, or requires excessively high costs;
- ln_2 – If the potential for technological improvement is objectively possible and does not require excessively high costs.

Thus, the fuzzy set "progressivity *vs* regressivity of energy innovations" (*A[p;r]*) takes the form:

$$A[p;r] \rightarrow \bigcup [x_1; x_2; x_3; x_4; x_5] \tag{6}$$

Each variable ($x_{1.2.3.4.5}$) in the fuzzy set (*A[p;r]*) can change from zero to one, therefore, it can be assigned to one of the subsets of S_A according to the gradation presented in Table 2.

Subsets of variables (x_i) in a fuzzy set (*A[p;r]*) intersect with each other. Therefore, it is necessary to determine the membership of each variable to each of the subsets using the membership function. To do this, we propose to distinguish ten levels of variable change in five main subsets (Table 3).

Table 2: Gradation of subsets in a fuzzy set "progressiveness *vs* regressivity of energy innovations" (*A[p; r]*) [compiled by the authors]

Subset	Variables (x_i)
Subset of very low-level variables (S_{A1})	0.0
	0.05
	0.10
Subset of very low and low-level variables ($S_{A1.2}$)	0.15
	0.20
	0.25
Subset of low- and below average-level variables ($S_{A2.3}$)	0.30
	0.35
	0.40
Subset of average-level variables (S_{A3})	0.45
	0.50
	0.55
Subset of variables above the average and high level ($S_{A3.4}$)	0.60
	0.65
	0.70
Subset of high- and very high-level variables ($S_{A4.5}$)	0.75
	0.80
	0.85
Subset of very high-level variables (S_{A5})	0.90
	0.95
	1.00

Table 3: Scheme for calculating the membership of each variable (x_i) to a subset (S_{Ai}) in a fuzzy set "progressivity *vs* regressivity of energy innovations" (*A[p; r]*) [compiled by the authors]

Variables (x_i)	Subsets of variables with gradation by level	Variable membership function (*fa*)
$0<(x_i)<0.05$ $0<(x_i)<0.1$	Subset of very low-level variables	$fa=1$
$0.1<(x_i)<0.15$	Subset of very low-level variables	$fa_1=10*(0.15-x_i)$
$0.1<(x_i)<0.15$	Subset of low-level variables	$fa_2=1-fa_1$
$0.15<(x_i)<0.25$	Subset of low-level variables	$f=1$
$0.25<(x_i)<0.35$	Subset of low-level variables	$fa_2=10*(0.35-x_i)$
$0.25<(x_i)<0.35$	Subset of average-level variables	$fa_3=1-fa_2$
$0.35<(x_i)<0.45$	Subset of average-level variables	$fa=1$
$0.45<(x_i)<0.55$	Subset of average-level variables	$fa_3=10*(0.55-x_i)$
$0.45<(x_i)<0.55$	Subset of average- and high-level variables	$fa_4=1-fa_3$
$0.5<(x_i)<0.6$	Subset of average- and high-level variables	$fa=1$
$0.6<(x_i)<0.7$	Subset of high-level variables	$fa_4=10*(0.7-x_i)$
$0.6<(x_i)<0.7$	Subset of high- and very high-level variables	$fa_5=1-fa_4$
$0.7<(x_i)\leq 1$	Subset of very high-level variables	$fa=1$

For each function describing the membership of a variable to a subset, its intermediate coefficient *(μ)* is calculated as the ratio of the sum of all variables in this functional subset (Σfa_i) to their number *(n)*. Since there can be only five variables in each functional subset, the formula takes the form:

$$\mu_i = \frac{\Sigma fa_i}{5} \tag{7}$$

The next step is the final assessment of the progressivity or regressivity of energy innovation. Here the membership confidence function is used but the integral indicator *(M)* is already weighted to one of the subsets. The integral indicator of the fuzzy set "progressivity *vs* regressivity of energy innovations" (*A[p;r]*) is calculated based on the following formula:

$$\underbrace{M}_{A[p;r]} = \mu_i * w_i \tag{8}$$

where: w_i is the weight of each intermediate coefficient, which can be set by Fishburne's rule (Fishburn, 2017), by the expert method, or using the random process function (Maddala and Lahiri, 1992).

Table 4 shows the main subsets for the integral indicator *(M),* as well as its function for calculating the confidence that this indicator belongs to one of the possible subsets.

