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Determining the Optimal Directions of Investment in Regional Renewable Energy Development

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Abstract: The growth of renewable energy facilities worldwide creates new challenges for sustainable regional development. Unregulated investment flows in the green energy sector cause disparities in the deployment of various renewable energy technologies, worsen the ability to balance national energy systems, etc. This article is the first comprehensive study that offers a methodology for multifactor modeling of investment flows in regional green energy deployment considering the priorities of national, regional, and local authorities within the sustainable development concept. The proposed methodological approaches help (1) determine the types of renewable energy technologies for priority development in the region, (2) select specific green energy projects to receive budgetary support on territories, and (3) form the optimal mechanism for budget financing distribution on regional development of renewable energy technologies. The modeling factors include natural conditions and resource base of a territory; its economically feasible renewable energy potential; the territory's energy needs; installed capacity and electricity generation of new green energy facilities; power plants' life cycle duration, the investment amount, etc. The model approbation on the example of household solar and wind power plants in the Sumy region, Ukraine, has shown the need to significantly increase financial support for renewable energy projects, primarily due to the region's energy deficit. Calculations revealed that the interest-free loan share for both technologies should be 2.843 and 2.844 times higher than the basic share of lending (20%). For the 30-kW solar power plant project, the indicator should be 64.67% instead of the basic one of 56.86% for home solar energy facilities. Thus, the methodological approaches presented in the article are new tools that allow territorial authorities to purposefully shape and manage investment flows in the renewable energy sector to ensure sustainable energy development of regions worldwide.

Keywords: region; investment; renewable energy; optimization; preferential financing; sustainable development; household

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1. Introduction

Recently, renewable energy (RE) has become a priority for sustainable energy sector development in many countries worldwide. To ensure the active deployment of green energy technologies, national governments resort to their economic incentives by setting high feed-in tariffs [1–3], applying RE quotas [4], auctions [5], preferential taxation [1,6], loans for RE projects [1,6], etc. [7–9]. However, while identifying the benchmarks for achieving the green energy share in the country's energy mix, legislators fail to outline the proportions of various RE technologies development and ensure control over their observance.

On the one hand, the absence of such restrictions helps green the energy sector faster. On the other hand, the delay in regulating investments in different RE sources may cause unexpected negative consequences for industry development. In the absence of state regulation of investment flows, funds directed to green energy technologies, which have the highest profitability under the current economic situation. The profit depends on the territories' climatic and natural conditions for RE deployment, the tendencies of cheapening green energy technologies on the world market, the feed-in tariff rates, etc. The consequences of free capital allocation in the industry based on economic expediency criterion alone are escalating serious problems that hinder the sustainable energy development. These problems include: the predominance of a limited number of the most profitable RE technologies in the industry; the increasing financial load on the national budget due to the absence of other sources for feed-in tariff payments; rising installed energy capacity in regions that have sufficient energy supply; the increasing load on local electricity grids that have low transmission capacity; exacerbation of power capacities balancing issues, etc. [2,10]. Paradoxically, the mentioned consequences may cause energy crises instead of the solution to the sector issues. In this regard, many European countries with considerable experience in RE development resort to regulating investment flows in the industry by systematically revising and reducing feed-in tariffs [11,12], introducing renewable portfolio standards [13] and auctions [14] that take into account the structure of green energy sources and other levers [15–17]. For countries that apply high feed-in tariffs and, therefore, have experienced a RE boom in recent years, the problem of regulating green energy investment for sustainable regional development is becoming increasingly important. A bright example is the solar and wind energy industries of Ukraine, which are developing rapidly under strong economic support. The lack of mechanisms to regulate the regional location of these power plants creates challenges for the stable functioning of the energy sector.

Given the above, the article aims to develop methodological approaches to forming a model for choosing the optimal investment directions of regional RE advancement on the example of Ukraine in order to promote sustainable green energy development. The purpose of the study has created a set of research objectives:

1. to analyze the key issues and factors influencing the deployment of various RE technologies and projects, as well as the effectiveness of investments in them in Ukraine's regions, taking into account global and local threats;
2. to develop the model for choosing the optimal investment directions in the regional RE development based on preferential financing mechanisms;
3. to approbate the model and form recommendations for energy policy improvements in the RE sector.

The choice of Ukraine as a study object is due to the following considerations. Recently, the state has experienced a green energy boom with the predominant development of solar and wind power plants because of generous economic incentives (high feed-in tariffs) for their construction and operation. However, there is a lack of balanced regulation of investments in other RE technologies. This disadvantage impedes implementing the territories' existing green energy potential. The predominant deployment of solar and wind energy causes distortions in the RE industry, worsens the national energy system balancing, creates new challenges for local energy infrastructure, and more. In addition, Ukraine's regions have different climatic conditions and resource bases for green energy potential implementation, different environmental quality, etc., which makes the country an interesting object for research.

A proposed methodology is a new approach in scientific literature aimed at solving the issue of investment flows distribution in regional RE development. The Ukrainian government can apply it to improve the existing energy policy and minimize risks of rapid and uncontrolled RE plants deployment. Since most states also encounter difficulties in regional RE development, the proposed methodology can be adapted and used by other countries facing similar problems.

The remainder of this article has the following structure. Section 2 presents a literature review. Section 3 describes the research methodology and data. It develops methodological approaches for creating a model to choose the optimal investment directions in regional RE deployment. Section 4 covers and discusses the study results, namely the analysis of factors determining the RE development and the effectiveness of investment in the industry within Ukraine's regions. The optimal amount of state investment support for constructing household solar and wind energy facilities is calculated using the proposed methodology. In addition, the amount of preferential financing for the project of a 30-kW home solar power plant in one of Ukraine's regions is substantiated. Section 5 concludes the paper and presents recommendations for using the study results. In addition, it contains an outlook on further research.

2. Literature Review

Many research publications are devoted to the issue of investment management for RE advancement (for example, [18–29]). However, these studies mostly focus on the problems of attracting cash flows to the industry [13,18,21,30,31], creating a favorable environment for different types of investors [22–24,27,28,32,33], involving various political levers for sustainable development of RE sources in the country [13,19,25,26,28,33], etc.

For instance, Nelson D. et al. [13] analyze the results of the national policies of Germany, Spain and Portugal (Iberia), the United Kingdom, and the Nordic countries of Norway, Sweden, and Finland regarding the investors' attraction to the RE field. The authors emphasize the need: (1) to balance cost-effectiveness and deployment goals; (2) to balance short-term cost-efficiency versus longer-term development in the green energy sector; (3) to develop technology mixes and options and (4) to shape the industry to achieve its objectives under public support. According to the researchers, it is advisable to form the RE national policy, taking into account investor types and investment impact by technology type.

IRENA [23] considers different institutional investors and their potential in RE financing. The authors analyze the investors' challenges and provide policy recommendations for involving these influential stakeholders in the RE deployment.

Mazzucato M. and Semieniuk G. [34] emphasize that investments in the RE industry have increased significantly in recent years. However, the focus on achieving more funding has diverted attention from what is being funded. Since investment flows are distributed evenly, it leads to an asymmetric distribution of investments in RE, so that some areas are overfunded while others are underfunded. Lack of attention to the relationship between investment and directionality causes problems for both the energy sector and investors.

Abba Z. et al. [35] investigate the importance of private investment for RE development and conclude that despite decreasing capital costs, investments in RE projects are low due to unattractive risk-return profiles. The authors reviewed risks in RE investment and methods used for their estimation and mitigation. In addition, they developed a 'holistic multi-dimensional investor risk management framework,' which can be used to identify actions for improving investment risks in a structured manner.

Romaniuk O. and Herasymchuk H. [27] study the global investment trends in RE development and highlight the key countries investing in green energy, geographical peculiarities, and promising areas of sectoral investment.

Kuzmina M. [26] explores the legal aspects of RE investment in Ukraine, considering the investment forms in the industry. The author notes the expediency of joint investment implementation, venture financing of RE projects, and energy cooperatives creation for attracting investments to the industry.

Boiko Yu. and Ryzhkova H. [20] determine the potential for using RE sources in Ukraine and propose a list of typical investment projects to increase energy generation and consumption efficiency. The authors highlight the strategic areas of RE investment and financing programs in Ukraine.

Yemelyanov O. et al. [33] develop mathematical models for financing energy-saving projects, including renewable ones, with the participation of both state financial resources and bank loans. On this basis, researchers justify the share of public funding for such projects and compare the effectiveness of different funding sources for energy-saving measures.

Atari S. et al. [36] introduced real option approaches for modeling the volatile frame condition for assessing green technologies investments. Olaniyi E. and Prause G. [37] used mathematical option models to evaluate the financial performance of energy-saving measures. The authors concluded that the financial result of such investments strongly depends on the economic environment.

