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Investment and Innovation Activity of Renewable Energy Sources in the Electric Power Industry in the South-Eastern Region of Ukraine

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Abstract: Nowadays, the Ukrainian electricity industry is experiencing difficult conditions, as it is operating in a mode of depletion of its production potential. At the same time, the transition to sustainable and renewable energy is the necessary basis for the country's welfare and for ensuring its energy security. Therefore, today we cannot do without the additional attraction of sources of funding from investors. The purpose of the survey is to study the pattern and effectiveness of investments and identify links and dependencies between key technical and economic parameters and investments in renewable energy sources. To achieve this goal, the authors divided the study into four successive stages, which made it possible to study the subject of the study comprehensively. As a result of the study, results have been obtained that complement the existing theoretical, methodological, and practical developments. Mathematical calculations (using the example of the largest wind power plants in the south-eastern region) revealed transparent relationships and dependencies between the critical technical and economic parameters of the WPP of South-Eastern Ukraine and investments in the wind energy sector. Among them: the installation of 1 MW of additional WPP generating capacity requires an average of EUR 1.51 million of investment resources, and the production of one additional kWh of electricity requires an investment EUR 0.42 euros; therefore, providing an additional thousand households with WPP electricity is possible with an investment of EUR 1.345 million.

Keywords: capital investments (KI); electric power industry; foreign direct investment (FDI); innovation activity; investments; renewable energy sources (RES)

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1. Introduction

Renewable energy sources, such as wind, solar, and hydropower, are increasingly considered a viable alternative to traditional fossil fuels due to their potential to reduce greenhouse gas emissions, improve energy security, and drive economic growth [1–5]. The investment and innovation activity of the electric power industry in renewable energy sources is a critical aspect of the global transition towards clean energy [6,7].

There are several reasons why the topic was chosen as relevant:

Global trends towards clean energy: There is a growing global trend towards renewable energy sources due to concerns about climate change and the negative environmental impacts of fossil fuels [8–10]. This trend drives investment and innovation in the renewable energy sector, making it an important topic to study.

Ukraine's energy mix: Ukraine is heavily dependent on fossil fuels for its energy needs, with coal and natural gas accounting for most of its electricity generation. However, the government has set a target to increase the share of renewable energy in the country's energy mix to 25% by 2035. Understanding the investment and innovation activities of the electric power industry in the south-eastern region of Ukraine, which is a crucial area for energy production, is essential to achieving this target.

Economic benefits: Investing in renewable energy sources can have significant economic benefits, including job creation [11,12], increased energy security [13], and reduced dependence on imported fossil fuels [14]. Therefore, understanding this sector's investment and innovation activities can help inform policy decisions and drive economic growth in the region.

Regional context: The south-eastern region of Ukraine has unique characteristics that can affect investment and innovation activities in the renewable energy sector, such as its climate, natural resources, and economic conditions. The region has significant potential for renewable energy sources, including solar, wind, and biomasses, which can help diversify the energy mix and improve energy security in Ukraine. The region is an essential area for energy production and distribution, and it has unique characteristics that can affect investment and innovation activities in the renewable energy sector. Understanding this sector's investment and innovation activities is crucial for achieving Ukraine's renewable energy targets, driving economic growth, and contributing to the global transition towards clean energy. This topic is essential because it provides insights into the challenges and opportunities for developing renewable energy sources in the region and can inform policy decisions and drive economic growth. Studying this region can provide insights into the challenges and opportunities for developing renewable energy sources in Ukraine as a whole.

Thus, the purpose of the survey is to study the pattern and effectiveness of investments and identify links and dependencies between key technical and economic parameters and investments in renewable energy sources.

To achieve this goal, it is necessary to solve the following tasks consistently:

- To conduct a comparative analysis of the general trends in the functioning of the energy complex of Ukraine and the south-eastern region;
- To assess the potential, status, and features of the development of renewable energy sources in Ukraine and the south-eastern region;
- To analyze the state and dynamics of investment and innovation processes in the south-eastern region;
- To diagnose the effectiveness of the impact of investment and innovation processes on the development of the electric power industry.

2. Literature Review

Many articles and studies focus on monitoring the study of innovation and investment processes in the electricity sector, as this is an important and rapidly evolving area of research. For example, the study [15] analyzes the investment and innovation dynamics in the renewable energy sector, focusing on the role of policy and regulatory frameworks in driving investment and innovation. However, the study does not consider factors such as government subsidies and energy prices. It could be valuable to research how these factors affect the innovation of green energy technology.

The article [16] provides a comprehensive overview of the research on innovation and investment in renewable energy technologies, highlighting the key drivers and barriers to investment and innovation in this sector. However, this study needs to determine innovation and investment development prospects. The study [17] analyzes the investment and innovation processes in the electricity sector across different countries, focusing on the impact of regulatory frameworks, market structures, and other factors on investment and innovation; however, the article needs more practical recommendations. In turn, practical suggestions are provided by the study [10], which uses a multi-criteria decision analysis approach to assess the effectiveness of renewable energy policies and investments in the power sector, considering economic, environmental, and social factors. Still, the study was concentrated in Asia, Europe, Latin America, and Africa, without approbation in other countries. The study [18] analyzes the energy sector's role in the macroeconomy, focusing on the inter-relationships between energy production, consumption, and economic growth. The study uses a range of indicators to assess the productivity, display, and environmental efficiency of the energy sector, including measures of energy intensity, carbon emissions, and investment flows. The authors themselves note that data on regional value added and interregional trade can strengthen the results and make them even more applicable and useful for full sustainability analysis. Another relevant article [19] examines how subpar electricity quality can adversely affect the functionality of electrical systems, specifically focusing on the factors that contribute to the decline in power quality within industrial power supply systems. This reduction in rate ultimately undermines the dependability and effectiveness of electrical equipment. The study also identifies various consumption and generation patterns of reactive power in lines operating at 27.5, 10, and 0.4 kV. The advantage of this article is the calculated quantitative indicators with which you can compare the results.

These are just a few examples of the many articles and studies that focus on monitoring the study of innovation and investment processes in the electricity sector. The most relevant article will depend on the specific research question and context of the study.

Many similar studies focus on the mathematical relationships and dependencies between critical technical and economic parameters of renewable energy systems and investments in the renewable energy sector. Some examples of similar studies include: a study [20] that analyzes the impact of renewable energy sources on economic growth for a panel of 28 EU member states from 2004 to 2017. The results of a random effects panel data regression model indicate that renewable energy sources, including wind, solar, biomasses, and geothermal and hydropower energy, positively impact economic growth at the EU level. Among these, biomasses have the most significant effect on economic growth, with a 1% increase in biomass primary production resulting in a 0.15% impact on economic growth. Based on the econometric analysis, the study suggests that EU public policies should prioritize investment in renewable energy sources. The review [21] provides a review of the economic research of renewable energy projects, including investment cost, levelized cost of electricity (LCOE), and financial and economic indicators such as net present value (NPV) and internal rate of return (IRR); another review [22] concerns the optimal design and operation of renewable energy systems, including the use of mathematical modelling and optimization techniques to analyze and evaluate the technical and economic parameters of these systems.