Thus, if the integral indicator *(M)* is ≤0.55-0.6, it should be considered as a reducing coefficient when evaluating the financial results of innovation implementation. If the integral indicator *(M)* varies from 0.56 to 1, then it should be used as an increasing financial coefficient. The application of this methodology in the practice of analyzing and evaluating the financial results of implementing energy innovations is considered below.

Table 4: Scheme for calculating the confidence of membership the integral indicator *(M)* of the fuzzy set "progressivity *vs* regressivity of energy innovations" (*A[p; r]*) to one of the resulting subsets [compiled by the authors]

Variable (*M*)	Resulting subsets	Confidence of membership (*AB*)
0<(*M*)<0.15	Energy innovation is regressive, it should be abandoned	$AB=1$
0.15<(*M*)<0.25		$AB_1=10*(0.25-(M))$
0.15<(*M*)<0.25		$AB_2=1-AB_1$
0.25<(*M*)<0.35		$AB=1$
0.35<(*M*)<0.45	Energy innovation is conditionally regressive, it is necessary to assess the possibilities of its improvement	$AB_2=10*(0.45-(M))$
0.35<(*M*)<0.45		$AB_3=1-AB_2$
0.45<(*M*)<0.55		$AB=1$
0.55<(*M*)<0.65	Energy innovation is conditionally progressive, a balanced assessment of the feasibility of its implementation is necessary	$AB_3=10*(0.65-(M)$
0.55<(*M*)<0.65		$AB_4=1-AB_3$
0.65<(*M*)<0.75		$AB=1$
0.75<(*M*)<0.85	Energy innovation is progressive, and it should be implemented	$AB_4=10*(0.85-(M)$
0.75<(*M*)<0.85		$AB_5=1-AB_4$
0.85<(*M*)<1		$AB=1$

4. RESULTS AND DISCUSSION

To demonstrate the application of the above-developed technique in practice, we collected data from two energy companies (let us call them conditionally company *A* and *B*):

- Company *A* has developed the energy innovation on the use of nuclear fission in small power plants to supply consumers in remote Northern regions with low population density;
- Company *B* has developed the energy innovation based on using biological waste collected in farms, which is subsequently converted into hydrogen fuel.

Data on the input variables included in the fuzzy set "progressivity *vs* regressivity of energy innovations" are presented in Table 5. The weights for intermediate ratios of membership function variables were determined using Fishburne's rule:

$$M\{A[p;r]\} = 0.05\mu_1 + 0.25\mu_2 + 0.45\mu_3 + 0.55\mu_4 + 0.95\mu_5$$

After that, the progressiveness or regressiveness of the energy innovations under consideration, which were created and were planned to be implemented in company *A* and company *B*, was assessed (Table 6).

The results of the analysis show that the energy innovation of company *A* should be considered with 53.4% confidence as conditionally regressive. Thus, an assessment of the possibilities of its improvement is necessary, or such an innovation can be considered as conditionally progressive with 46.6% confidence, however, a balanced assessment of the feasibility of its implementation is necessary. In both cases, we see that the analysis results do not indicate that the innovation should be implemented. In company *B*, the energy innovation is only 7.5% conditionally progressive, i.e. a balanced assessment of the feasibility of its implementation is necessary. At the same time, the energy innovation is certainly progressive by 92.5%, its implementation is necessary.

The ratio of confidence (1) and confidence (2) allows calculating the downward and upward coefficients for each innovation. In the case of company *A*, the downward coefficient will be:

$$k_A = 100\% - \frac{53.4\%}{46.6\%} = -14.59\%$$

Table 5: Initial data for the analysis of the progressiveness of energy innovations [compiled by the authors]

Variables included in the fuzzy set	Company *A*	Company *B*
Environmental harmlessness	0.69	0.48
Safety for current and future generations	0.11	0.72
Accessibility for private and corporate consumers	0.75	0.53
Benefits for generating companies	0.54	0.29
Potential for technological improvement	0	0.69

This means that either the amount of capital invested in the energy innovation of company *A* should be increased by 14.59%, or the expected revenues should be reduced by the same level, or both events should occur simultaneously. For company *B*, the upward coefficient will be:

$$k_B = \frac{7.5\%}{92.5\%} = +8.08\%$$

This means that company *B* can increase the volume of expected revenues from the implementation of innovations by 8.08%, or reduce capital investments, or both events should occur simultaneously.

