“Mechanisms of socially responsible investment in housing sector decarbonization projects: social, labor, and management aspects”

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MECHANISMS OF SOCIALLY RESPONSIBLE INVESTMENT IN HOUSING SECTOR DECARBONIZATION PROJECTS: SOCIAL, LABOR, AND MANAGEMENT ASPECTS

Abstract

The article examines the social, labor, and management dimensions of housing decarbonization processes in the context of socially responsible investment. The relevance of the study is determined by the need to improve the effectiveness of municipal energy efficiency projects in the context of post-war reconstruction, which enhances the role of non-financial factors, in particular human capital and management quality. The purpose of the article is to justify the mechanism of socially responsible investment (Social-ESCO) and to assess the impact of managerial and educational determinants on the effectiveness of housing sector decarbonization projects in 2026.

The methodological basis of the study is input-oriented CCR DEA modeling, which allows integrating traditional quantitative performance indicators and the effectiveness of human resource management practices as active input parameters. The empirical basis of the study is a sample of 25 municipal projects for the energy modernization of the housing stock in the cities of Zhytomyr and Lviv. The modeling results showed a nonlinear relationship between the level of reinvestment of energy savings in human capital development and the economic efficiency of projects. It was established that the optimal level of reinvestment is about 15%, which ensures the stabilization of the internal rate of return (IRR) in the range of 12-14% with a simultaneous increase in social effectiveness. The results confirm the feasibility of using the Social-ESCO mechanism as an institutional form of combining the financial, social, and labor interests of key stakeholders.

Keywords socially responsible investment, decarbonization, energy sector of the economy, housing sector, human capital, Social-ESCO, DEA modeling, energy efficiency, sustainable development

JEL Classification J28, M54, Q48, G31

І. О. Рябоконь (Україна)

МЕХАНІЗМИ СОЦІАЛЬНО ВІДПОВІДАЛЬНОГО ІНВЕСТУВАННЯ В ПРОЄКТИ ДЕКАРБОНІЗАЦІЇ ЖИТЛОВОГО СЕКТОРУ: СОЦІАЛЬНІ, ТРУДОВІ ТА УПРАВЛІНСЬКІ АСПЕКТИ

Анотація

У статті досліджено соціально-трудовий та управлінський виміри процесів декарбонізації житлового фонду в контексті соціально відповідального інвестування. Актуальність дослідження зумовлена потребою підвищення ефективності муніципальних енергоефективних проєктів в умовах повоєнного відновлення, що посилює роль нефінансових чинників, зокрема людського капіталу та якості управління. Метою статті є обґрунтування механізму соціально відповідального інвестування (Social-ESCO) та оцінювання впливу управлінських і освітніх детермінант на ефективність проєктів декарбонізації житлового сектору в умовах 2026 року.

Методологічною основою дослідження є input-oriented CCR DEA-моделювання, яке дає змогу інтегрувати традиційні кількісні показники результативності та ефективність практик управління людськими ресурсами як активні вхідні параметри. Емпіричну базу дослідження становить вибірка з 25 муніципальних проєктів з енергомодернізації житлового фонду міст Житомира та Львова. Результати моделювання засвідчили наявність нелінійної залежності між рівнем реінвестування енергоекономії в розвиток людського капіталу та економічною ефективністю проєктів. Встановлено, що оптимальний рівень реінвестування становить близько 15%, що забезпечує стабілізацію внутрішої норми доходності (IRR) у діапазоні 12-14% за одночасного зростання соціальної результативності. Отримані результати підтверджують доцільність використання механізму Social-ESCO як інституційної форми поєднання фінансових, соціальних і трудових інтересів ключових стейкхолдерів

Ключові слова соціально відповідальне інвестування, декарбонізація, житловий сектор, енергетичний сектор економіки, людський капітал, Social-ESCO, DEA-моделювання, енергоефективність, сталий розвиток

Класифікація JEL J28, M54, Q48, G31

INTRODUCTION

The current state of Ukraine's housing stock and the challenges of post-war reconstruction require the immediate implementation of high-tech decarbonization solutions.

According to a joint report by the World Bank, the Government of Ukraine, the European Union, and the United Nations (World Bank Publications, 2025), the direct damage to Ukraine's housing sector as a result of hostilities exceeds USD 57.6 billion, while the total needs for housing restoration and reconstruction, taking into account the principles of energy efficiency and decarbonization, are estimated at approximately USD 83.7 billion. The scale of these needs indicates that it is impossible to cover them solely from budget resources, which necessitates the involvement of socially responsible investment (SRI) mechanisms.