Overall, many studies focus on the mathematical relationships and dependencies between technical and economic parameters of renewable energy systems and investments in the renewable energy sector and use quantitative methods to analyze and evaluate these relationships. However, some studies may have a narrower focus, concentrating on a specific type of renewable energy technology or a particular geographic region. As a result, the generalizability of their findings to other contexts may be limited.

Therefore, the literature analysis showed previously unexplored aspects that we will consider in our study.

3. Materials and Methods

Methods of monitoring the study of innovation and investment processes in the electricity sector of Ukraine and its south-eastern region involve the implementation of four successive stages of the study:

Stage 1: Comparative analysis of general trends in the functioning of the power complex of Ukraine and the south-eastern region

When conducting a qualitative statistical assessment to determine trends in the electricity industry at both national and regional levels, information support is essential due to the peculiarities of electricity production by different types of power plants and the strategic importance of ensuring the livelihood of the country, which is formed from various information resources:

- Reports, presentations, news, press conferences, and administrative data from the official websites of central and local authorities;
- Statistical data of the State Statistics Service of Ukraine and the Main Departments of Statistics in the studied south-eastern region;
- Information, publications of state administrative and private enterprises of the electric power complex, their branch associations by type of electric power production, and scientific and analytical centres of analysis and study of problems with the development of the energy sector for the economy of Ukraine [23–35].

Trends in the functioning of the power complex are expressed mathematically using a system of absolute and relative indicators, which according to the method of obtaining, are conventionally divided into primary (initial) and derivative (analytical). Among the most crucial output indicators that characterize the key parameters of the electricity sector are the following:

- The installed capacity of power plants by type and in the regional context;
- The volumes of electricity production in general, by type of power plants and regional distribution;
- The volumes of use (consumption) of electricity in general, by types of economic activity and regions;
- The number of emissions of harmful substances in the regional dimension and terms of the main power facilities in the south-eastern region of Ukraine;
- The forecast values of the leading indicators of the electricity complex: production, consumption, and emissions of harmful substances (according to state programs, development strategies, and expert opinions of energy experts).

Analytical indicators allow us to estimate of the level of prevalence, intensity, and efficiency of the development of processes in the electric power complex through the calculation of the corresponding relative indicators [36]:

- The installed capacity utilization factor (ICUF) of power plants (in general, in the regional context and type of power plants), which is calculated as the ratio of actual power generation of the generating unit for a certain period of operation to the theoretically possible year (1) and (2).

$$ICUF_y = \frac{AVEP_y}{MPAEGU_y}, \quad (1)$$

$$MPAEG_y = 365 \cdot 24 \cdot TVE_h \quad (2)$$

where

$ICUF_y$—the coefficient of utilization of the installed capacity of power plants for the year;

$AVEP_y$—actual volumes of electricity production for the year;

$MPAEGU_y$—the maximum possible amount of electricity that the generating unit in a year can produce;

TVE_h—the amount of electricity that can be produced in one hour, according to the installed capacity of power plants.

- The installed capacity of power plants and the level of electricity production per enterprise in the industry;
- The level of consumption and production of electricity per 1 thousand population;
- The share of some areas of Ukraine and the south-eastern region in the production and consumption of electricity and the installed capacity of power plants;
- The coefficient of localization of the installed capacity of power plants, which characterizes the territorial concentration of the production capacity of power plants and is

calculated by Formula (3), as the ratio of the share of installed capacity of the generating units in the i-th region of the total installed capacity to the share of area of the i-th region in total between regions, with all values close to 1; the greater the power of the generating capacities concentrated in the *i*-th region, the more $CLICPP_i$ deviates from 1.

$$CLICPP_i = \frac{SIC_i}{SA_i}, \quad (3)$$

where

$CLICPP_i$—the coefficient of localization of the installed capacity of power plants in the *i*-th region;

SIC_i—the share of installed capacity of the *i*-th region in the total installed capacity in the country;

SA_i—the share of the area of the *i*-th region in the total area of the country.

Coefficients of localization of production, consumption, and emissions of harmful substances are calculated on the same principle as the ratio of the share of production, consumption, and emissions of harmful substances of the *i*-th region in the whole country adjusted for the share of territory belonging to the *i*-th region:

– The number of emissions of harmful substances per one enterprise of the electric power complex of the *i*-th region;
– The coefficient of the electricity deficit of the region allows us to estimate the level of coverage of electricity needs of the *i*-th region. It is calculated as the ratio between the volume of electricity use and its production for a certain period, usually a year. If the value is more than one, the study area belongs to the electricity-deficient, while the electricity surplus has a value greater than one.

Stage 2: Assessment of the potential, state, and features of the development of renewable energy sources in Ukraine and the south-eastern region

According to the provisions of the "Energy Strategy of Ukraine until 2035" and the draft "Concept of green "energy transition of Ukraine until 2050," in the short and medium term (until 2025), the share of renewable energy is projected to significantly increase to 12–25% by 2035 and up to 50% in 2050 [32,34].

The leading absolute indicators that allow for assessing the potential, state, and features of the development of renewable energy sources (RES) in Ukraine and the south-eastern region are as follows:

– The potential of the installed capacity of RES power plants in terms of their types and regional location;
– The available installed capacity of RES power plants by type and in the regional dimension;
– The volumes of electricity production with RES in general, by type of power plants and regional section;
– The volumes and cost of RES electricity sold at the "green tariff" by type of power plant and regional breakdown;
– The number of solar power plants in private households, their installed capacity, and the amount of electricity sold at the "green tariff";
– The forecast values of the leading indicators of the RES industry for the short and medium-term (according to government programs, development strategies, and expert opinions of energy experts).

Among the relative indicators that assess the territorial features of the RES industry, the following should be noted:

1. The utilization factor of the installed capacity of RES by type of power plants and regional location is calculated as the ratio of available installed capacity of the RES *i*-region at a particular time according to expert data in a given area.
2. The resource capacity utilization factor of RES power plants (in general, in the regional context and type of power plants);

3. The coefficient of the localization of the installed capacity and volumes of electricity production from RES characterizes the territorial features of the location of the production capacity of RES power plants in terms of their main types: solar, wind, and others;
4. The ratio of the structure of electricity in terms of cost and volume of production for each energy source allows you to track the dynamics of trends in changes in the price of electricity from different sources of its production.

Stage 3: Analysis of the state and dynamics of investment and innovation processes in the south-eastern region of Ukraine

The volume and intensity of investment and innovation processes in electricity are closely correlated with the parameters that reveal the results of the electricity sector regarding production, environmental, and resource plans.