Thus, if we calculate the basic financial results of implementing energy innovations in the two compared companies, we will see that the project of company *A* is in many respects more economically successful than the project of company B (Table 7).

At the same time, if we use the above-calculated correction coefficients, then we can note that the project of company *A*, which will need to increase capital expenditures (or reduce the volume of expected revenues) becomes economically unprofitable since the innovation being implemented is conditionally only 46% progressive, which indicates the need for a balanced assessment of the feasibility of its implementation (Table 8). The project implementation period is increasing, its internal rate of return is falling very significantly.

Table 6: The results of the analysis of the energy innovations progressiveness in the company A and company B

Variable and its membership function	fa_1	fa_2	fa_3	fa_4	fa_5
Energy innovation of the company *A*					
Environmental safety	0.000	0.000	0.000	0.100	0.900
Safety for current and future generations	0.835	0.165	0.000	0.000	0.000
Accessibility for private and corporate consumers	0.000	0.000	0.000	0.250	0.750
Benefits for generating companies	0.000	0.000	0.100	0.900	0.000
Potential for technological improvement	1.000	0.000	0.000	1.000	0.000
Intermediate coefficient	0.367	0.033	0.020	0.450	0.330
Assessment of the progressiveness or regressiveness of an energy innovation			0.597		
Confidence (1) that the energy innovation is conditionally regressive, it is necessary to assess the possibilities of its improvement			53.4%		
Confidence (2) that energy innovation is conditionally progressive, a balanced assessment of the feasibility of its implementation is necessary			46.6%		
Energy innovation of the company *B*					
Environmental safety	0.000	0.000	0.700	0.300	0.000
Safety for current and future generations	0.000	0.000	0.000	0.000	1.000
Accessibility for private and corporate consumers	0.000	0.000	0.200	0.800	0.000
Benefits for generating companies	0.000	0.600	0.400	0.000	0.000
Potential for technological improvement	0.000	0.000	0.000	0.069	0.931
Intermediate coefficient	0.000	0.120	0.260	0.234	0.386
Assessment of the progressiveness or regressiveness of an energy innovation			0.643		
Confidence (1) that energy innovation is conditionally progressive, a balanced assessment of the feasibility of its implementation is necessary			7.5%		
Confidence (2) that the energy innovation is progressive, its implementation is necessary			92.5%		

Table 7: Comparison of the basic financial results of energy innovation implementation projects in company *A* and company *B*

Project implementation period	Capital investments, mln $	Expected income, mln $	Discount rate	Net present income, mln $
Company *A*				
N1	13.21	0	0.880	-11.62
N2	6.44	3.25	0.774	-2.47
N3	3.08	6.69	0.681	2.46
N4	0	12.97	0.600	7.78
N5	0	26.52	0.528	14.00
Total	22.73	49.43	---	10.14
Discounted profitability index				1.54
Discounted payback period				Four years and one month
Internal rate of return at the cost of capital investments 12%				18%
Company *B*				
N1	14.09	0.29	0.880	-12.14
N2	7.11	3.44	0.774	-2.84
N3	3.12	6.25	0.681	2.13
N4	0	13.27	0.600	7.96
N5	0	23.55	0.528	12.43
Total	24.32	46.8		7.53
Discounted profitability index				1.38
Discounted payback period				Four years and five months
Internal rate of return at the cost of capital investments 12%				13%

On the contrary, in company *B*, where energy innovation is progressive by more than 90%, a decrease in the capital investments or an increase in the expected revenues axiomatically leads to an increase in the economic efficiency of the project (Table 9).

When correcting the financial results of the energy innovation implementation project of company *B*, the project payback period is not reduced significantly, which in general should be considered normal, since shortening the project implementation time may negatively affect its quality. But at the same time, it is obvious that the internal rate of return increases quite significantly from 13 to 17-18%.

Thus, after the assessment of the energy innovation progressiveness that the two companies under consideration plan to implement is carried out, the project of company *B* should be recognized as financially feasible and cost-effective, while before the assessment, the project of company A seemed to be financially feasible and cost-effective.