However, in the context of a state budget deficit, the main limiting factor remains the "investment gap" and the difficulty of assessing the effectiveness of such projects for private capital (Statman, 2007; CBRE Investment Management, 2024). Traditional financial valuation methods, in particular Discounted Cash Flow and market multiples, have a limited ability to take into account non-monetary benefits associated with ESG factors and intangible assets, which leads to a systemic underestimation of socially responsible investment projects in the market (Shiraishi & Mupa, 2025). At the same time, the decarbonization of the housing sector poses new challenges for the municipal management system, which highlights the need to review the professional competencies of staff and introduce KPIs focused on social and labor performance. As studies of public sector efficiency show, it is precisely management and human resource factors that are key determinants of resource use efficiency (World Bank, 2025; OECD, 2025; Smajlović et al., 2025). The problem lies in the lack of a comprehensive methodological toolkit that would allow for the integration of environmental, social, and governance (ESG) parameters into a single assessment system. The way out of this crisis lies in a paradigm shift in financing: from direct subsidies to attracting responsible investors based on the Social-ESCO model, where social impact and workforce development become full-fledged assets.

In the context of post-war recovery in 2026, the implementation of the proposed model becomes not only an internal need of the community, but also a critical requirement of international donors and financial institutions such as the IFC and EBRD. The use of DEA modeling incorporating ESG criteria serves as a compliance tool for social inclusion and human capital development, which is a prerequisite for obtaining preferential financing and grant support for housing sector decarbonization projects. The purpose of the article is to justify the mechanism of socially responsible investment (Social-ESCO) and to assess the impact of managerial and educational determinants on the effectiveness of decarbonization projects in the housing sector in 2026.

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1. LITERATURE REVIEW

The problem of attracting investment in decarbonization and energy efficiency in the housing sector is the focus of many contemporary researchers. Fundamental aspects of socially responsible investment (SRI) and the integration of ESG criteria in the corporate and public sectors have been further developed in contemporary empirical studies. In particular, Fristamara and Musmini (2024) argue that ESG integration is transforming from an ethical approach into a systematic tool for investment decision-making that combines financial expediency with the sustainability of long-term results.

In turn, Ranty et al. (2024) emphasize that taking environmental, social, and governance factors into account forms a new paradigm of investment strategy, in which ESG is not an additional constraint but a factor in reducing risks and increasing the adaptability of investment portfolios. Empirical evidence from financial markets confirms a positive relationship between the quality of ESG disclosure and asset value, as well as the importance of ESG integration for optimizing the performance of specialized assets. In particular, Baldi and Lambertides (2024) demonstrate that environmental and governance components of ESG significantly improve the risk-adjusted returns of infrastructure funds. Their study highlights that responsible investment practices act as a risk-mitigation tool, especially when managed by institutional frameworks that prioritize long-term sustainability over short-term gains.

In contemporary scientific discussions, the issue of energy efficiency is considered not only as a tool for sustainable development, but also as a critical factor for Ukraine's national security and stability in a state of martial law. An analysis of the current state and prospects for improving energy efficiency, in particular through the implementation of energy management systems in accordance with international standards, is thoroughly presented in the study by Hrinchenko and Orlenko (2024). The strategic vector for decarbonisation of the energy sector and low-carbon development scenarios until 2050 are defined in the Ukraine 2050 Low Emission Development Strategy (Ministry of Environmental Protection and Natural Resources of Ukraine, 2021), which remains the foundation for the development of state energy conservation measures. Financial mechanisms to support the green transition and attract investment in the context of the economic crisis are outlined in detail in the programs of the International Finance Corporation (IFC, 2023), which emphasize the priority of emergency energy security and infrastructure reconstruction based on energy efficiency. In addition, the practical implementation of innovations in bioenergy value chains and the monitoring of effectiveness of such projects with the support of international donors, such as the Global Environment Facility (GEF), are reflected in the EBRD reports (GEF & EBRD, 2025).

The technical aspects of the energy transition and the potential of renewable energy sources in Ukraine, in particular the analysis of the roadmap for the development of the industry until 2050, are covered in detail in the works of Geletukha et al. (2020). At the same time, in the current conditions, the social and investment dimensions of energy transformations are of particular importance. The issue of energy poverty, its economic content, and the specifics of its measurement in the context of European integration are thoroughly analyzed in a study by Naumenko and Tishchenko (2025). The authors emphasize the importance of monitoring the availability of energy resources for the population as a prerequisite for sustainable economic development. At the same time, the implementation of energy reforms based on social responsibility and environmental safety is made possible by the widespread introduction of ESG (Environmental, Social, and Governance) approaches. As Dyakovsky (2024) notes, the use of ESG investment principles is a key factor in attracting capital for the reconstruction of energy infrastructure and ensuring sustainable economic growth in Ukraine.

In international scientific practice, the Data Envelopment Analysis (DEA) method is widely used to assess efficiency in the energy sector and the public sector. The classic CCR and BCC models developed by Charnes et al. (1978) were later adapted for environmental performance analysis (Färe & Lovell, 1978). Recent studies demonstrate the expansion of DEA from purely technical and economic analysis to a comprehensive assessment of the performance of state and municipal management. Thus, Smajlović et al. (2025) confirm the effectiveness of DEA for identifying financial and managerial sources of inefficiency in the public sector. This approach allows for the integration of financial, operational, and managerial indicators into a single analytical structure, which is essential for a comprehensive evaluation of municipal activities. Among Ukrainian researchers who use economic and mathematical modeling to analyze socio-economic systems, Ivanov (2023), Makarenko (2023), and Kulakova and Grigorieva (2025) have made significant contributions. They confirm the possibility of using DEA to assess the quality of management decisions, taking into account non-financial parameters, in particular ESG criteria, sustainable development indicators, and intangible assets, which is conceptually consistent with the approach used in this study.