Appiah-Otoo I. et al. [38] explore the relationship between crowdfunding and RE generation for 32 national economies from 2013 to 2018 without considering the regional level. The authors estimate crowdfunding influence on energy generation from different RE sources. In particular, they have revealed that a 1% increase in crowdfunding leads to a 0.45% increment in solar energy, 0.37% in wind energy, and 0.30% in other RE generations. However, it does not change hydroelectricity generation. These results are essential for governments to manage RE investments.

Hazan P. [39] studies the regional context of RE deployment issues and proposes to assess the level of RE potential implementation of the territories using the indicators of RE and local energy sector development and indicators of RE advancement impact on the regional energy infrastructure. Ischuk S. and Kazmirchuk M. [40] consider the regional and sectoral structures of RE in Ukraine and highlight such reasons for green energy development as energy scarcity in some regions of the country, depletion of fossil energy resources, environmental contamination due to energy generation by thermal and nuclear power plants, high potential of the major RE types. The authors substantiate the priority of developing decentralized RE objects by low population density, emergency shutdowns of centralized electricity grids consumers, the regional environmental situation, and other factors. However, the recent papers examining the regional RE context do not pay attention to the green energy investment issues.

Bashynska Yu. [41] studies the region's organizational and economic mechanism of RE advancement and identifies its investment component. The researcher notes the problems related to financing the RE facilities construction in Ukraine and substantiates the strategic areas of RE development in the country's Western region by the types of green energy technologies. The paper assesses the foreign investment impact on the regional RE sector deployment, but there are no recommendations for regulating sectoral investment flows.

Kuznetsova H. [42] develops the methodology for selecting the region's priority areas and scale of RE advancement. The author offers to choose local RE objects for priority financing comparing projects' integrated assessments of economic, social, environmental, and other effects. However, the tools formation to justify the regional distribution of green energy investment remains beyond her consideration. Prokopenko O. et al. [43] explored directions for reorienting investment flows under the influence of the COVID-19 pandemic, particularly in the RE sphere.

Overall, the researchers mainly focus on attracting as much investment as possible in the RE industry. At the same time, there is a significant literature gap concerning the territorial regulation of RE investments. Uncontrolled investment flows may create additional problems in the industry, especially in the territorial context. Therefore, the working hypothesis of the paper is that the improvement of the methodology for managing regional investment flows can ensure the balanced deployment of various RE technologies and help better use the local RE potential.

3. Materials and Methods

This section presents the authors' methodological approaches to choosing the optimal RE technology and selecting the optimal RE project for regional investment. In addition, it offers the developed mechanism for budget financing distribution on regional development of RE technologies. The overview of the research data used for the approbation of the developed methodology is provided.

3.1. The Model for Choosing the Optimal Area of Investment in RE in the Region

Until now, RE has been an industry that needs government support. As the most popular scheme of the sector's economic stimulation, feed-in tariffs have been established at the national level. However, they cannot consider the territories' specifics. To solve this issue and use the local potential of RE sources effectively, the regional authorities should regulate the development of various green energy technologies by managing investment flows. Differentiated preferential funding can help implement local RE projects identified by regional authorities as priorities. Additional financing will increase the interest of the population and businesses in constructing certain green energy facility types.

Considering the high feed-in tariffs in Ukraine and facilitating access of homes and businesses to financial resources aimed at the RE development, interest-free loans for green energy capacities construction are the most appropriate for the state and regional authorities to provide. The preferential investment amount can be regulated by increasing or decreasing the basic share of the interest-free loan in the total investment costs for constructing facilities with a particular RE technology. The Section 4 discusses the key factors influencing the basic share change.

The methodology proposed in this study is based on the methodological approach suggested in [44]. This approach determines the optimal investment scenario in RE development by introducing a mechanism of interest-free lending for the construction of RE capacities based on two components: the level of regional man-caused load on the environment and the cost of electricity generation by various RE plants. We have modified and significantly supplemented the above methodological approach, and, on its basis, have formed an extended multifactor model for choosing the optimal directions of investment in the regional RE deployment:

$$LSh_{i,j} = LSh_b \times \sum_{f=1}^{7}(u_f \times c_{fij}), \quad (1)$$

where $LSh_{i,j}$ is the share of the interest-free loan in the total amount of investment costs per 1-MW generating facility in the j-th region for the i-th RE technology, %; LSh_b is the basic share of the interest-free loan in the total amount of investment costs per 1-MW generating facility, %; u_f is the weight of the f-th factor of influence, the unit share, $f = \overline{1,7}$, $\sum_{f=1}^{7} u_f = 1$; c_{fij} is the coefficient reflecting the influence of the f-th factor on the i-th RE technology development in the j-th region, the unit share.

The weights u_f can be determined by the expert assessments method and should be periodically reviewed depending on RE technologies deployment in the regions. Table 1 presents the characteristics of c_{fij} indicators. Similar to weights, they are also dynamic and should be systematically reassessed depending on the regional RE industry and the whole energy sector changes.

The specifics of a particular RE technology and the region of its implementation determine the method for c_{fij} coefficients' calculating. For example, for solar energy, the coefficient c_{fij} may consider the insolation of the j-th territory, the number of sunny days per year, etc. For bioenergy facilities running on biofuels, it is essential to take into account the volume of biofuel produced in the region and supplied from the other areas, the sufficiency and quality of biofuels to ensure the RE facilities' operation, etc. The indicators of the actually achieved and target shares of the i-th RE technology in the regional RE structure use the same calculation algorithm. They reflect the implementation degree of the economically feasible potential of the i-th RE technology in the territory. In particular, for solar energy, the formula for calculating c_{fij} will be the following:

$$c_{1solj} = \frac{Ins_j}{\overline{Ins}} \times x_1 + \frac{D_{sunj}}{\overline{D}_{sun}} \times x_2 + \frac{S_{sol\ j\ tg}}{S_{sol\ j\ act}} \times x_3, \quad (2)$$

where c_{1solj} is the coefficient of the unimplemented economically feasible potential of solar energy in the j-th region, the unit share; Ins_j is insolation in the j-th region, kWh/m^2; $\overline{Ins}$ is average insolation in all regions of the country, kWh/m^2; D_{sunj}, $\overline{D}_{sun}$ are, respectively, the number of sunny days per year in the j-th region and on average around the country; $S_{sol\ j\ tg}$, $S_{sol\ j\ act}$ are, respectively, the solar energy target share in the RE structure of the j-th region (declared in state and regional program documents according to the regional economically feasible potential of solar energy) and actually achieved share, %; x_1, x_2, x_3 are the weights (determined by experts), respectively, for the insolation factor, the number of sunny days and the implementation degree of the economically feasible potential of solar energy, the unit share; $x_1 + x_2 + x_3 = 1$. Instead of or in addition to the indicators of insolation and the sunny days' number, other parameters can be used to reflect the territory's solar energy potential. For example, Koppen's climate classification can supplement an information base to determine climate-dependent indicators for solar energy development in a particular region [45].

Table 1. The characteristics of the coefficients c_{fij} (developed by the authors).

Coefficient	The Coefficient Name	Characteristics
c_{1ij}	the coefficient of unimplemented economically feasible potential of the *i*-th RE technology in the *j*-th region	considers the natural conditions and resource base for the *i*-th RE technology development in the *j*-th region, the implementation degree of the economically feasible potential of the *i*-th RE technology in the territory, and the achieved share of *i*-th RE technology in the regional green energy structure
c_{2ij}	the coefficient of economic stimulation of the i-th RE technology in the *j*-th region	takes into account the feed-in tariff installed for the *i*-th RE technology, the *i*-th RE technology's cost on the world market, and the financial load on the national budget caused by feed-in tariff payments for this technology
c_{3ij}	the coefficient of energy provision of the *j*-th region	considers the degree of meeting energy needs for the *j*-th territory
c_{4ij}	the coefficient of environmental load in the *j*-th region	takes into account the level of environmental pollution in the *j*-th region, the potential of its reduction due to the *i*-th RE technology use, and the environmental friendliness of the *i*-th RE technology
c_{5ij}	the coefficient of energy infrastructure development in the *j*-th region	considers the state and regional level of energy infrastructure development, transmission capacity of energy grids, the focus of RE development on centralization or decentralization of energy supply
c_{6ij}	the coefficient of the *i*-th RE technology influence on balancing energy capacities in the *j*-th region	takes into account the level of balancing energy capacities in the *j*-th region, the need for maneuvering capacities, and the potential growth of balancing energy capacities due to the *i*-th RE technology use
c_{7ij}	coefficient of financial resources available for investing in the *i*-th RE technology in the *j*-th region	considers the existing state, regional, and local programs of preferential investment, lending, assets taxation on the *i*-th RE technology in the *j*-th region

If the target indicators of the solar energy share in the regional RE structure have already been achieved, i.e., $S_{sol\ j\ tg} \leq S_{sol\ j\ act}$, any incentives such as interest-free loans for further solar energy development in the region should not be applied. The RE technology potential has already been implemented at this stage. Therefore, the authorities should support other technologies. Under this condition, further calculation of the c_{1solj} coefficients is inexpedient, and the indicator $LSh_{sol}\ j = 0$. Similarly, if the economically feasible potential of any other RE technology in the region is exhausted ($S_{ij\ tg} \leq S_{ij\ act}$), then $LSh_{ij} = 0$. Thus, existing state, regional and local RE development programs should not provide financial support. However, progress in green energy technologies increases their economically feasible potential over time. Therefore, $S_{ij\ tg}$ should be revised periodically, which may require introducing new programs for RE deployment. Again, the need to stimulate the i-th RE technology advancement in the j-th region using preferential loans may appear.