Among the indicators that reveal aspects of investment and innovation development of the electricity industry, special attention should be paid to the following:

- The volumes of capital investments (KI) involved in the type of economic activity "Supply of electricity, gas, steam and air conditioning" in general, in the regional context, and in individual enterprises within the electricity sector;
- The volumes of c in the studied industry by territorial principle and type of power plants;
- The number of enterprises in the field of electricity that were engaged in innovation activities in terms of the studied regions;
- The total amount of expenditures on innovations, including by sources of funding (from own funds; state budget; funds of foreign investors, other sources);
- KI and FDI per unit area, population, and enterprises in the field of electricity;
- The relative indicators of structure and localization of capital and foreign direct investments in electricity, gas, steam, and air conditioning supplies.

Stage 4: Diagnosis of the effectiveness of the impact of investment and innovation processes on the development of the electricity sector

In the simplest sense, the effectiveness of any process is measured by the absolute increase or relative comparison of the result—the effect and costs and the efforts spent to achieve it, i.e., the amount of investment. Therefore, the quantitative increase in the value of this ratio in the range from 1 indicates the level of growth of the efficiency of the studied phenomenon and vice versa.

The study of the effectiveness of the impact of investment and innovation processes on the development of the electricity sector should be carried out in three areas:

1. Economic indicators that reflect the efficiency of investment in the electricity sector include changes in the values of indicators that characterize the introduction of fixed assets—installed capacity in general and by type of power plants, installed capacity utilization, electricity production, and the sales and revenues of electricity companies.
2. Indicators of social efficiency consider the social results of investment in this sector of the economy, mainly changes in unemployment and the number of newly created jobs, wages, and social stability in the industry.
3. Resource and environmental efficiency indicators reflect the impact of investment on the production volume and consumption of a particular type of resource in the industry.

A correlation analysis should be used to confirm or refute hypotheses about the presence or absence of relationships between indicators that characterize the volume of investment and other variables that can be both a factor and a result of investment processes. The level of effectiveness of investment processes in the electricity sector can be assessed using a system of relative indicators: average annual growth rates of KI, FDI, electricity production, emissions, gross value added, electricity losses in power grids, and others; KI involvement productivity index; the FDI engagement performance index; the environmental efficiency index of KI use; the coefficient and index of production efficiency of KI use; the coefficient of investment capacity of electricity production.

At the regional level, this indicator is calculated as the ratio of the share of the KI region in the industry in the total volume of the KI region to the share of gross value added (GVA) of the region of the activity in the entire GVA region (4).

$$IPPACI(egsac)_{ij} = \frac{\frac{KI(egsac)_{ij}}{KI_{ij}}}{\frac{GVA(egsac)_{ij}}{GVA_{ij}}} \quad (4)$$

where

IPPACI(egsac)$_{ij}$—the index of productivity of capital investments in the field of electricity, gas, steam, and air conditioning supplies of the *i*-th region in the *j*-th period;

KI(egsac)$_{ij}$—the capital investments of the *i*-th region in the *j*-th period in the field of electricity, gas, steam, and air conditioning;

KI_{ij}—the volume of attracted capital investments of the *i*-th region in the *j*-th period;

GVA(egsac)$_{ij}$—the gross value added of the i-th region in the *j*-th period, created by economic entities in the field of electricity, gas, steam, and air conditioning;

GVA_{ij}—the gross value added of the *i*-th region in the *j*-th period.

At the macro level, this index is calculated as the ratio of the share of KI invested in the EGSAC industry in total government investment to the share of GVA generated by the type of economic activity of the industry in the total GVA of the country.

Since the operation of the power complex is significantly influenced by both KI and FDI, for a comprehensive assessment of investment processes in this industry, this figure should be calculated for FDI by Formula (5).

$$IPADFI(egsac)_{ij} = \frac{\frac{FDI(egsac)_{ij}}{FDI_{ij}}}{\frac{GVA(egsac)_{ij}}{GVA_{ij}}} \quad (5)$$

where

IPADFI(egsac)$_{ij}$—the productivity index of foreign direct investment in the field of electricity, gas, steam, and air conditioning in the *i*-th region in the *j*-th period;

FDI(egsac)$_{ij}$—the foreign direct investment of the *i*-th region in the *j*-th period in the field of electricity, gas, steam, and air conditioning;

FDI_{ij}—the amount of capital investment attracted in the *i*-th region in the *j*-th period.

GVA(egsac)$_{ij}$—the gross value added of the *i*-th region in the *j*-th period, created by economic entities in the field of electricity, gas, steam, and air conditioning;

GVA_{ij}—the gross value added of the *i*-th region in the *j*-th period.

The value of these indices is more than one, indicating that the share of investment in electricity in the study area is growing faster than the share of its GVA. If the region's share of EGSAC investment flow at the country level coincides with its relative weight in its GVA, the index will be 1. A value of less than one indicates an extensive development of the region's electricity sector, as the share of investment is less than the share of production.

The environmental effects of electricity in the accumulation of financial resources are reflected through changes in anthropogenic pressure on the environment over some time, usually a year, and are mathematically expressed through the calculation of environmental efficiency index KI, which is calculated regionally by Formula (6) as the ratio of emissions substances in the EGSAC industry of the i-th region to the share of the KI i-th region directed to the economic activity of the EGSAC industry.

$$IEEUACI(egsac)_{ij} = \frac{\frac{EHS(egsac)_{ij}}{EHS(egsac)_{j}}}{\frac{KI(egsac)_{ij}}{KI_{j}}} \quad (6)$$

where

IEEUACI(egsac)$_{ij}$—the index of ecological efficiency of the use of attracted capital investments in the type of economic activity of electricity, gas, steam, and air conditioning supplies of the i-th region in the *j*-th period;

EHS(egsac)$_{ij}$—the emissions of harmful substances in the field of EGPK of the *i*-th region in the *j*-th period;

EHS(egsac)$_{j}$—the emissions of pollutants in the field of EGSAC in the whole country in the *j*-th period.

The values of individual CPECI will more clearly reflect the relationship between the environmental situation and the volume of investment in specific sites, while the region reflects the average trends of enterprises in the EGSAC industry.

The main production effect of the development of electricity is expressed through electricity generation, which concerning investment can be estimated using the coefficient and index of production efficiency of KI.

This factor allows for determining the dynamics of the change in the amount of electricity produced per 1 USD. The US has attracted investment over time in the i-th region (7).

$$CPECI(egsac)_{ij} = \frac{LEP_{ij}}{KI_{ij}}, \text{ kW·h/USD} \quad (7)$$

where

CPECI(egsac)$_{ij}$—the coefficient of production efficiency of capital investments in the *i*-th region in the *j*-th period;

LEP$_{ij}$—the level of electricity production in the *i*-th region in the *j*-th period.