A separate area of contemporary research is devoted to the role of human capital as a key factor in the effectiveness of public investment. According to the Human Capital Trust Fund Annual Report (World Bank, 2025), investments in human capital development – including education, professional skills, and cross-sector support – contribute significantly to the long-term performance of sustainable projects in developing countries. Empirical cases, such as those described in the AIIB (2024) publication, further confirm that strategic investments in human capital enhance the operational efficiency and sustainability of infrastructure projects.

In the context of socially responsible investing and the integration of ESG criteria, considerable attention has been paid to the financial attractiveness of sustainable infrastructure assets. Analytical reports by InfraRed Capital Partners (2025) and CBRE Investment Management (2024) indicate a stabilization of the internal rate of return (IRR) for value-add infrastructure projects within the range of 12-14%, provided that social, climate, and governance components are effectively integrated. The former report estimates the target net internal rate of return (IRR) for such projects at 14.7% as of early 2025, which is consistent with CBRE Investment Management's (2024) forecasts for the long-term stabilization of sustainable asset returns, provided that ESG risks are managed effectively.

The results of a systematic review by Aggarwal et al. (2025), combined with empirical studies of ESG portfolios, confirm that the integration of ESG criteria is seen not as a compromise on profitability, but as a mechanism for reducing risk and increasing investment sustainability.

Empirical studies confirm that integrating ESG criteria into investment decisions not only does not reduce financial performance, but can also provide additional benefits for investors. For example, Useche et al. (2023), based on an analysis of the stock markets of Chile, Colombia, and Peru, demonstrate that portfolios with high ESG ratings outperform both low-ESG portfolios and portfolios of companies that do not disclose ESG information on a number of risk-and-return indicators. An important theoretical contribution of the authors is the introduction of the concept of a "psychic dividend" – the additional utility or ESG premium that investors receive from the awareness of the positive social and environmental impact of their investments. This approach expands the classic mean–variance paradigm, confirming the advisability of taking non-financial effects into account in models for assessing the effectiveness of socially responsible investing.

The social and labor dimension of decarbonization is linked to the creation of "green" jobs and the behavioral aspects of innovation implementation. According to the International Energy Agency (IEA, 2025), the transition to a low-carbon economy is accompanied by steady growth in employment in the energy sector, with the number of new jobs in clean energy already exceeding losses in the fossil fuel sectors. At the same time, the European Environment Agency (EEA, 2025) emphasizes the critical role of green professions in achieving climate goals, highlighting the need for large-scale retraining of personnel as a condition for ensuring a just transition. However, the success of decarbonisation depends not only on technology, but also on overcoming cognitive barriers; as noted in the OECD report (2025), the use of behavioral science tools is necessary to stimulate green change at the level of individual decisions and municipal management. The success of housing decarbonization projects largely depends on the level of financial literacy and awareness of key stakeholders. As Utami (2025) notes, financial

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literacy is a critical moderating factor that enhances the impact of the environmental attractiveness of assets on real investment intentions. In this context, housing association managers act as agents of change because, according to the study's findings, overcoming the information deficit and increasing financial awareness are prerequisites for transforming ethical intentions into concrete actions for thermal modernization and increasing real estate capitalization.

At the same time, a number of studies focus on institutional and information barriers that hinder the development of socially responsible investment. Empirical studies also show that the key barriers to the development of ESG and SRI investments are not a lack of ethical motivation, but information asymmetry and a shortage of specialized knowledge, which reduces the willingness of financial agents to participate in such projects (Bongini et al., 2025). Research by Gupta and Goswami (2024) confirms the existence of an intention-behavior gap among investors in the field of sustainable finance. The authors argue that even with ethical motivation, investors need external incentives and nudging mechanisms to overcome cognitive inertia. This correlates with the findings of Lundström and Rosberg (2017) regarding the decisive role of information barriers and low self-efficacy as major obstacles to scaling up SRI projects.

Despite significant scientific achievements, the issues of integrating social responsibility and human capital as key inputs in the DEA model for assessing the effectiveness of decarbonization projects in Ukraine's housing sector remain insufficiently covered, which necessitates this study.

2. RESEARCH METHODOLOGY

To assess the effectiveness of decarbonization projects, the study used the Data Envelopment Analysis (DEA) method. This tool was chosen because of its ability to perform a comprehensive comparative assessment of decision-making units (DMUs) with multiple inputs and outputs that have different units of measurement. Unlike classical index methods, DEA allows modeling the direct transformation of financial and technological resources into socio-environmental effects without losing information due to excessive aggregation of indicators.