The calculation of c_{2ij} coefficient is given in the formula:

$$c_{2ij} = \frac{\overline{Ft}}{Ft_i} \times y_1 + \frac{LCOE_i}{LCOE_{ij}} \times y_2 + \frac{S_{Fti}}{S_{Ftij}} \times y_3, \quad (3)$$

where $\overline{Ft}$, Ft_i are, respectively, the average feed-in tariff rate for all RE technologies presented in the country and the feed-in tariff rate for the i-th RE technology, the unit share; $LCOE_i$, $LCOE_{ij}$ are, respectively, the average cost of generating 1 MWh by the i-th RE technology in the world market and the j-th region, EUR/MWh; S_{Fti}, S_{Ftij} are, respectively, the share of average regional feed-in tariff payments for the i-th RE technology in the country's budget and the share of feed-in tariff payments for the i-th RE technology in the j-th region in the country's budget, %; y_1, y_2, y_3 are the weights (determined by the expert method), respectively, for the feed-in tariff rate, the green energy generation cost and the share of the feed-in tariff payment, the unit share, $y_1 + y_2 + y_3 = 1$.

The coefficient c_{3ij} can be calculated by the formula:

$$c_{3ij} = \frac{N_{es}/N_{ge}}{N_{esj}/N_{gej}}, \quad (4)$$

where N_{esj}, N_{gej} are, respectively, the energy needs satisfied with own resources and the general energy needs of the j-th region, MWh/year; N_{es}, N_{eg} are, respectively, the average regional energy needs satisfied with own resources and the average regional general energy needs, MWh/year.

The level of meeting the territory's energy needs at the expense of its resources should be assessed for the RE development stimulation in the region. The higher the level of unsatisfied energy needs of the j-th region than the regional average level (i.e., c_{3ij}), the more relevant the economic incentives for developing RE technologies are to increase the territory's energy independence. However, c_{3ij} considers the region's energy supply based on both traditional and green energy technologies. To achieve sustainability, the region should increase the RE share in its energy mix, meeting more and more energy needs with the RE's help. The coefficient c_{1ij} considers this requirement by accounting for the target and actual shares of the i-th RE technology in the general RE structure of the region.

The coefficient c_{4ij} can be calculated by the formula:

$$c_{4ij} = \frac{L_{epr\ ij}}{L_{ej}}, \quad (5)$$

where $L_{epr\ ij}$, L_{ej} are, respectively, the potential economic losses from the environmental pollution in the j-th region and the total economic losses from the energy complex operating in the j-th region, averted due to the i-th RE technology introduction, EUR/MWh.

The economic losses caused by environmental pollution assess the impacts of energy generation and consumption on the environmental components such as harmful substances emissions, discharges into the water, waste generation, biodiversity loss, etc. The methodology for calculating economic losses indicators is developed in [46–48]. The economic losses averted due to the i-th RE technology introduction reflect the level of RE environmental friendliness and its potential to reduce environmental contamination in the region.

Along with economic losses indicators, world practice widely uses other environmental indicators to assess the effectiveness of green energy deployment. The most popular of them is carbon dioxide emission reductions due to the implementation of RE projects. In particular, in this study, we used the methodology "ACM0002: Large-scale consolidated methodology for grid-connected electricity generation from renewable sources" [49] to evaluate the components of the c_{4ij} coefficient. According to the methodology, the reduction of CO_2 emissions is calculated by the formula:

$$ER_t = BE_t - PE_t, \quad (6)$$

where ER_t is emission reduction in the period t, tons of CO_2-equivalent; BE_t is basic emissions in the period t, tons of CO_2-equivalent; PE_t is projected emissions in the period t, tons of CO_2-equivalent.

Regarding [49], the basic emissions of carbon dioxide from electricity generation by solar power plants are calculated as follows:

$$BE_t = QE_t \times EF_t, \quad (7)$$

where QE_t is the amount of electricity generated by the green power plant in the period t, MWh; EF_t is specific CO_2 emissions from thermal power plants connected to the United Energy System of Ukraine (UESU), due to the electricity generation in the period t, tons CO_2-equivalent.

The calculation of the coefficient c_{5ij} is carried out according to the formula:

$$c_{5ij} = AEl_j \times z_1 + CSR_{ij} \times z_2 + c_{dcj} \times z_3 = AEl_j \times z_1 + \frac{R_{avj}}{R_{rij}} \times z_2 + \frac{S_{dc\ tg\ j}}{S_{dc\ actj}} \times z_3, \quad (8)$$

where AEl_j is access to electricity (electricity grids) in the j-th region, the unit share; CSR_{ij} is the capacity sufficiency ratio of power grids in the j-th region that allows implementing the economically feasible potential of the i-th RE technology. CSR_{ij} is calculated as the ratio of available electricity grid capacity (R_{avj}, MW) to the required electricity grid capacity (R_{rij}, MW) in the j-th region that allows implementing economically feasible potential of the i-th RE technology; c_{dcj} is the coefficient of energy supply decentralization, calculated by the ratio of the target decentralized energy supply share ($S_{dc\ tg\ j}$) in the energy sector structure of the j-th region, declared in state and regional program documents, and the actual decentralized energy supply share ($S_{dc\ actj}$), %; $z_1,\ z_2,\ z_3$ are the weights (determined by the expert method), respectively, for the access to electricity (electricity grids), the capacity sufficiency ratio of power grids and the coefficient of energy supply decentralization, the unit share, $z_1 + z_2 + z_3 = 1$.

The electricity access indicator AEl_j is well-known and widely used by international organizations, particularly the World Energy Council and the International Energy Agency [50,51]. The coefficient c_{5ij} determines the technical capabilities of transferring electricity generated with the i-th RE technology in the region. In addition, it shows the territory's strategy performance in terms of focusing on decentralized or centralized energy supply development. AEl_j and CSR_{ij} values, less than one, indicate the technical problems with connecting new RE facilities to regional electricity grids. Therefore, in this case, the preferential financing of RE projects is irrelevant. Instead, at first, the region's energy infrastructure must be improved. However, it is not an issue for the decentralized RE facilities development, the operation of which does not depend on local electricity grids quality.

The coefficient c_{6ij} can be calculated by the formula:

$$c_{6ij} = \frac{CI_{bj\ act}}{CI_{bij}}, \quad (9)$$

where CI_{bij}, $CI_{bj\ act}$ are, respectively, the index of capacities growth for balancing the UESU if the economically feasible potential of the i-th RE technology would be implemented in the j-th region and the actual index of capacities growth for balancing the UESU, the unit share. Calculations of both indices are carried out according to the formulas:

$$CI_{b\ ij} = \frac{MC_{ij} + SC_{ij}}{GC_{ij}};\ CI_{bj\ act} = \frac{MC_{act} + SC_{act}}{GC_{act}}, \quad (10)$$

where MC_{ij}, MC_{act} are, respectively, the maneuvering installed capacity in the country if the economically feasible potential of the i-th RE technology would be implemented in the j-th region and actual maneuvering installed capacity, MW; SC_{ij}, SC_{act} are, respectively, the energy storage installed capacity in the country if the economically feasible potential of the i-th RE technology would be implemented in the j-th region and the actual energy storage installed capacity, MW; GC_{ij}, GC_{act} is, respectively, the total installed capacity of energy generating facilities in the country if the economically feasible potential of the i-th RE technology would be implemented in the j-th region and actual total installed energy capacity, MW.

The c_{6ij} value more than one means that adding RE capacities reduces the need to balance the UESU. For example, installing the decentralized RE plants raises the c_{6ij} value. Therefore, these projects should be encouraged by increasing preferential funding. If c_{6ij} is less than or equal to one, the new green energy capacity worsens the UESU balance. Due to this, their construction requires less government support or even its abolition.