The KI efficiency index is calculated similarly by substituting the absolute values in Formula (7) for the respective shares and is calculated according to Formula (8) as the ratio of the share of electricity production in the *i*-th region for a specific period of the region's share in the investment.

$$IPECI(egsac)_{ij} = \frac{\frac{LEP(egsac)_{ij}}{LEP(egsac)_{j}}}{\frac{KI(egsac)_{ij}}{KI_{j}}} \quad (8)$$

IPECI(egsac)$_{ij}$—the index of production efficiency of capital investments in the *i*-th region in the *j*-th period;

Given the active reform of the electricity sector in Ukraine, low values of these indicators suggest that the energy system of the *i*-th region is at the stage of establishment and active development, as the volume of investment (share) is relatively high and the level (share) of electricity production is low, while high values give reason to argue about the energy maturity of the study area.

The coefficient of the investment capacity of electricity production determines the amount of KI per 1 thousand kWh of electricity produced in the *i*-th region in the j-th period (9).

$$KIEP(egsac)_{ij} = \frac{KI_{ij}}{LEP_{ij}} \cdot 1000 \text{ kW·h/USD} \quad (9)$$

The sharp increase in the value of this ratio in the short term with constant production volumes indicates the region's investment attractiveness in the field of EGSAC. The long-term predominance of investment while maintaining electricity production at a stable low level could be a more efficient use of financial resources.

4. Research Results

Trends in the development of the electricity industry in Ukraine: macro- and regional aspects. Ukraine's electricity is derived from the United Energy System (UES). Thanks to system-forming and regional distribution lines, it combines into a single technological complex of producers and consumers of electricity, centrally supplies electricity to domestic consumers, and provides the export and transit of electricity [24].

The generating capacity of the United Energy System (UES) of Ukraine consists of four nuclear power plants (NPP), which operate 15 power units and 12 thermal power plants (HPP), which as of 2018, operate 75 units, 3 turbines, 7 hydropower plants (HEPP), 3 hydroelectric storage power plants (HESPP), thermal power plants (TPP), small hydropower plants (SHEPP), wind power plants (WPP), solar power plants (SES), etc. [37].

In general, as of December 2021, the installed capacity of Ukrainian power plants was 54,498 MW, a quarter of which was NPP, 40%—HPP, another 11%—TPP and SHEPP/HESPP, and almost 12%—SES and WPP [38].

Measures of state policy to provide significant preferences for technologies that use RES for electricity generation have created favourable conditions for attracting substantial investment in purchasing and installing the equipment needed to launch alternative power generation facilities. Thus, during 2015–2020, the average annual growth rate of the SES production capacity was almost 80%, WPP—41% [39].

Today, while maintaining the existing electricity generation capacity at a stable level in Ukraine, there is a clear tendency to reduce its production slowly. In 2019, the enterprises of the electricity industry produced 154.1 billion kWh of electricity, which is 3.6% less than in 2018 and almost 21% less than in 2011 [40,41].

As of early 2022, more than half of the electricity generated came from nuclear power plants (almost 54%), another 38% from thermal power plants, and 8% from renewable energy facilities (WPP, HEPP, SES).

During 2015–2021, according to the national energy company "Ukrenergo", in the overall structure of installed HPP capacity, the share of power plants running on anthracite coal decreased from 43% to 30%, while the gas group increased significantly to almost 50% in 2021 [40,41].

Along with the high level of electricity production, the south-eastern region of Ukraine is characterized by the most increased volumes of its consumption [40,41].

The leader in terms of electricity use is the Dnipropetrovsk region, which in 2021 accounted for a quarter of consumer needs for this product. The top five areas in terms of electricity use, except the Dnipropetrovsk region, include Donetsk, Zaporizhia, the Kharkiv region, and Kyiv, where 10.3%, 9.8%, 6.9%, and 4.6% of Ukraine's electricity consumption was consumed, respectively (Table 1).

The five largest producers include Zaporizhia and South Ukraine NPP, which in 2021 produced 70% of the region's electricity, and Zaporizhia, Kryvyi Rih, and Prydniprovska HPP. The efficiency of the installed capacity was traditionally highest in NPP (0.73 for Zaporizhzhya and 0.68 for South Ukrainian NPP), while the average capacity utilization of HPP and TPP was only 0.2, which again indicates inefficient use of the potential of this type of power plant and confirms the fact of wear and obsolescence of their technologies [25].

In the territorial dimension, the highest potential for alternative electricity development is in the south-eastern region was as follows: Kherson, Dnepropetrovsk, Mykolaiv, Zaporizhia, and partly the Kharkiv region, where, according to scientists, natural and climatic conditions allow for obtaining an average of 1530, 1494, 150, 230, and 1207 kW of 1 sq. m of territory, respectively [44].

According to the Atlas of Energy Potential of Renewable Energy Sources of Ukraine, about 35% of the total RES capacity of Ukraine is concentrated in these oblasts, including 40% of wind energy and 25% of solar potential.

In terms of oblasts, as of the beginning of 2022, the leaders in installed capacity are the regions of south-eastern Ukraine: Dnipropetrovsk oblast—16.5% of the generating RES capacity of Ukraine, and the Zaporizhia, Kherson, and Mykolaiv oblasts, which account for an average of 12%. In general, 52.5% of all the RES capacities of Ukraine are concentrated in the south-eastern region of Ukraine [33,45,46].

Despite the rapid development of the industry in recent years, the share of households that have established SES remains extremely low (0.4% in March 2020), indicating significant potential for the development of "clean" household energy and the need to attract significant investment resources for its implementation [23].

Table 1. Technical and economic indicators of the leading industrial producers of electricity in the south-eastern region of Ukraine in 2020–2021.

Type	Name	Installed Capacity, MW	Production Volumes, Million kWh	Installed Power Utilization Factor	Location	Emissions of Harmful Substances, t per Million kWh of Energy
			Dnipropetrovsk region			
HPP	Kryvyi Rih	2079	3134	0.17	Zelenodolsk city	9.81
	Prydniprovska	910	2882	0.36	Dnipro city	14.8
TPP	Dniprovska	61.6	87	0.16	Kamyanske city	1.3
HEPP	Middle Dnieper	388	705	0.21	Kamyanske city	-
			Zaporizhzhia region			
NPP	Zaporizhzhia	6000	38,436	0.73	Energodar city	-
TEC	Zaporizhzhia	2850	6040	0.24	Energodar city	15.7
HPP	Dniprovska	1563.1	1898	0.14	Zaporizhzhia city	
			Mykolaiv region			
NPP	South Ukrainian	3000	17,879	0.68	Yuzhnoukrainsk city	-
TPP	Mykolayiv	40	87.7	0.25	Mykolayiv city	0.81
HESPP	Tashlytska	302	194.7	0.07	Yuzhnoukrainsk city	-
			Kharkiv region			
HPP	Zmiivska	2265	2576	0.13	village Slobozhanske	22.0
TPP	TPP-2	150	561.7	0.43	village Eshar	13.0
	TPP-3	62	104	0.19	Kharkiv city	-
	TPP-5	540	1422.1	0.30	village Podvirki	2.4
			Kherson region			
HEPP	Kakhovka	343.2	766.5	0.25	Nova Kakhovka city	-

Source: Calculated by the authors using the data [27,42,43].