The methodological approach is based on the use of primary quantitative and qualitative parameters. In order to overcome the problem of data multidimensionality, all input and output indicators are subjected to linear normalization in the range [0;1]. The decision-making units (DMUs) within the modeling are 25 projects for the decarbonization of the housing stock. The empirical basis for the calculations was provided by data from the Sustainable Energy and Climate Action Plans (SECAP) of Zhytomyr (Zhytomyr City Council, 2025), Lviv (Lviv City Council, 2022), and Kamianets-Podilskyi City Council (2011). The quantitative parameters were verified through reports from the Covenant of Mayors for Climate & Energy (CoM East) platform. To build the model, a system of parameters was developed that reflects the specifics of the Social-ESCO mechanism within the SRI paradigm. The input parameters (I_1-I_4) capture financial, technological, and managerial–educational capital, while the output parameters (O_1-O_4) represent the multi-vector performance of the project. The constructed system of indicators enables a comprehensive interpretation of the effectiveness of decarbonization projects by jointly accounting for financial, social, labor, and managerial aspects within a unified analytical framework.

A detailed description and logic of the formation of each parameter are given in Table 1.

The rationale for the selected set of parameters is based on the need to balance the three vectors of SRI investing: economic (I1, O), technological (I2, O1) and social-labor (I3, I4, O2, O3). The inclusion of human capital parameters and the educational component in the list of inputs allows for the consideration of the community's managerial readiness as a factor that transforms financial investments into sustainable social outcomes. The assessment of management potential (I3) was carried out by surveying specialists whose composition corresponds to the list of responsible departments specified in

Table 1. System of input and output parameters for assessing decarbonization projects, taking into account social and labor determinants

Source: Author's development based on an analysis of the SRI investment concept and strategic priorities for community energy development (Zhytomyr City Council, 2025; Covenant of Mayors for Climate & Energy, n.d.).

Code	Category	Parameter name	Content and measurement logic	Units of measurement
I	Input	Private capital and loans	Volume of investment and credit resources attracted per unit of area of the modernized facility	UAH/m^2
I_2	Input	Technological resource	Baseline energy consumption of the building prior to the implementation of measures, which determines the scale of the necessary intervention	kW·h/m^2
I_3	Input	Human capital	Community management capacity and level of professional competence of staff	Points
I_4	Input	Educational component	Investment in competence development: expenses for professional development, specialized training of energy managers, and implementation of ESG education programs	thousand UAH
O_1	Output	Environmental effect	Actual reduction in CO_2 emissions as a result of modernization	t CO_2
O_2	Output	Social impact	Energy poverty reduction index (optimization of household expenses)	% (reduction in the share of household expenditure on energy resources)
O_3	Output	Labor market	Number of new green jobs created at the modernization site.	units
O_4	Output	Budgetary effect	The amount of state funds freed up as a result of reduced demand for housing subsidies,	thousand UAH/year

Section 1.3 of the Zhytomyr SEAP (economic management, department energy managers). This made it possible to transform the qualitative characteristics of municipal management, laid down in the strategy until 2050, into quantitative determinants for assessing the effectiveness of Social-ESCO in the conditions of 2026 (Zhytomyr City Council, 2025).

A methodological feature of the approach is the quantification of these qualitative determinants through the results of an expert survey of 24 specialists (heads of condominiums, municipal energy managers, representatives of investment funds). Subjective assessments on a 5-point Likert scale were aggregated and normalized in the range [0;1], which made it possible to convert the qualitative characteristics of management readiness into quantitative data for DEA modeling. This approach minimizes the risk of ignoring the "human factor" when evaluating capital-intensive decarbonization projects.

Quantitative input and output data for parameters I_1, I_2, O_1 and O_4 were obtained from official community reports on the Covenant of Mayors for Climate & Energy (CoM East) platform and verified PDSERK indicators, which guarantees high accuracy and reproducibility of results.

The selection of the expert group was based on the organizational structure of the SEAP management (Zhytomyr City Council, 2025, Section 1.3), which includes specialists from the departments of economy and those responsible for energy monitoring. This ensured high relevance of the assessment of management capacity as an input resource for the model.

The mathematical assessment of the effectiveness of each project (DMU_0) is carried out by maximizing the objective function of the ratio of weighted results to costs:

$$E_0 = \frac{\sum_{r=1}^{s} v_r y_{rj0}}{\sum_{i=1}^{m} u_i x_{ij0}} \to \max, \tag{1}$$

under the following conditions:

$$\frac{\sum_{r=1}^{s} v_r y_{rj}}{\sum_{i=1}^{m} u_i x_{ij}} \le 1, \ \ j = 1,\ldots,n, \ \ u_i, v_r \ge \varepsilon, \tag{2}$$

where s – number of outputs; m – number of resources (Inputs); n – number of objects (DMUs); where j_0 – index of the decision-making unit under study (DMU_0), whose efficiency is assessed relative to the entire set of objects in the sample; v_r, u_i – weight coefficients of the r-th output and

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i-th resource, determined by solving the linear programming problem; ε – a non-Archimedean infinitesimal value.

To confirm the research hypothesis, the test was conducted on a sample of 25 municipal projects selected based on the criterion of completeness of reflection in the strategic decarbonization plans of Zhytomyr, Lviv, and Kamianets-Podilskyi. The sample size (n = 25) meets the classic requirements for constructing DEA models (Cooper et al., 2007), according to which the number of objects must exceed three times the sum of the input and output parameters ($n \geq 3(m + s)$). This provides sufficient degrees of freedom to identify the efficiency frontier in the context of the current challenges of 2026.