The coefficient c_{7ij} can be calculated by the formula:

$$c_{7ij} = \frac{\overline{F_{pref\ i}}}{F_{pref\ ij}} \times q_1 + \frac{\overline{F_{sup\ i}}}{F_{sup\ ij}} \times q_2, \tag{11}$$

where $\overline{F_{pref\ i}}$, $F_{pref\ ij}$ are, respectively, the average regional number of existing state, regional, and local programs for preferential financing of the i-th RE technology development in the country and the number of the current state, regional and local programs for preferential financing of the i-th RE technology deployment in the j-th region, units; $\overline{F_{sup\ i}}$, $F_{sup\ ij}$ are, respectively, the average regional financial support amounts of investment projects on the i-th RE technology and the financial support amountes of projects on the i-th RE technology in the j-th region, EUR/MW of installed capacity; q_1, q_2 are the weights (determined by the expert method), respectively, for the factors of the preferential funding programs number and the financial support amount, the unit share, $q_1 + q_2 = 1$.

Thus, model (1) determines the rating of the i-th RE technology for its implementation in the j-th region using preferential financing.

3.2. Selection of the Optimal RE Project for Investment in the Region

In addition to the considered approach, the indicator $LSh_{i,j}$ can be adjusted according to the features of a certain RE project:

$$LSh_{i,j,n} = LSh_{i,j} \times \textstyle\sum_{l=1}^{4} (u_l \times w_{l,i,j,n}), \tag{12}$$

where $LSh_{i,j,n}$ is the share of an interest-free loan in the total amount of investment costs per 1 MW of the installed capacity of the n-th generating facility, which uses the i-th RE technology in the j-th region; u_l is the weight of the l-th characteristic of the n-th project, the unit share, $l = \overline{1,4}$, $\sum_{l=1}^{4} u_l = 1$; $w_{l,\ i,j,n}$ is the indicator that reflects the l-th characteristic of the n-th project that uses the i-th RE technology in the j-th region, the unit share.

The weights u_l can be determined by expert assessments and should be periodically reviewed depending on the RE technologies development in the region. Table 2 presents the essence of indicators $w_{l,\ i,j,n}$.

According to the specified coefficients in Table 2, the RE projects for the business sector and households should be considered separately. The reason is the different financial opportunities for businesses and the population to invest in RE and the scales of the proposed projects. For example, homes are willing to install small green power plants to meet their needs. At the same time, business structures prefer to build larger RE facilities to maximize profits from selling electricity at a feed-in tariff. These factors cause lower competitiveness of household RE facilities than industrial ones. Therefore, both sectors should receive preferential funding under different programs and based on other criteria.

Table 2. Characteristics of the coefficients $w_{l,\ i,j,n}$ (developed by the authors).

Coefficient	The Coefficient Name	Characteristics
$w_{1,i,j,n}$	the coefficient of the installed capacity of the n-th facility planned for construction in the j-th region and using the i-th RE technology	It is calculated as the ratio of the n-th RE facility's installed capacity (MW) to the regional average installed capacity of the power plants using the i-th RE technology in the j-th region (MW). Thus, the larger the installed capacity of the n-th facility, the more attractive it is for the regional government on equal terms because larger facilities provide lower generation costs per 1 kWh.
$w_{2,i,j,n}$	the coefficient of the annual energy volume generated by the n-th facility planned for construction in the j-th region and using the i-th RE technology	It is calculated as the ratio of the annual electricity volume generated by the n-th RE facility (MWh) to the regional yearly average electricity volume generated by all power plants using the i-th RE technology in the j-th region (MWh). As the purpose of RE preferential financing in the regions is to increase the green energy share in the territory's energy mix, the priority projects are the ones that provide the larger annual volume of green energy generation on other equal terms.
$w_{3,i,j,n}$	the coefficient of the life cycle of the n-th facility planned for construction in the j-th region and using the i-th RE technology	It is calculated as the ratio of the life cycle of the n-th RE facility (years) to the regional average life cycle duration of power plants using the i-th RE technology in the j-th region (years). Thus, the longer the life cycle of a RE facility, the more attractive it is for the regional government (on other equal terms), as it can generate electricity over a more extended period, meeting the region's energy needs.
$w_{4,i,j,n}$	the coefficient of the investment cost of the n-th facility planned for construction in the j-th region and using the i-th RE technology	It is calculated as the ratio of the average regional investment cost per 1 MW of installed capacity of facilities using the i-th RE technology in the j-th region (EUR) to the investment cost per 1 MW of installed capacity of the n-th RE facility (EUR). The less specific investment cost is required for the construction of the n-th RE facility, the more attractive it is for the regional government on other equal terms.

3.3. The Mechanism for Budget Financing Distribution on Regional Development of RE Technologies

Usually, the budgets of different levels have limited funds to finance RE projects. Therefore, management decisions on the state and local budget funds allocation to cover the share of interest-free loans ($LSh_{i,j}$ and $LSh_{i,j,n}$) for specific RE projects in the regions should be based on the following rule:

$$\sum_{n=1}^{N}(LSh_{i,j,n} \times I_{nijt}) \leq F_{bud\ ijt}, \tag{13}$$

where $F_{bud\ ijt}$ is the total amount of allocated budget funding to cover the share of interest-free loans on projects using the i-th RE technology in the j-th region in the t-th year, EUR; I_{nijt} is an investment in the n-th facility ($n=\overline{1, N}$) using the i-th RE technology in the j-th region, in the t-th year, EUR; N is the number of projects using the i-th RE technology in the j-th region in the t-th year and selected for preferential financing. At the same time, the $F_{bud\ ijt}$ value should be determined separately for households and the business sector.

Following the rule (13) guarantees the budget financing of selected projects in a particular year but limits the range of facilities that may receive such funding. Therefore, the criterion for including the n-th facility in the funding list is obtaining a higher $LSh_{i,j,n}$ value ($LSh_{i,j,n} \rightarrow$ max) by the project compared to its competitors. After the projects' ranking according to $Sh_{i,j,n}$, the funding amounts for each project is calculated considering $LSh_{i,j,n}$ and I_{nijt}. Regarding the rule (13), the projects with lower $LSh_{i,j,n}$ are cut off if inequality ceases to be followed.

The $F_{bud\ ijt}$ calculation provides the distribution of the total budget funding allocated in the t-th year for the RE development in the j-th region between different green energy technologies. The distribution mechanism includes two stages.

At the first stage, the model (1) is applied to determine the indicators $LSh_{\ i,j}$ for each from K RE technologies developing in the j-th region. The weights for the i-th RE technology in the j-th region (d_{ij}) are calculated by the formula:

$$d_{ij} = \frac{LSh_{\ i,j}}{\sum_{i=1}^{K} LSh_{\ i,j}}. \tag{14}$$

At the second stage, $F_{bud\ ijt}$ indicators are processed for different RE technologies in the j-th region:

$$F_{bud\ ijt} = d_{ij} \times F_{bud\ jt}, \tag{15}$$

where $F_{bud\ jt}$ is the total allocated budget funding for the RE development in the j-th region in the t-th year, EUR.

Implementing the proposed methodological approach ensures budget support for investment in the region's priority areas of RE development. It helps optimally allocate available public financial resources for green energy projects, taking into account the territories' specifics.

3.4. Research Data

The approbation of the developed methodology was performed on the example of households of the Sumy region, Ukraine, for projects involving 30-kW solar and wind power plants construction. 30 kW is the highest permitted capacity for the Ukrainian home RE facilities to acquire a feed-in tariff. The national government sets the feed-in tariff until 2030. In addition, 30-kW green energy facilities are characterized by the lowest levels of energy generation costs compared to home RE plants of smaller capacity due to the scale effect. Therefore, 30-kW RE facilities demonstrate higher competitiveness and faster payback.

The necessity to increase energy independence and energy efficiency of the residential sector in Ukraine explains the choice of households for approbation. The Ukrainian homes need to transfer from energy consumers to prosumers, who produce and consume energy for their own needs. Most of the population in the country has low incomes, which significantly limit the opportunities to invest in small RE projects. Ukrainian feed-in tariffs ensure the profitability of domestic RE plants. However, households lack affordable financial resources for their construction. Therefore, feed-in tariffs should be supplemented with state financial support to increase investment in the green energy sector, improve low-income homes' energy supply, and ensure the diversity of RE technologies developing in the regions.

Home wind and solar energy installations have been chosen for research among other RE technologies because today Ukraine's households can acquire a feed-in tariff only for these RE technology types. The choice of the Sumy region for the study is due to the following considerations:

- this northern territory is an energy-deficient region;
- it has sufficient potential for RE development, and
- the level of the population income is slightly lower than the average Ukrainian one.

Thus, investment support for solar and wind energy projects in the territory's residential sector is highly relevant. In addition, the high level of physical and moral depreciation of fixed assets of energy and housing and communal enterprises in the region, which is typical for Ukraine [52,53], requires assets' renewal based on energy-efficient and RE technologies.

The information base for calculations includes open data of the World Bank, World Energy Council, State Agency on Energy Efficiency and Energy Saving of Ukraine, National Commission for State Regulation of Energy and Public Utilities of Ukraine, State Statistics Service of Ukraine, NEC "Ukrenergo", Global Solar and Wind Atlases as well as the data from the authors' previous studies.