In the regional context, as of April 1, 2021, the largest number of installed SES was recorded in the Dnipropetrovsk region—3200 or 13% of all SES of Ukraine [23].

In general, about 25% of all SES in Ukraine is concentrated in the south-eastern region of Ukraine; the prevalence of SES is 361 per 100 thousand households, which is twice as much as in Ukraine [23,40,41].

The diagnosis of efficiency of regulation of investment and innovation processes of the electric power industry in the south-eastern region of Ukraine.

In general, during 2010–2019, the economic activity "Supply of electricity, gas, steam and air conditioning," according to the State Statistics Service, in the south-eastern region of Ukraine attracted about USD 2.7 billion. Capital investment is 14% of the national value and USD 1.7 billion is US foreign direct investment [40,41].

A comparative analysis of capital investments aimed at developing the electricity sector of Ukraine and the south-eastern region allowed for tracing two precise time intervals of growth in investment during 2012–2015 and 2017–2021 and a period of sharp decline in investment activity in 2014–2015 (Figure 1).

The volume of attracted foreign direct investment by type of economic activity, "Supply of electricity, gas, steam and air conditioning", is relatively less intensive but significant for the electricity industry's renewal and modernization. During 2012–2021, USD 1.7 billion of US foreign direct investment was invested in the energy complex of the south-eastern region or USD 157 million annually. Moreover, the highest share (about 60%) fell in the Zaporizhzhia region, and another 15% in the Dnipropetrovsk and Mykolaiv regions (Figure 2) [40,41].

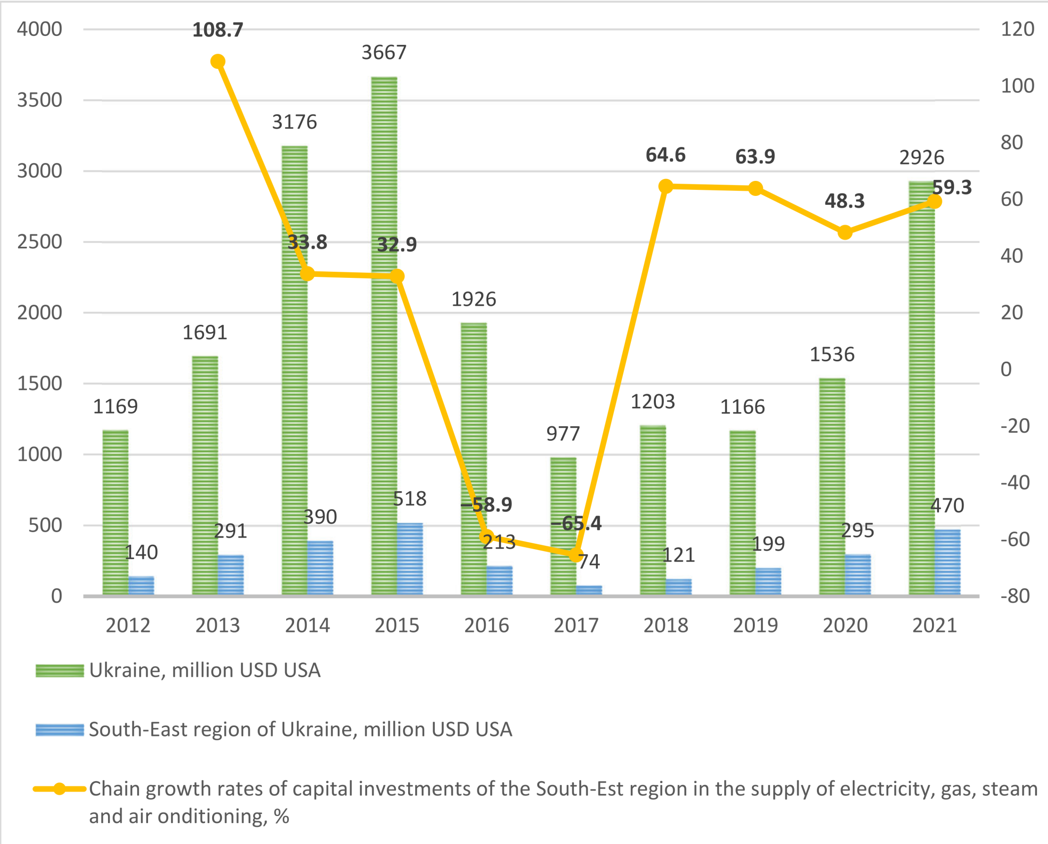

Figure 1. Volumes and chain-growth rates of capital investment inflows in the supply of electricity, gas, steam, and air conditioning in Ukraine and the south-eastern region in 2012–2021, by USD 1 million (constructed by the authors according to the data [40,41]).

In particular, the dynamics of the coefficient of localization of KI in the electricity sector for 2012–2021 clearly shows that until 2019, the electricity industry of the south-eastern region of Ukraine belonged to the investment deficit, as the territorial concentration attracted capital resources, despite the significant share in production of Ukraine's electricity level at 50% and considerable potential for RES development, which significantly fell short of the national average and ranged from 0.48 to 0.63 during 2014–2018 (Figure 3).

At the same time, from 2019, along with the growth of absolute values of investment financing, there is a moderate increase in the level of localization of KI in the regions of South-Eastern Ukraine by 0.62 in 2016 to 1.35–1.34 in 2020–2021. The level of KI concentration in 2021 was in the Kherson region—3.89, which is almost three times more than in the south-eastern region and is most likely due to the rapid growth of new power plants producing electricity from RES.

In general, the productivity of KI involvement in the industry renewal in the south-eastern region remained reasonably low compared to the country's situation during 2013–2021 (Figure 4).

The share of KI in the EGSAC region of South-Eastern Ukraine in 2013–2014 and 2016 grew slightly slower than the share of GVA created in the electricity sector, which confirms the inefficient and extensive use of production capacity and potential of the electricity sector.

In other periods, the figure ranged from 1 to 2 and only in 2021 reached 2.2. In general, the trends of 2018–2021 indicate a positive dynamic of growth of KI weight in the creation of the GVA industry EGSAC in the south-eastern region.