Based on the above, we can conclude that the developed methodology is not only workable but also allows making decisions in the field of analysis and evaluation of the implementation of various energy innovations with greater objectivity.

Table 8: Analysis of the adjusted financial results of the energy innovation implementation project in the company *A*

Project implementation period	Capital investments, mln $	Expected income, mln $	Discount rate	Net present income, mln $
Increase in the volume of capital investments				
N1	15.14	0	0.880	-13.32
N2	7.38	3.25	0.774	-3.20
N3	3.53	6.69	0.681	2.15
N4	0.00	12.97	0.600	7.78
N5	0.00	26.52	0.528	14.00
Total	26.05	49.43		7.41
Discounted profitability index				1.35
Discounted payback period				Four and a half year
Internal rate of return at the cost of capital investments 12%				12%
Reduction of expected revenue				
N1	13.21	0.00	0.880	-11.62
N2	6.44	2.78	0.774	-2.84
N3	3.08	5.71	0.681	1.79
N4	0.00	11.08	0.600	6.64
N5	0.00	22.65	0.528	11.95
Total	29.85	42.23		5.93
Discounted profitability index				1.32
Discounted payback period				Five years
Internal rate of return at the cost of capital investments 12%				11%

Table 9: Analysis of the adjusted financial results of the energy innovation implementation project in the company *B*

Project implementation period	Capital investments, mln $	Expected income, mln $	Discount rate	Net present income, mln $
Reduction of the volume of capital investments				
N1	12.85	0.29	0.880	-11.05
N2	6.48	3.44	0.774	-2.36
N3	2.85	6.25	0.681	2.32
N4	0.00	13.27	0.600	7.96
N5	0.00	23.55	0.528	12.43
Total	22.18	46.8		9.30
Discounted profitability index				1.51
Discounted payback period				Four years and two months
Internal rate of return at the cost of capital investments 12%				18%
Increase in the volume of expected revenues				
N1	14.09	0.32	0.880	-12.12
N2	7.11	3.74	0.774	-2.61
N3	3.12	6.80	0.681	2.51
N4	0.00	14.44	0.600	8.66
N5	0.00	25.62	0.528	13.52
Total	24.32	50.92		9.96
Discounted profitability index				1.50
Discounted payback period				Four years and three months
Internal rate of return at the cost of capital investments 12%				17%

5. CONCLUSIONS

Within the framework of the conducted research, a methodology focused on evaluating the financial results of implementing energy innovations is developed using an interdisciplinary approach, which allows drawing the following conclusions:

- First, not all energy innovations can be considered technologically progressive;
- Secondly, technological progress or technological regression of energy innovations can be expressed by a certain set of criteria;
- Third, not all criteria of technological progressiveness or technological regressiveness of energy innovations can be expressed by specific quantitative or financial indicators.

Therefore, *fuzzy logic* and *fuzzy sets* were chosen as the tools. The evaluation methodology includes consideration of five primary or input variables, which are converted into an integral indicator of the fuzzy set “progressivity *vs* regressivity of energy innovations” using the membership functions and confidence of the membership.

The article demonstrated the efficiency of the proposed methodology on the example of two projects for the implementation of energy innovations. One innovation was evaluated as conditionally progressive with 46% confidence and conditionally regressive with 54% confidence, which is quite logical since this innovation assumed the use of nuclear fission technologies in the production of small power plants. The technology had no potential for technological improvement and was not characterized by safety for current and future generations. The second innovation was recognized as definitely progressive with a confidence of 92.5%, which is also quite logical because within the framework of this innovation it was supposed to produce biofuels from biological waste accumulated on livestock farms.

Based on the obtained data on the value of the integral indicator of the fuzzy set “progressiveness *vs* regressiveness of energy innovations,” the upward and downward coefficients were calculated to correct the financial results of each of the energy innovation implementation projects. Initially, the project, which was associated with the use of nuclear fission technologies in small energy generation, was financially and economically more successful than the project based on the implementation of technologies aimed at the production of biofuels from biological waste. But after making adjustments, the project of implementing nuclear decay technologies into small energy generations lost its financial and economic attractiveness, while the project of producing biofuels of waste, on the contrary, showed better expected financial results.

Thus, the developed methodology for assessing the financial results of the energy innovations implementation can be used in practice to support the adoption of the most rational managerial decisions at the micro- or macroeconomic level.

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