4. Results and Discussion

Based on the proposed methodology and factor analysis of regional RE development, this section substantiates the optimal amount and mechanisms of state investment support for constructing household solar and wind energy facilities on the example of Ukraine's region.

4.1. Factor Analysis of Regional RE Development

Today national governments face many issues of regional RE deployment, which are related mainly to the shortcomings of state regulation. Let us summarize these problems on Ukraine's example and highlight the key factors determining the need for investment management in green energy advancement.

1. Lack of state regulation of RE investment flows causes uneven green energy capacity distribution throughout the country due to better climatic and natural conditions in some (including southern) regions. RE development is more profitable in the south and the south-east; therefore, it encourages the active construction of green energy facilities. A striking example of imperfect RE policy is the concentration of more than 30% of Ukrainian solar power capacities in Crimea in 2014, which were lost due to the peninsula's annexation by the Russian Federation.
2. The uneven deployment of various RE technologies in the regions is due to the substantial state economic support for certain RE types. A bright example is solar energy in Ukraine. Solar power plants have the highest feed-in tariffs; therefore, these projects are the most profitable. Another reason for the predominant development of certain RE technologies is faster progress in reducing their cost. For example, the Levelized Cost of Energy (LCOE) for wind decreased from 169 USD/MWh in 2009 to 54 USD/MWh in 2020, or 3.13 times [54]. Such an accelerated decline in the RE technologies' cost significantly increases the profitability of relevant projects. As a result, solid economic incentives and reducing energy generation costs for wind and solar installations in Ukraine have led to the predominant development of solar (the first place) and wind power plants (the second place) recently. Simultaneously, the feed-in tariff payments from the national budget for these RE facilities have significantly increased. Instead, other sub-sectors of the RE industry remain underdeveloped. Among them is bioenergy, which can use local resources and ensure organic waste processing into fuel and electricity while strengthening regional energy and environmental security.
3. The existing mismatch between the RE facilities' installed capacity and the actual energy needs of the territories requires state regulation, including changes in investment policy. The consequences of rising imbalance are electricity shortages in some regions (for example, the industrialized eastern ones) and surpluses in others (for instance, the southern territories, where many solar power facilities are located). Since electricity transmission causes technological losses and additional economic costs for the energy infrastructure construction and operation, it is more effective to encourage investment in new decentralized green energy capacities based on local energy needs.
4. Failure to consider the territories' environmental issues while developing the RE capacities reduces the positive ecological effects of investing in green energy deployment. In particular, RE technologies should be boosted in industrial regions with a high level of environmental pollution that can be reduced due to green energy. In addition, RE development in tourist and recreational areas is essential from an ecological point of view.
5. The choice of RE projects for investment should take into account the peculiarities of energy infrastructure and terrain. For example, developing green energy capacities is more reasonable in remote and mountainous areas to ensure their autonomous energy supply. In addition, building and connecting RE facilities to centralized energy grids requires raising their capacity. Uncontrolled connection of green power plants to local

electricity grids can lead to accidents and increased depreciation of power equipment due to grid overloading.

6. The investment policy in the RE sector should promote an increase in balancing capacities of the UESU for its sustainable operation. Currently, the green energy facilities (mainly solar and wind power plants) only add to the problems of balancing the UESU. It is due to the state-guaranteed purchase of 100% of green electricity generated and the unpredictability and instability of RE facilities' work. Instead, the development of maneuvering hydro and water-storage power plants would contribute to the energy supply stabilization.
7. The lack of reliable financial support for the construction of regional RE plants hinders the industry's advancement. In the absence of affordable lending programs, preferential taxation, etc., high investment costs in constructing green energy facilities deter the population and businesses from investing in RE, despite attractive feed-in tariffs. Therefore, implementing state and local investment programs can provide financing or co-financing of those RE technologies most needed by a particular territory.
8. The growing political orientation of Ukraine towards the European Union highlights future development paths of the national RE policy comprising the regulatory frame conditions for RE investments. CO_2 taxation is an essential instrument for supporting green investments in the European Union since it internalizes environmental costs into energy production. Philipp R. et al. [55] investigated the financial performance of energy-saving investments under the frame conditions of increasing CO_2 taxation schemes. They revealed that in the long-term, RE investments might become economically favorable.

The issues mentioned above cause unfair consumption of RE social and economic benefits in different regions. They distort the development of certain RE types and infrastructure, accumulate the UESU balancing problems, increase the financial load of green energy on the national budget, provide extra profits for owners of the most promising RE technologies, etc. These problems were exacerbated during 2018–2021 due to the rapid development of solar energy on high feed-in tariffs and the lack of state regulation of RE capacities. In addition, during the spring lockdown of 2020, the issue of balancing the UESU became critical for the first time when environmentally dirty and expensive but maneuverable thermal power plants were used to balance the county's energy system.

Thus, based on the conducted analysis, we can identify the following key factors which affect the current RE development in the regions and should be considered when adjusting the state investment policy in the RE industry:

- climatic conditions and resource base for a certain RE technology deployment in the region;
- the degree of implementing the economically feasible potential of a certain RE technology in the region;
- the feed-in tariff value for a particular RE technology;
- the rate of the energy generation cost reduction for a certain RE technology;
- the degree of RE technologies diversification in the region and the share of a specific RE technology in the overall RE structure on the territory;
- the degree of regional energy needs satisfaction;
- the level of environmental pollution in the region and targets for its reduction;
- the degree of environmental friendliness of a certain RE technology (for example, solar and wind energy facilities are the most environmentally friendly; bio- and small hydropower plants are less ecologically friendly, and large hydropower plants are associated with a higher environmental load);
- the level of energy infrastructure development in the region, the transmission capacity of energy grids;
- the level of balancing energy capacities in the region and the need for maneuvering capacities;
- region's orientation to energy supply centralization or decentralization (in particular, depending on the terrain and available energy infrastructure);

- availability of financial resources for investment in projects using a certain RE technology in the region, RE financial support from local authorities.

In addition, financial support for regional RE projects should consider the facilities' installed capacity planned for construction (larger power plants provide lower energy generation costs, so they are more financially attractive), annual energy volumes generated by RE facilities, the life cycle duration of RE projects, and the investment amount for green power plants.

The developed model for choosing the optimal investment directions in RE deployment in the region considers the above-mentioned factors influencing green energy advancement and can justify the amount of financial support for RE projects.

4.2. Considering the Regional Development Goals for Choosing RE Investment Directions

The primary goals of regulating investments in the regional RE advancement are to ensure sustainable development of local energy industries, reduce the territories' dependence on external energy resources, use local resource and energy base efficiently, improve the regions' environment, meet the energy needs of population and businesses, and provide a reliable energy supply.

Firstly, state regulation should ensure relatively even placement of RE facilities in regions with deteriorating, intense and catastrophic environmental situations [44]. Secondly, investment policy should stimulate the development of new RE technologies poorly represented or absent in the domestic RE market (for example, geothermal energy, offshore wind farms, etc.). Thirdly, the state should encourage spreading the cheapest green energy facilities. The latter will reduce the feed-in tariff payments from the national budget and decrease the weighted average electricity price on the market.

Using the methodology from Section 2, let us determine the share of the interest-free loan in the total investment costs per 1 MW of the generating facility ($LSh_{i,j}$) on the example of home 30-kW solar photovoltaic ($LSh_{sol,Sumy}$) and wind power ($LSh_{win,Sumy}$) plants located in the Sumy region, Ukraine.

When calculating $LSh_{i,j}$ for the two mentioned technologies, the following assumptions were applied:

- weights of factors u_l, u_f and weights x, y, z, q were taken equal to each other when calculating coefficients c_{fij}, i.e., for example, $x_1 = x_2 = x_3 = 1/3$, $q_1 = q_2 = 1/2$, etc.;
- cost values calculations were performed in euros to avoid the impact of Ukraine's national currency (the hryvnia) exchange rate fluctuations. Moreover, due to hryvnia's instability, the feed-in tariff is legally fixed in euros;
- in the absence of available official data, alternative information was used to calculate the indicators, or they were replaced by others that best met the calculation objectives. If the data was completely absent, the indices were not calculated;
- calculations were performed as of 31 December 2020, as most of the indicators were available on this date. The official exchange rate of hryvnia to euro on this date was UAH 34.74 for 1 EUR. It was used to assess cost values in euros [56].

Calculation of the coefficient of the unimplemented economically feasible solar energy potential for the Sumy region ($c_{1sol\ Sumy}$) was performed using the formula (2). Table 3 presents the indicators to assess $c_{1sol\ Sumy}$. Due to a lack of regional data, the number of sunny days was replaced with two other parameters: specific photovoltaic power output and air temperature.

A formula similar to the formula (2) was used to process the coefficient of the unimplemented economically feasible wind energy potential for the Sumy region ($c_{1win\ Sumy}$). However, the number of sunny days and insolation were replaced with mean power density and mean wind speed (see Table 3).