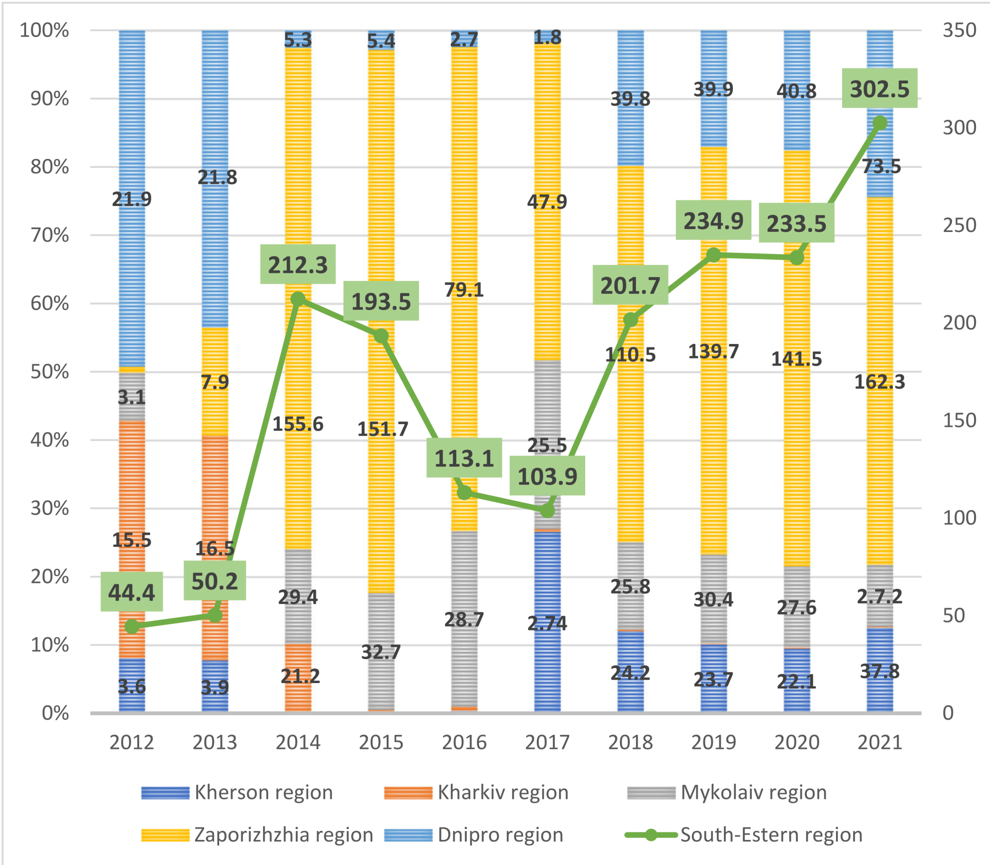

Figure 2. Volumes of foreign direct investment in the south-eastern region of Ukraine in the field of electricity, gas, steam, and air conditioning in general and by region in 2012–2021 (constructed by the authors according to the data [40,41]).

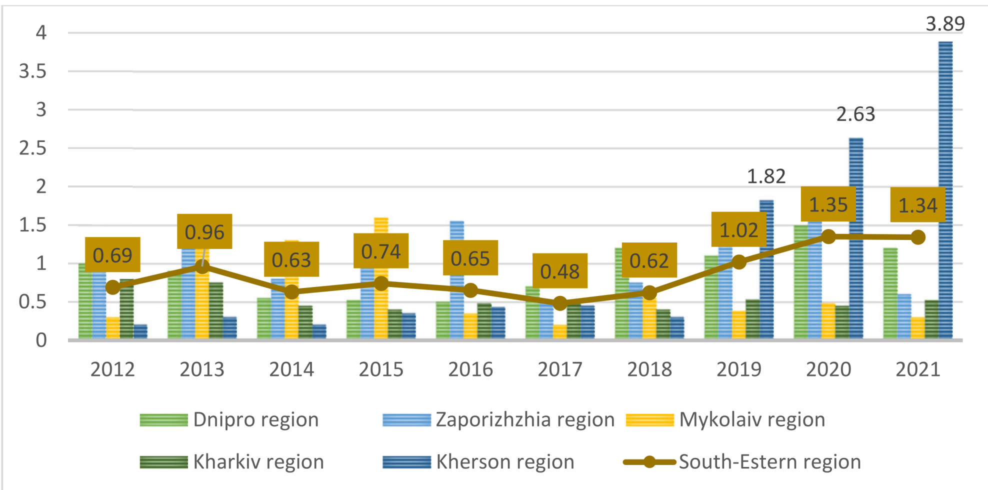

Figure 3. Coefficient of localization of capital investments in the field of industry "supply of electricity, gas, steam and air conditioning" in the south-eastern region for 2012–2021 (constructed by the authors according to the data [40,41]).

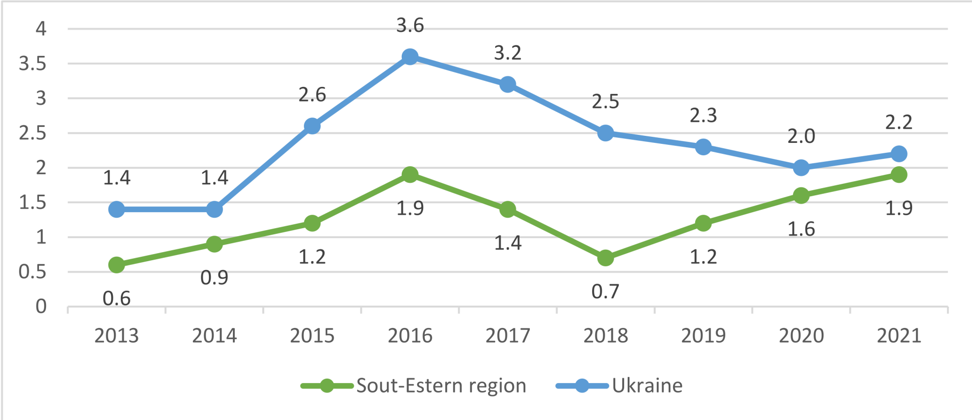

Figure 4. Productivity index of capital investments in the supply of electricity, gas, steam, and air conditioning in the south-eastern region of Ukraine in 2013–2021 (constructed by the authors according to the data [40,41]).

Similar calculations of the FDI involvement index in EGSAC's economic activity showed that the share of FDI in EGSAC in the south-eastern region grew three to five times slower than the share of GVA associated with the electricity sector (Figure 5).