3. RESULTS AND DISCUSSION

The first stage of the study was to determine the optimal financial architecture of the model.

The reliability of expert assessments of management potential (I_3) and the educational component (I_4), used as input parameters for the DEA model, was preliminarily verified using Kendall's concordance coefficient. The obtained value of W = 0.78 indicates a high level of consistency of expert judgments and confirms the validity of using aggregated social and labor indicators in further modeling. These scenarios differ in the intensity of financial resources allocated to social, labor, and management goals, which allows us to track changes in the structure of efficiency depending on the level of reinvestment.

This approach made it possible to move from a general assessment of effectiveness to an analysis of the model's sensitivity to changes in key management parameters. In particular, varying the share of reinvestment of generated energy savings was considered as a tool to influence the balance between the financial and social-labor outcomes of projects. This creates a basis for comparing alternative configurations of the Social-ESCO mechanism under different management priorities.

Based on iterative tests, three scenarios were developed that reflect the relationship between the level of reinvestment of savings and the overall effectiveness of the project (Table 2).

The data obtained show that when the reinvestment level reaches 15% (scenario S2), the highest E0coefficient of 0.94 is achieved. It is important to note that with this distribution, the internal rate of return (IRR) for a private investor stabilizes in the range of 12-14%, which correlates with the indicators for Value-add strategies for 2026 (InfraRed Capital Partners, 2025, p. 15). The estimated payback period is 7-10 years.

Thus, the results of scenario modeling indicate the existence of a clearly defined optimum financial and management configuration of the Social-ESCO model. The identified non-linearity of the relationship between the level of reinvestment and integral efficiency confirms the feasibility of using DEA as a tool for identifying not only the technical and economic but also the social and labor performance of decarbonization projects.

From a management perspective, scenario S_1 reflects an inertial model in which energy modernization is viewed exclusively as a technical project, without institutional support and

Table 2. Sensitivity analysis of the Social-ESCO model's effectiveness depending on the level of reinvestment

Source: Calculated by the author based on iterative DEA modeling and PDSERK data (Zhytomyr City Council, 2025; Covenant of Mayors for Climate & Energy, n.d.).

Scenario	% reinvestment of savings	Average efficiency coefficient (E_0)	Marginal change in social effect (ΔO_2)	Note
S_1(Conservative)	5	0.72	+2.1	Insufficient incentive for competence development
S_2 (Balanced)	15	0.94	+14.8	Optimal point of intersection between costs and returns
S_3 (Radical)	25	0.81	+16.2	Risk of reduced financial attractiveness for investors

investment in human capital. The lack of sufficient educational and motivational components limits the ability of staff and residents to adapt to new technologies, which reduces long-term efficiency even with initial resource savings.

For a correct differentiation of results and their further interpretation, the basic characteristics of scenario S_1 are presented at the level of empirical description, while the managerial and socio-labor consequences of this scenario are detailed in the Discussion section.

Scenario S_1, which assumes a minimum level of reinvestment (5%), requires separate discussion. The results obtained demonstrate an extremely low social return (ΔO_2 = +2.1%) under formally acceptable financial parameters. Such a configuration may create the illusion of economic efficiency, but from the perspective of social and labor analysis, it actually preserves the deficit of management competencies and does not create the preconditions for sustainable development.

Thus, scenario S_1 confirms that minimizing social costs in the short term leads to strategic losses, as it does not ensure the reproduction of management potential and does not allow the project to approach the efficiency frontier.

Scenario S_2, which involves reinvesting 15% of the energy savings achieved, demonstrates the highest integral efficiency coefficient (E_0 = 0.94) among all the options tested. The achieved level of social impact (ΔO_2 = +14.8%) indicates the formation of a critical mass of investment in human capital sufficient to change behavioral and management practices within the project. From a management perspective, this scenario ensures the synchronization of the investor's financial interests and the community's social and labor priorities.

It is important to emphasize that under scenario S_2, the internal rate of return (IRR) for a private investor stabilizes in the range of 12-14%, which is consistent with the projected returns for value-add infrastructure strategies. This confirms the feasibility of the chosen level of reinvestment as one that does not create an excessive financial burden, while ensuring an acceptable project payback period of 7-10 years. Thus, scenario S_2 can be considered as the basic parameter of the financial architecture of the Social-ESCO model.

Scenario S_3, which provides for an increase in the reinvestment share to 25%, is accompanied by a further increase in the social effect (ΔO_2 = +16.2%), but does not provide a proportional improvement in the overall efficiency of the project. The recorded decrease in the E_0 coefficient to 0.81 indicates the onset of a zone of diminishing marginal returns, within which additional investments in the social component cease to compensate for the increase in the financial burden on invested capital.