In the absence of local targets for various RE technologies development in Ukraine's regions, it was impossible to determine the relevant indicators, so they were excluded from consideration.

Table 3. Indicators of solar and wind potential of Ukraine and the Sumy region (compiled by the authors according to [57,58]).

Indicator	Ukraine in Average	The Sumy Region
The indicators of solar energy potential		
Specific photovoltaic power output, kWh/kWp per year	1183.9	1171.1
Insolation (direct normal irradiation per year), kWh/m^2	1134.0	1077.7
Air temperature (average per year), °C	9.1	8.0
The indicators of wind energy potential		
Mean power density (data for 10% windiest areas, height 10 m), W/m^2	131	105
Mean wind speed (data for 10% windiest areas, height 10 m), m/s	4.47	4.42

According to calculation results, $c_{1sol\ Sumy} = 0.94$ and $c_{1win\ Sumy} = 0.9$. These values are less than one. Thus, the available economically feasible potential of the considered RE technologies is slightly lower than the average Ukrainian one. Therefore, financing solar and wind energy deployment in the region is less effective than, for example, in the southern territories because of less favorable natural and climatic conditions.

The calculation of the coefficients of solar and wind energy economic stimulation for the Sumy region ($c_{2sol\ Sumy}; c_{2win\ Sumy}$) was carried out using the formula (3).

The algorithms specified in [59] were applied to process the feed-in tariff rates. The feed-in tariff coefficients corresponded to residential solar and wind power plants put into operation from 1 January 2020 to 31 December 2024 [60]. Table 4 summarizes the calculation results.

Table 4. Feed-in tariff and cost (according to the LCOE method) of electricity generated by household 30-kW solar and wind power plants (calculated by the authors).

Indicator	Solar Power Plants	Wind Power Plants
Feed-in tariff, EUR/MWh	15.86	9.91
Average feed-in tariff rate for all RE technologies presented on the market of Ukraine's private households, EUR/MWh	12.89	
The cost of generating 1 MWh in the Ukrainian residential sector, calculated according to the LCOE method, EUR/MWh	61.41	58.14
The average world cost of generating 1 MWh, calculated according to the LCOE method, EUR/MWh	40.07	48.59

LCOE for household 30-kW solar and wind power plants was estimated in the study [61]. Recent scientific literature has no coherent data on the world average cost of electricity generation by home solar and wind power plants. Therefore, we used the electricity generation cost data for the mentioned RE technologies on the world market in 2020 [54]. The calculation results are shown in Table 4.

The feed-in tariff payments shares in the national budget for solar and wind power plants were calculated by multiplying electricity volumes generated by households in Ukraine (regional average indicator) and the Sumy region using each RE technology in 2020 [62,63] and the feed-in tariff rates for the mentioned technologies (see Table 4). The open sources do not contain data on electricity generation by household solar power plants in the Sumy region in 2020, but information on their installed capacity of 16.58 MW [64]. Therefore, we calculated the indicator based on forecasted annual volumes of electricity generated by solar power plants in the Sumy region, namely 1169 MWh/year per 1 MW of installed capacity [65].

As for wind power plants, there are no small wind turbines with a feed-in tariff in the local households [66]. Thus, it is impossible to calculate the ratio of feed-in tariff payments shares ($\frac{S_{Fti}}{S_{Ftij}}$). Therefore, this indicator for wind energy was excluded from consideration. Table 5 presents the calculation data.

Table 5. The feed-in tariff payments from the national budget for solar and wind energy facilities in Ukraine and the Sumy region (calculated by the authors).

Indicator	Solar Power Plants	Wind Power Plants
The electricity amount generated by households in Ukraine, MWh	733,000.00	384.00
The average regional electricity volume generated by households in Ukraine, MWh	30,541.67	16.00
The electricity amount generated by households in the Sumy region, MWh	19,382.02	0.00
Feed-in tariff for household power plants in Ukraine, EUR/MWh	15.86	9.91
The total amount of feed-in tariff payments from the national budget in Ukraine's residential sector, EUR	11,625,380.00	3805.44
Average regional amount of the feed-in tariff payments from the national budget in the residential sector, EUR	484,390.83	158.56
The amount of the feed-in tariff payments from the national budget in the residential sector of the Sumy region, EUR	303,910.10	0.00

According to the calculations, $c_{2sol\ Sumy} = 1.02$ and $c_{2win\ Sumy} = 1.07$. The indicators' values are more than one. Thus, additional preferential funding is feasible for two RE technologies development in local households. At the same time, wind energy needs more economic support.

The energy provision coefficient of the Sumy region c_{3iSumy} was processed by the formula (4). We assessed the degree of regional electricity need satisfaction (regardless of energy generation source) with the local energy production. Since both solar and wind energy can meet the territory's energy needs, the coefficient was assumed to be the same for both considered RE sources ($c_{3sol\ Sumy} = c_{3win\ Sumy}$). According to [67], the electricity release in the Sumy region in 2020 amounted to 160 thousand MWh, and the annual volume of consumed electricity was 1196.9 thousand MWh. That year the average regional electricity release in the country amounted to 5487.88 thousand MWh, and the yearly average electricity volume used in the regions was 3355.54 thousand MWh. Therefore, $c_{3sol\ Sumy} = c_{3win\ Sumy} = 12.23$. The large value of the indicator is due to the high energy deficit in the Sumy region compared to other Ukraine's regions since the average region in the country generates 1.64 times more electricity than it consumes. Thus, financial support for RE technologies in the household sector is essential for improving the territory's energy supply.

The formula (5) was used to process the coefficients of environmental load in the Sumy region ($c_{4sol\ Sumy}$; $c_{4win\ Sumy}$) considering operation of home solar and wind power plants. The numerator and denominator of the fractions were determined by dividing the total amount of relevant environmental losses by the volume of, respectively, green and total electricity generated in the region.

The open statistical data on environmental load indicators in Ukrainian regions is characterized by the lack of detailed information on cost estimates of losses from environmental pollution caused by different businesses and population activities. Economic losses are occasionally studied by Ukrainian scientists and reported. However, there are no systematic official assessments published in open sources. Therefore, based on available information, we have estimated the averted losses from the CO_2 emissions reduction due to the RE projects implementation. Carbon dioxide emissions are one of the main components of environmental pollution in the energy sector. Their volumes are used worldwide to assess the environmental performance of energy-saving measures and green power plants, as well as to determine international and national commitments to improve environmental quality.

Ukraine is among the TOP-30 countries globally that are the largest CO_2 emitters due to fossil fuel use [68]. Regarding environmental contamination, the energy industry ranks first among other sectors of the Ukrainian national economy; its contribution is about 76% of the total carbon dioxide emissions in recent years [69].

In line with the updated nationally determined contribution to Paris Climate Agreement, Ukraine has committed itself to reduce greenhouse gas emissions to 35% compared to 1990 [69]. The list of measures to achieve this indicator includes, in particular, the modernization of energy companies [69]. The government will replace most existing coal-fired power plants to cut emissions to the level set by Directive 2010/75/EU of the European Parliament and the Council on Industrial Emissions (integrated pollution prevention and control) [70]. According to [69], green energy facilities are considered to be a cost-effective replacement for old coal-fired power plants. Therefore, in this study, we have focused on estimating the CO_2 emissions reduction due to replacing electricity generated by coal-fired thermal power plants with electricity from household solar and wind energy installations.

To facilitate calculations, it was assumed that specific (per 1 ton of CO_2) economic losses caused by CO_2 emissions and averted because of a particular RE technology introduction and specific economic losses from CO_2 emissions due to the operation of the Sumy region energy sector are equal. Therefore, the environmental load coefficients $c_{4sol\ Sumy}$; $c_{4win\ Sumy}$ can be determined as the ratio of CO_2 emission reductions per 1 MWh of green electricity due to the introduction of a particular RE technology in the residential sector and total CO_2 emissions per 1 MWh of total electricity generated by the region's energy industry. Unfortunately, official statistics have no territorial data on carbon dioxide emissions by type of economic activity. Therefore, the indicator of CO_2 emissions from stationary pollution sources in the Sumy region was used for calculation. It amounted to 1295.3 thousand tons in 2020. To ensure data comparison, the amount of electricity consumed in the region (1196.9 thousand MWh) was used instead of the amount of electricity generated [67,71].

According to "ACM0002 methodology: Large-scale consolidated methodology for grid-connected electricity generation from renewable sources" described in Section 2, the project emissions (PE_t) from solar and wind power generation are zero. Specific CO_2 emissions from electricity generation by thermal power plants replaced with the green ones are 1.063 tons of CO_2-equivalent/MWh [72]. Thus, this indicator reflects the CO_2 emissions reduction per 1 MWh of green electricity generated by solar and wind installations of households. Given the above, $c_{4sol\ Sumy} = c_{4win\ Sumy} = 0.98$.