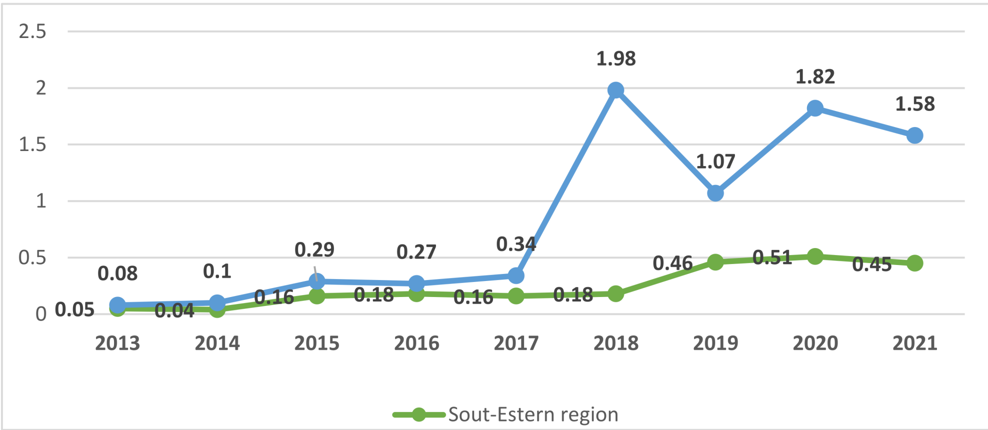

Figure 5. Productivity index for attracting foreign direct investment in electricity, gas, steam, and air conditioning in the south-eastern region of Ukraine, 2013–2021 (constructed by the authors according to the data [40,41]).

This state of affairs testifies to the critically weak interest of foreign investors in investing financial resources in the EGSAC industry of the study region. In Ukraine, since 2015, the situation has relatively stabilized, as the values of this indicator slightly exceeded one, while the regions of South-Eastern Ukraine continued to record critically low values in the range of 0.18–0.51.

The graphic representation of the results of the calculation of the index of productivity of KI in the context of individual regions of the south-eastern region of Ukraine revealed the territorial features of changes in the values of this indicator during 2013–2021 (Figure 6).

In particular, most oblasts, except for Kherson and partly Mykolaiv in some years, needed to be more effective in terms of the productivity index of investment attraction, while the index of productivity of attracting KI in the Kherson region in 2021 was 11.5, which is five times higher than the average in the south-eastern region.

Obviously, during 2019–2021, in all regions of South-Eastern Ukraine, most of the investment resources were directed to developing alternative energy.

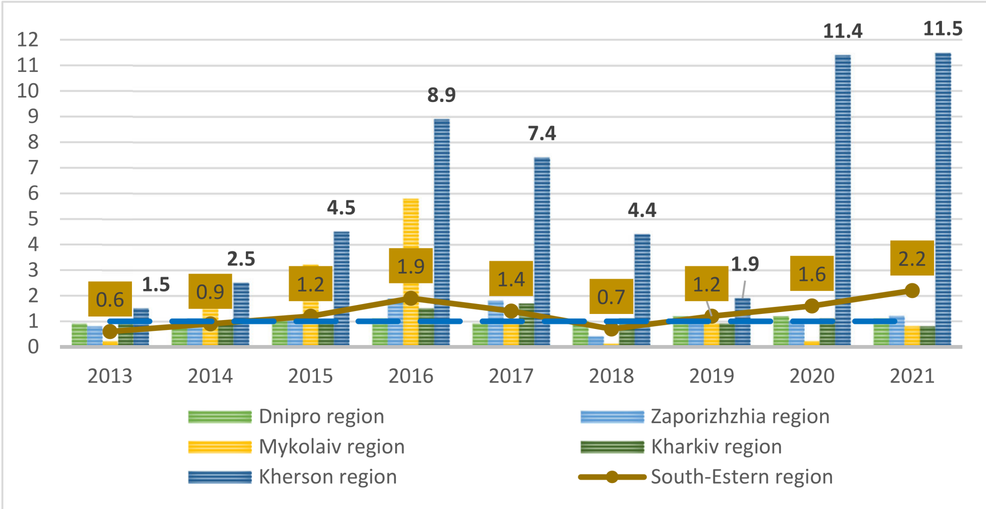

Figure 6. Productivity index of capital investments in electricity, gas, steam, and air conditioning supplies in the south-eastern region of Ukraine and some regions, 2013–2021 (constructed by the authors according to the data [40,41]).

However, the presence of large industrial giants in the Dnipropetrovsk, Zaporizhia, and Mykolaiv oblasts (HPP, TPP, NPP), due to the inevitable annual ageing of technologies and equipment of these generating plants, required more and more additional financial resources to ensure the operation of the power complex. These arguments confirm the results of calculations of the coefficient of investment intensity of electricity production and the correlation analysis that are presented in Table 2.

Table 2. Estimation of the density of the relationship between investment indicators and indicators for assessing the performance of the power complex of South-Eastern Ukraine (correlation analysis).

Electricity Evaluation Indicators	Investments		
	Capital Investments, USD	Capital Investment per 1 sq. m	Capital Investments per 1 Person
Electricity losses in the power grid, per thousand kWh	−0.34	−0.32	−0.24
Installed capacity of power plants, per thousand kW	−0.23	−0.24	−0.49
Volumes of electricity production, per million kWh	−0.35	−0.3	−0.33
Installed capacity of RES facilities, per MW	0.74	0.77	0.79
Annual increase in capacity of generating installations of RES facilities	0.85	0.91	0.89
Volumes of electricity production from RES, per million kWh.	0.65	0.70	0.72
Installed capacity of SES, per MW	0.82	0.72	0.61
Annual increase in SES capacity, per MW	0.73	0.78	0.84
SES electricity production volumes, per million kWh	0.56	0.64	0.63
Number of emissions of harmful substances in the field of EGSAC, per tons	0.45	0.4	0.01
Number of enterprises by type of economic activity EGSAC	0.67	0.6	0.53
Gross value added in the field of EGSAC	−0.17	−0.2	−0.51
Installed power utilization factor (ICUF), per %	−0.3	−0.19	0.16
Regional electricity and energy deficit coefficient	−0.4	−0.3	0.02

Source: Calculated by authors according to the data [25,27,29,38,40,41].

An assessment of the density and direction of the links between investment indicators and indicators that characterize the state and dynamics of development of the power complex of South-Eastern Ukraine confirmed the hypothesis that maintaining and ensuring the operation of traditional power facilities through annual investment infusions in current and emergency repairs, the modernization of existing equipment to reduce losses in the power grid and the greening of production by reducing emissions of harmful substances does not yield the expected results. Mathematically, it is reflected in the weakening and sometimes even change in the direction of logical connections between investment and production indicators.

Therefore, the growth of KI in the field of EGSAC in absolute terms or per 1 sq. m of the area in the region or 1 person of the current population, according to the results of the correlation analysis, leads to a slight reduction in production, a slight reduction in installed production capacity, and a decrease in the value of GVA in the EGSAC. Opposite weak links suggest that the positive effects of attracting investment in the development of traditional electricity are virtually non-existent.

On the other hand, studies of the relationship between indicators that reflect the production characteristics of electricity generation facilities with RES and investment have confirmed the hypothesis of a moderate and tight connection between these indicators.

In particular, considering the correlation coefficient between KI as a whole, based on the area of the region or population and the installed capacity of GVA facilities, the annual increase in capacity of generating units of GVA facilities and established capacity ranges from 0.74 to 0.79; 0.85–0.91; and 0.73–0.84. There is also a moderate relationship between investment growth and the number of EGSAC businesses.