From the perspective of project management and investment logic, this result indicates that the optimal level of reinvestment has been exceeded, at which point social priorities begin to outweigh economic rationality. This creates the risk of reducing the investment attractiveness of the model for a private partner, especially in conditions of increased macroeconomic uncertainty. Therefore, scenario S_3 should be interpreted not as recommended, but as a limit benchmark that defines the upper limit of acceptable social burden within the Social-ESCO mechanism.

The second stage was to test the model on a sample of 25 municipal decarbonization projects in the housing and budgetary sectors, selected on the basis of verified SEAP reports from Zhytomyr and other communities that are signatories to the Covenant of Mayors.

The empirical base includes energy consumption and investment cost indicators recorded in the communities' strategic plans until 2050, which ensures the relevance of the assessment for the conditions of 2026. An important prerequisite for the DEA assessment was the preliminary classification of input resources (I_1-I_4), which made it possible to transform the qualitative characteristics of management capacity into formalized quantitative parameters of the model. The investment component (I_1) and technological resource (I_2) were verified based on the estimated cost of thermal modernization projects presented in the SEAP materials. The indicators of human capital (I_3) and the educational component (I_4) were formed on the basis of the results of a survey

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of energy managers of local communities and an assessment of the level of implementation of energy consumption monitoring systems.

This preparatory phase of modeling made it possible to minimize the influence of subjective factors in the formation of the sample and to ensure the comparability of objects that differ significantly in terms of technical, functional, and spatial characteristics – from the historic residential buildings of central Lviv to the typical panel buildings of Zhytomyr. Under these conditions, the determination of the integral efficiency indicator E_0 for each object was considered not as an end in itself, but as a tool for identifying the reasons why individual projects do not reach the efficiency frontier in the context of implementing municipal decarbonization strategies.

The results show that for most projects, deviations from the efficiency frontier are due not so much to limited financial resources as to institutional and managerial factors related to maintaining the achieved level of energy savings after the completion of the active phase of modernization, this aspect was used as the basis for further typology of 25 objects according to management models, the results of which are presented below.

The application of the CCR model made it possible to identify the efficiency frontier and classify projects by type of management capital in the context of the implementation of the Social-ESCO mechanism (Table 3).

The choice of an input-oriented CCR model is justified by its ability to assess the level of optimization of the resources involved (I1-I4) to achieve the decarbonization targets. The use of this particular model allows identifying the asymmetry of the impact of management factors: it has been empirically proven that even with identical amounts of financial investment (I1), the variability of the values of management potential (I3) and the educational component (I4) leads to a statistically significant gap in the coefficient E0.

This distribution of objects relative to the efficiency frontier confirms that, within the chosen methodology, human capital is not an auxiliary element but a determining endogenous resource. This allows us to interpret management determinants as key drivers that determine the ability of a municipal object to transform financial capital into environmental and social returns.

The DMU_2 entity illustrates a situation typical for Ukrainian condominiums, in which the pace of technical renewal (I_1, I_2) outpaces the development of the managerial and educational components, forming a so-called "technological competence gap" that limits the achievement of efficiency limits.

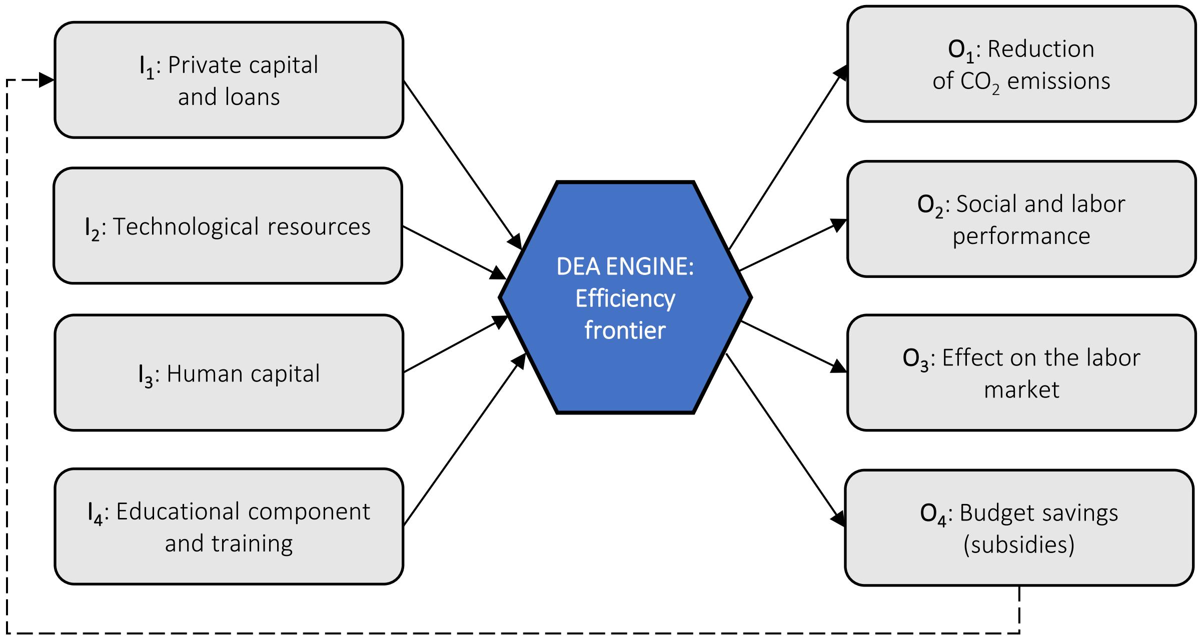
The interaction of the identified factors and

Table 3. Results of the DEA assessment of typical management models for decarbonization projects (CCR model)

Source: Calculated by the author based on DEA modeling, expert survey results, and PDSERK data (Zhytomyr City Council, 2025; Lviv City Council, 2022; Covenant of Mayors for Climate & Energy, n.d.).