The values of the coefficients are less than one. On the one hand, this may indicate that measures to reduce energy consumption are more effective than transition to green electricity generation. Therefore, preferential funding for RE projects is less important. On the other hand, the obtained results may be ambiguous due to assumptions since we considered CO_2 emissions from stationary sources and electricity consumed in the whole region, not precisely in the energy sector.

The formula (8) was applied to process the coefficients of energy infrastructure development in the Sumy region $c_{5sol\ Sumy}$; $c_{5win\ Sumy}$. According to the World Bank [73] and World Energy Council [50], the access to electricity in Ukraine is 100%, i.e., $AEl_{Sumy} = 1$. As our study is based on RE deployment indicators, set out in state program documents, the industry advancement is planned regarding the provision of sufficient electricity grids capacity. Otherwise, it threatens systemic blackouts in the power sector. Therefore, $CSR_{sol\ Sumy} = CSR_{win\ Sumy} = 1$. The reliable calculation of the energy sources decentralization coefficient c_{dcSumy} is impossible due to the lack of official statistic data on the actual levels of energy sources decentralization in Ukraine and the lack of these targets in state and regional program documents. Thus, c_{dcSumy} was excluded from the calculations. Therefore, $c_{5sol\ Sumy} = c_{5win\ Sumy} = 1$.

Determination of the coefficients of RE technology influence on balancing energy capacities in the region ($c_{6sol\ Sumy}; c_{6win\ Sumy}$) was carried out according to the formula (9). The open statistical sources in Ukraine do not contain data on the regional distribution of maneuvering capacities and their impact on balancing the UESU. In addition, there is a lack of information about regional needs for maneuvering and energy storage capacities depending on different RE technologies development. Considering the available data for calculating the components of the formula (9) and the UESU as an integral object, the balancing of which is carried out regardless of the territorial principle, we assumed that actual and required maneuvering and energy storage capacities were used for maneuvering both solar and wind power plants of households. Therefore, the calculation of CI_{bij}, $CI_{bj\ \mathrm{act}}$ is the same for two studied RE technologies.

As of the end of 2020, the installed capacity of Ukrainian power plants was 54,773 MW, with a predominance of more maneuvering thermal power plants (Table 6). In 2020, only 15 power plants had passed the certification of available maneuvering capacity and could provide ancillary services for balancing the UESU. They include hydro power plants (HPP)—Dnipro HPP-1, Serednyodniprovska HPP, Kaniv HPP, Kakhovka HPP, Dnipro HPP-2, Kremenchuk HPP, Kyiv HPP, Dniester HPP; thermal power plants (TPP)—Kurakhiv TPP, Zaporizhzhya TPP, Prydniprovska TPP, Kryvyi Rih TPP, Ladyzhyn TPP, Burshtyn TPP and a combined heat and power plant (CHP)—Kharkiv CHP-5 [74].

Table 6. Installed capacity of Ukraine's power facilities in 2020, MW [74].

Energy Facilities	MW	%
Thermal power plants	21,842	39.9
Nuclear power plants	13,835	25.3
Hydro power plants	4829	8.8
Hydro accumulating power plants	1488	2.7
Combined heat and power plants	6105	11.1
Solar power plants	5363	9.8
Wind power plants	1111	2.0
Biopower plants	200	0.4
Total	54,773	100

The mentioned energy capacities can provide the following services [74]:

1. Regulation of frequency and active capacity of the UESU, namely the provision of (1) frequency support reserves (primary regulation-FSR); (2) frequency recovery reserves (secondary control (FRS), FRS may consist of reserves activated in automatic (aFRS) and manual (mFRS) modes; replacement reserves-RR).
2. Maintenance of reliability and electricity quality parameters in the UESU, namely: (1) services for voltage and reactive power regulation; (2) services to ensure the restoration of the UESU operation after system accidents.

As of the end of 2020, the total volume of certified FSR was ±157 MW, aFRS was 1629 MW (±904.5 MW), mFRS was 3960 MW (−3909 MW) and RR was 4658 MW [75]. Thus, the actual capacity of maneuvering power generating facilities in the country was 10,404 MW.

In 2020, Ukraine had no energy storage capacities. The system operator NEC "Ukrenergo" together with the European Bank for Reconstruction and Development and the International Finance Corporation, is planning to implement the first projects of constructing a network of energy storage facilities with a capacity of 220 MW in the nearest future within the signed memorandum [76]. According to NEC "Ukrenergo," the effective integration of green electricity into the UESU and the system safe operation require the following additional maneuvering and energy storage capacities: for 2021—1.6 GW, for 2025—1.8 GW, and for 2030—2 GW [77].

Given the above, Table 7 shows the initial data for calculating $c_{6sol\ Sumy}$; $c_{6win\ Sumy}$. Due to the lack of regional information, the data correspond to the whole country. The value of installed power generating capacity for August 2021 [78] is conditionally accepted as the total installed energy capacity in the country under implementing the economically feasible potential of RE technologies. According to the calculation results, $c_{6sol\ Sumy} = c_{6win\ Sumy} = 0.88$, i.e., the deployment of solar and wind energy in households will add problems with balancing the UESU. Thus, additional preferential funding for green energy projects is not appropriate regarding this issue.

Table 7. Data for calculating $c_{6sol\ Sumy}$; $c_{6win\ Sumy}$.

Indicator	Indicator Value
Installed capacity of maneuvering energy generating facilities in the country under the condition of implementing economically feasible potential of RE technologies, MW (MC_{ij})	12,004
The actual capacity of maneuvering energy generating facilities in the country (as of 2020), MW (MC_{act})	10,404
The installed capacity of energy storage capacities in the country under the condition of implementing economically feasible potential of RE technologies and the actual one, MW (SC_{ij}, SC_{act})	0
The total installed capacity of energy generating facilities in the country under the conditions of implementing economically feasible potential of RE technologies, MW (GC_{ij})	55,675
The actual installed capacity of energy generating facilities in the country (as of 2020), MW (GC_{act})	54,773

To assess the coefficients of financial resources available for investing in RE projects $\left(c_{7sol\ Sumy}; c_{7win\ Sumy}\right)$, let us consider the existing state program of "warm" loans. It provides partial funding for households united in condominiums or housing cooperatives to purchase heat pumps and solar collectors for improving homes' heating and hot water supply [79,80]. However, this program does not support investments in residential solar photovoltaic and wind power plants. The reason is high feed-in tariffs for green energy generated by households. According to legislators, these tariff rates are sufficient to develop the sector. Moreover, Ukraine's local authorities do not provide investment support for small RE projects. The only opportunity for the population is two loan programs of state banks such as "Eco Energy" of Ukrgasbank [81] and "Green Energy" of Oschadbank [82]. Since these programs are commercial proposals formed in partnership with engineering companies operating in the domestic RE market, they cannot be considered as state support for green energy deployment. Given the above, it is impossible to calculate the coefficients $c_{7sol\ Sumy}$; $c_{7win\ Sumy}$ in the absence of current state RE investment support for homes.

Table 8 summarizes the results of calculating c_{fij} coefficients and the share of the interest-free loan in the total amount of investment costs per 1 MW of installed capacity for domestic 30-kW solar photovoltaic ($LSh_{sol,Sumy}$) and wind power ($LSh_{win,Sumy}$) plants located in the Sumy region, Ukraine. The basic share of the interest-free loan in the total investment costs per 1 MW of installed capacity of the RE generating facility is set at 20%. Its value is analogical to the minimum reimbursement rate for loans given to the population on the "warm" loans state program for implementing energy efficiency measures [79]. If necessary, the basic share can be reduced or increased depending on preferential funding providers' (state or local authorities) decisions.

The calculations demonstrate that household solar and wind power plants in the Sumy region received almost the same financial support. However, the projects for constructing home wind power plants in the area should become slightly higher (by 0.014 percentage points) interest-free loan share. The estimated shares are more than 2.8 times higher than the 20% base rate. They indicate the need to strengthen financial support for RE projects in the regional residential sector. The main factor increasing the basic share of funding was the territory's energy deficit.

Table 8. Calculation of interest-free loan share in the total investment costs per 1 MW of installed capacity for home solar photovoltaic and wind power plants located in the Sumy region, Ukraine (calculated by the authors).