Facility code (DMU)	Project characteristics (modernization object)	Input resources (average score I_3, I_4)	Efficiency coefficient (E_0)	Social and environmental return (relative to investment)	Object status beyond efficiency
DMU_1	Progressive model: high level of investment in staff development and energy management	0.92	1.0	+22	Benchmark
DMU_2	Conservative model: maintenance prevails over competence development	0.65	0.84	+4	Ineffective (requires training)
DMU_3	Crisis model: shortage of professional management personnel and lack of ESG training	0.41	0.7	–	Critically ineffective

Source: Developed by the author based on the Social-ESCO concept and the Zhytomyr Sustainable Energy and Climate Action Plan (SECAP) (Zhytomyr City Council, 2024).



Note. The dotted line reflects the cycle of reinvesting budget savings (O_4) into the input capital of subsequent modernization stages (I_1), which ensures the viability of the model.

Figure 1. Conceptual diagram of assessing the effectiveness of decarbonization projects using the DEA method within the Social-ESCO model

recursive relationships within the model are visualized in Figure 1.

The diagram reflects the closure of the self-financing cycle through the reinvestment of budget savings (O_4) into the input capital of subsequent stages (I_1), which is a key result of the development of the Social-ESCO architecture.

The empirical results obtained form the basis for a deeper interpretation from the perspective of labor potential management, behavioral economics, and socially responsible investment. It is these aspects that go beyond a purely quantitative assessment of effectiveness and require conceptual understanding, which determines the logic of further discussion.

The results obtained during the modeling confirm the hypothesis that the financial viability of decarbonization projects in Ukraine in 2026 is a nonlinear function of the quality of human capital. The equilibrium point identified (scenario S_2) shows that a 15% reinvestment in the educational component is not a "social tax" on the investor's profit, but is a necessary condition for stabilizing the IRR at 12-14%.

From the point of view of human resource management theory, the results confirm the advisability of moving from a resource-oriented management model to a behavioral-institutional paradigm. Within this paradigm, human capital is viewed not as an accompanying factor in the implementation of infrastructure projects, but as a central element of the mechanism for creating added value. This allows us to interpret the Social-ESCO mechanism not only as a financial instrument, but as a form of socio-economic contract between the investor, the municipality, and the labor communities.

Within the interpretation of the model, special attention should be paid to levelling psychological barriers and overcoming the cognitive inertia of HOA and housing cooperative staff. As the DMU_3 analysis has shown, low environmental literacy and resistance to innovation often become the main destructive factors that negate the expected technological benefits of energy

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modernization. The analysis of identified barriers to effective decarbonization of the housing sector, in particular for inefficient facilities such as DMU_3, correlates with the conclusions of Lundström and Rosberg (2017). The authors argue that the key determinants of low interest in socially responsible investment are not financial unattractiveness, but rather information deficits and low levels of investor self-efficacy. In the context of the proposed DEA model, this confirms that the underdevelopment of educational and managerial components (I_4) creates information asymmetry, which blocks rational decision-making even when the technical potential for energy efficiency exists. At the same time, the authors' empirical results confirm the dominance of financial expectations in the investment decision-making process, which further justifies the feasibility of the scenario S_2 with a moderate level of reinvestment (15%), which combines the preservation of market profitability with the financing of social and labor goals.

The social and labor aspect of the Social-ESCO concept involves the integration of social dialogue tools, such as strategic sessions and participatory management mechanisms. This allows for the transformation of passive resistance to change into active and productive participation of residents in the decarbonization process. Given the intention-behavior gap identified by Gupta and Goswami (2024), the Social-ESCO mechanism proposed in this paper can be seen as an institutional nudging tool. It automates the process of reinvesting in human capital (I_4), transforming the passive ethical motivation of investors into concrete decarbonization results, which allows overcoming the information barriers described by Lundström and Rosberg (2017).

The lack of such institutional and communication support leads to the implemented KPIs being perceived by employees solely as a means of external control, which inevitably provokes a decrease in the integral efficiency coefficient E_0. Thus, we prove that the deficit in human capital funding (I_4) is the reason for the shortfall of about 16% of potential environmental performance.