Indicator	Indicator Value	Indicator	Indicator Value
$c_{1sol\ Sumy}$	0.94	$c_{1wind\ umy}$	0.90
$c_{2sol\ Sumy}$	1.02	$c_{2win\ Sumy}$	1.07
$c_{3sol\ Sumy}$	12.23	$c_{3win\ Sumy}$	12.23
$c_{4sol\ Sumy}$	0.98	$c_{4win\ Sumy}$	0.98
$c_{5sol\ Sumy}$	1.00	$c_{5win\ Sumy}$	1.00
$c_{6sol\ Sumy}$	0.88	$c_{6win\ Sumy}$	0.88
u_f	0.17	u_f	0.17
LSh_b	20.00%	LSh_b	20.00%
$LSh_{sol,Sumy}$	56.86%	$LSh_{win,Sumy}$	56.87%

The slight difference between $LSh_{sol,Sumy}$ and $LSh_{win,Sumy}$ is due to using generalized data for both RE technologies. The lack of detailed statistical information defines the model's limitations. In fact, only c_{1ij} and c_{2ij} coefficients were calculated separately for two technologies. It somewhat limits the application of obtained results for developing individual policies for solar and wind energy industries but at the same time, can serve as a guide for adjusting the volume and mechanisms of investment support for RE deployment in the residential sector.

4.3. Identifying Priority Home Green Energy Projects for Financing in the Region

Further stimulation of residential green power plants construction should help develop different RE technologies on the territory and implement the RE projects with the best technical and economic characteristics. Considering these criteria, let us calculate the interest-free loan share in the total amount of investment costs per 1 MW of installed capacity ($LSh_{i,j,n}$) on the example of a home 30-kW solar photovoltaic power plant located in the Sumy region, Ukraine.

As there were no residential wind energy facilities on the territory in 2020, it is impossible to justify the interest-free loan share for funding new wind power plants due to the lack of a comparison base. Therefore, when determining the first projects on constructing small wind energy capacities in the area, it is advisable to use their ranking. The latter may involve well-known approaches to selecting investment projects, for example, discussed in [83]. As the region's wind energy develops, the interest-free loan share for further projects can be calculated by the formula (12).

To determine $LSh_{i,j,n}$ for a home 30-kW solar photovoltaic power plant ($LSh_{sol,Sumy,30}$) according to the formula (12), the same assumptions were applied as those used for $LSh_{sol,Sumy}$ calculation. The initial data for processing the coefficients $w_{l,\ i,j,n}$ by the algorithms of Table 2 is given below.

As of 31 December 2020, 628 solar power plants' installed capacity in the Sumy region was 16.58 MW, i.e., 26.4 kW per household on average [64]. The electricity volume sold by residential solar power plants at the feed-in tariff in 2020 amounted to 19.4 million kWh or 30,891.71 kWh per household on average [64]. According to [84], the annual electricity volume generated by a 30-kW solar power plant is 32,523 kWh/year.

The estimated life cycle of solar panels is 25 years [85,86]. Thus, we assume that both the project and regional average life cycles of solar batteries are 25 years.

According to [65,87–91], the average regional investments amount per 1 MW of installed capacity for solar power plants in Ukraine is UAH 23,261.131 thousand. The average investment costs for constructing a solar power plant in the Sumy region residential sector per 1 MW of installed capacity are UAH 17,098.667 thousand. This difference in investment costs is because the average regional investment per 1 MW of installed capacity considers both household and industrial energy facilities; the construction cost of the latter is much higher. The indicator's value for homes in the Sumy region was processed for solar power plants with maximum allowable installed capacity (30 kW) and adjusted to 1 MW. Table 9 presents the coefficients $w_{l,\ i,j,n}$ calculation for a home 30-kW solar power plant.

Table 9. Calculation of the coefficients $w_{l,\ i,j,n}$ and $LSh_{i,j,n}$ for the project of constructing a home 30-kW solar photovoltaic power plant located in the Sumy region, Ukraine (calculated by the authors).

Indicator	Indicator's Value for a 30-kW Solar Power Plant
The coefficient of the RE facility installed capacity, $w_{1,sol,Sumy,30}$	1.136
The coefficient of annual energy volume generated by the RE facility, $w_{2,sol,Sumy,30}$	1.150
The coefficient of the RE facility life cycle, $w_{3,sol,Sumy,30}$	1.00
The coefficient of the RE facility investment cost, $w_{4,sol,Sumy,30}$	1.360
The weight of the l-th project's characteristic, u_l	0.25
$LSh_{sol,Sumy}$	56.86%
$LSh_{sol,Sumy,30}$	64.67%

Thus, the interest-free loan share for constructing a home 30-kW solar photovoltaic power plant in the Sumy region should be 64.67%, i.e., 7.81 percentage points higher than the base share for residential solar energy projects in the area. The reason is that green energy installations of higher capacity provide lower costs per energy unit and generate larger volumes of electricity. It is in line with the current targets of regional energy development, such as decarbonization and strengthening energy independence. However, regional priorities for project selection can change. They may focus on generating green electricity by households to meet their needs but not sell energy at the feed-in tariff. It will reduce the interest-free loan share for large residential solar power plants as their generation exceeds the household needs. Since we have considered only one option for a green energy facility construction, the verification of the model requires further research based on the analysis of solar power plants with different capacities.

Analyzing only two RE projects makes it impossible to apply the budget funding distribution algorithm to cover the interest-free loan share on projects involving different RE technologies according to the formulas (13)–(15). The application of this approach will be carried out in further research.

5. Conclusions and Policy Implications

RE advancement is a generally accepted way for the energy sector to achieve sustainable development. At the initial stages of green energy technologies spread, the priority goal is expanding RE capacities and increasing its share in the country's energy mix under state economic support. At the same time, in the absence of investment flows regulation in the industry, as time passes, disparities may arise in the development of various RE technologies in the regions. Instead of greening and liberalizing the energy sector and increasing its competitiveness, these distortions may cause additional problems associated with capacity maneuvering, energy infrastructure overloading, increasing the RE financial load on the national budget, etc. Therefore, it is essential to form long-term plans and invest in the territories' green energy development considering the balanced deployment of various RE technologies, natural and climatic conditions, local resource base, regional energy needs, environmental contamination level, the economically feasible potential of RE technologies, government economic support level, and the rate of reduction in the green energy cost. The methodological approaches proposed by the authors take into account the mentioned and other key factors to determine the optimal directions for investment in the regional RE development.

Based on the multifactor analysis, the article presents the model for choosing the optimal investment directions in regional green energy deployment on Ukraine's example. The model allows fair redistribution of territory's budget funds on RE technologies advancement while preventing global and local energy, environmental, and economic development threats. In addition, the offered approaches include the mechanism for distributing preferential funding between facilities' construction projects using a particular RE technology in the region. The mechanism provides assessing the projects' competitive characteristics from the standpoint of local government. It allocates budget support as an interest-free loan share in the total amount of investment costs per 1 MW of the generating facility in the region for a particular RE technology. Thus, more promising technologies and projects receive more investment support as affordable loans.

A separate two-stage algorithm is proposed for the budget funding distribution to cover the interest-free loan shares of the projects using different green energy technologies. At the first stage, the interest-free loan share is determined for every RE technology used in the region. At the second stage, the amount of funding allocated for the regional development of these technologies is calculated. The algorithm's implementation guarantees the financing of chosen RE facilities' construction on the territory.

Approbation of the developed model was conducted on the example of residential solar photovoltaic and wind power plants in the Sumy region, Ukraine. It showed that if a basic share of an interest-free loan is 20%, preferential funding for solar and wind energy projects should be increased to 56.86 and 56.87%, respectively, i.e., more than 2.8 times. The critical factor influencing the indicators increase is the region's energy deficit, which raises the issue of local RE facilities construction. Therefore, to stimulate the development of the selected green energy technologies, local authorities should compensate targeted loans' share to the population at a sufficiently high level.

The competitive characteristics assessment of a 30-kW home solar photovoltaic power plant revealed that the project's interest-free loan share should be increased to 64.67% instead of the previously calculated basic share (56.86%). It is due to higher green electricity generation volumes and lower investment costs per 1 MW, which make constructing a household solar power plant with a maximum allowable installed capacity of 30 kW more attractive for local authorities.

The practical implementation of the proposed approaches to determining differentiated interest-free loan shares to finance various RE technologies and projects will contribute to a more balanced territorial green energy deployment. In addition, it will help achieve national strategic goals of sustainable energy sector development. The proposed model is recommended for local and state authorities to regulate the national and regional RE markets, separately for the household and the business sectors. The reason is a significant gap in the competitiveness of industrial and home RE facilities due to the scale effect.

It should be noted that the proposed methodology has no close analogs in the scientific literature. The theoretical value of methodology lies in its universality; it can be easily adapted to the needs of other countries developing green energy sector and seeking improvements in regional RE policy. The limitations of the study deal with the lack of detailed statistical information for calculating the indicators offered to use for each country.

Further scientific research may include expanding the factors range of the proposed model depending on the priorities of state and local energy policies. In particular, an integrated index of regional human development can supplement the methodology. The index can consider and regulate the level of regions' depressiveness, the risks of doing business in the territory, etc. In addition, introducing regional indicators of the population's energy poverty in the model will allow a more objective assessment of the interest-free loan share to households, given their financial situation. Moreover, further attention should be focused on studying the ways of regulating investment flows in the RE industry using other instruments of economic support to stimulate balanced territorial energy development.

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