Based on the decomposition of the results of DMU_3, critical structural bottlenecks have been identified. Our results correlate with the conclusions of Smajlović et al. (2025), who, based on an analysis of the public sector, proved that management factors have a decisive impact on the overall efficiency of resource use. In particular, the critical inefficiency of DMU_3 identified by us confirms the authors' thesis that bridging the gap between costs and results lies not so much in additional funding as in optimizing management processes and increasing the professional responsibility of managers. This study empirically proves that overcoming inefficiency lies not in increasing subsidies, but in changing the paradigm of labor force management. To bring "crisis" objects to the efficiency frontier, the following hierarchical tools are proposed:

- Institutional level: formation of a network of municipal energy competence centers to implement Lifelong Learning programs among managers in the housing sector.
- Incentive level: introduction of a flexible KPI system for technical personnel, correlated with SRI investment indicators.
- Career level: creation of "social lifts" through independent professional ESG certification of managers.

The specificity of the Social-ESCO model is its ability to generate secondary social and labor effects in the local labor market. The modeling results (output O_3) confirm that the processes of decarbonization of the housing stock stimulate the formation of demand for new professional profiles, in particular energy auditors, ESG consultants, and specialists in the operation of intelligent metering systems.

In the context of post-war recovery in 2026, this is particularly important for the reintegration of internally displaced persons and veterans. Thus, management potential (I_3) is transformed into the creation of "green" jobs, generating a multiplier effect for the municipal economy. At the same time, the lack of targeted funding for the educational component (I_4) poses the risk of preserving low-skilled employment, which significantly reduces the long-term viability of socially responsible investment strategies. An additional argument in favor of the strategic viability of the Social-

ESCO model is its compliance with market trends recorded in the CBRE Investment Management report (2024). Analysts emphasize that in conditions of high-interest rate volatility, assets with "active management" and built-in inflation protection demonstrate the greatest stability. The financial recursion mechanism proposed in the paper allows capitalizing on energy efficiency without constant dependence on external credit markets, which minimizes the sensitivity of projects to monetary policy and confirms the feasibility of transitioning to sustainable value-add infrastructure investments.

The transformation of Ukraine's housing stock requires the valorization of social externalities. Taking into account factors such as a reduction in morbidity among the population and a reduction in budget expenditures on subsidies allows capital-intensive projects to achieve high social returns. In this context, the Social-ESCO mechanism is the most promising, as it closes the self-financing cycle: savings in budget expenditures (O_4) are reinvested in the initial capital of subsequent stages (I_1).

Based on the patterns identified, it can be argued that the success of decarbonization depends on the depth of institutionalization of new management standards. Without adapting municipal management regulations – in particular, revising job descriptions and formalizing continuous training programs – SRI financial instruments will only operate at 50-60% of their design capacity.

As a result, the theoretical and methodological basis for the implementation of socially responsible investment mechanisms allows us to formulate the final conclusions of the study.

CONCLUSIONS

This study achieved its aim of substantiating the mechanism of socially responsible investment (Social-ESCO) and assessing the impact of managerial and educational determinants on the effectiveness of residential sector decarbonization projects in 2026. The analysis conducted made it possible to substantiate and demonstrate the importance of managerial and human capital as key factors in the effectiveness of energy modernization projects within the framework of municipal sustainable development strategies.

The results of the study confirm the feasibility of using the Data Envelopment Analysis (DEA) method to assess the effectiveness of housing sector decarbonization projects, taking into account not only financial but also social, labor, and management factors. The use of a multidimensional approach allows overcoming the limitations of classical financial evaluation methods, which do not take into account the non-monetary effects of socially responsible investment.

The integration of human and managerial capital as endogenous input parameters in the DEA model indicates that the quality of management and the level of professional competence of personnel are important determinants of the financial stability and effectiveness of energy modernization projects. Empirical results show that reinvesting part of the generated savings in the educational component does not reduce the investment attractiveness of projects, but rather contributes to the stabilization of the internal rate of return and an increase in the integral efficiency coefficient.

The Social-ESCO mechanism proposed in the study is interpreted not only as a financial instrument, but also as a socio-economic contract between the investor, the municipality, and the labor communities, within which resource savings are transformed into sustainable human capital development. This approach helps reduce behavioral and informational barriers, increases staff engagement, and promotes trust in socially responsible investment instruments.

The practical significance of the results lies in the possibility of their use by local authorities and institutional investors to justify the priorities for financing decarbonization projects in the housing stock.

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In particular, testing the model based on the SEAP of Zhytomyr and other cities that have signed the Covenant of Mayors confirms that taking management capital into account allows communities to more accurately predict the socio-economic effects of implementing energy modernization measures in 2026.

The findings also expand methodological approaches to assessing the effectiveness of public investments and lay the groundwork for further research aimed at integrating ESG criteria and human capital indicators into investment decision-making systems.

This study contributes to the field by incorporating ESG-related indicators and human capital as endogenous variables within the DEA framework, contextualized for the challenges of post-war infrastructure reconstruction.

AUTHOR CONTRIBUTIONS

Conceptualization: Ivan Riabokon.
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Formal analysis: Ivan Riabokon.
Investigation: Ivan Riabokon.
Methodology: Ivan Riabokon.
Project administration: Ivan Riabokon.
Resources: Ivan Riabokon.
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Supervision: Ivan Riabokon.
Validation: Ivan Riabokon.
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Writing – review & editing: Ivan Riabokon.

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