In general, the identified relationships between the growth of KI and the installation of GVA indicate the effectiveness of processes in the "green" sector of the power sector, which in absolute terms is confirmed by a significant increase in installed capacity (85 MW, 392 MW, and 2379 MW during 2019–2021.) and the growth of electricity production by alternative power plants in the south-eastern region as a whole (from 1.139 million kWh to 3.634 million kWh during 2019–2021) and in terms of individual regions [31,40,41].

One of the approaches to assessing the effectiveness of investment development in the power sector is to identify the production efficiency of KI in the RES sector by calculating the coefficient (Figure 7).

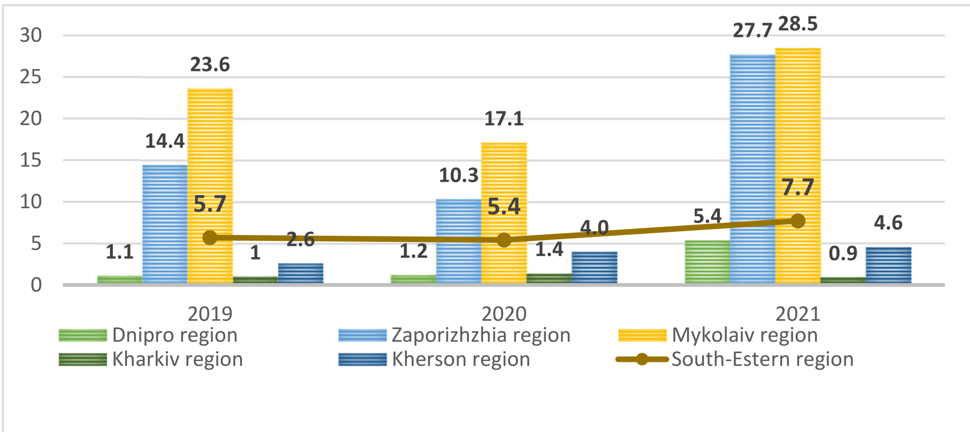

Figure 7. Coefficient of production efficiency of KI use in the RES sector in terms of the south-eastern region of Ukraine in 2019–2021, per kWh/USD (constructed by the authors according to the data [31,40,41]).

The highest values of these coefficients are in the Mykolaiv and Zaporizhia oblasts (28.5 and 27.5 kWh/USD, in 2021), which allows us to assert the progressive development of the RES industry in these regions. The low production efficiency of KI is observed in the Kharkiv region (0.9 kWh/USD). Due to the weak infrastructure network of RES facilities, the installation of alternative electricity is currently in its infancy.

The calculation of the index of environmental efficiency of investment in the south-eastern region in 2017–2021 showed that the dynamics of the share of emissions in the economic activity of EGSAC in the south-eastern region in the overall structure of the country gradually decreased, while the share of KI in the field of EGSAC has grown (Figure 8).

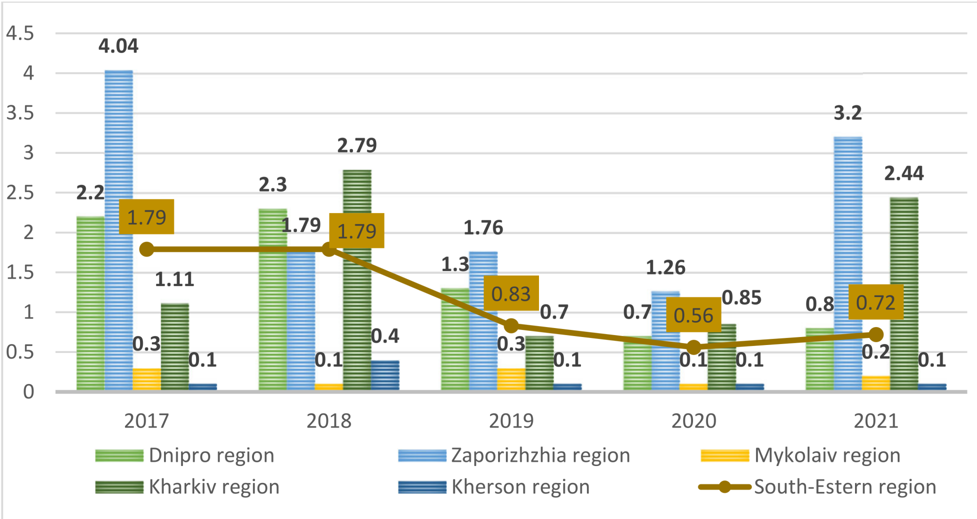

Figure 8. Index of environmental efficiency of investment in EGSAC in the context of the south-eastern region, 2017–2021 (constructed by the authors according to the data [31,40,41]).

In particular, the value of the environmental efficiency index of investment in the electricity sector in the south-eastern region decreased from 1.79 to 0.72 during 2017–2021. The Zaporizhia and Mykolaiv oblasts account for the most significant number of enterprises (3.2 and 2.44 in 2021), while the Kherson region has the highest efficiency level in the eastern area of Ukraine.

To solve the problem of information support, the state of efficiency and prospects for further investment is assessed based on point statistics of some of the largest in scope and capacity wind farm projects implemented in the south-eastern region of Ukraine in 2019–2021: the construction of the Orel, Primorsky, Myrne, and Overyanovsk WPP (Table 3) [38].

The mathematical calculations revealed clear correlations between the critical technical and economic parameters of the WPP of South-Eastern Ukraine and investments in the wind energy sector as of 2019: to install 1 MW of additional WPP generating capacity requires an average of EUR 1.51 million of investment resources; production of one additional kWh of electricity requires the investment of EUR 0.42; providing an additional thousand households with WPP electricity is possible with an investment of EUR 1.345 million; and the reduction of emissions of harmful substances per 1 ton requires additional infusions of financial resources at the level of EUR 401 thousand [38].

The above patterns between the amount of investment and production effects outlined possible prospects for innovation and investment processes to determine the optimal amount of additional investment in WPP development, which will ensure the level of WPP electricity production fully meet the needs of households.

Therefore, additional investment is at the level of EUR 3.81 billion. This will cover the household electricity needs of households in the south-eastern region by 100%, increasing the capacity of the wind energy sector by 2530 MW and will be reflected in the growth of WPP electricity production by 1586 million kWh.

Table 3. Actual, estimated, and forecast technical and economic indicators of attracting investment in the development of the wind power sector within the south-eastern region.

Name	Wind Power Plants (WPP)					Data as of 2021
	Orlivska	Myrnenska	Primorska	Overyanivska	Total	Actual/ Estimated
Investment volume, per million EUR	131	245	321	103	800	1534.6
Installed capacity, MW	100	163	200	68.4	531.4	1019.40
Planned volume of electricity production, per million kWh	380	574	700	266	1920	2107.60
Reduction of emissions of harmful substances, per thousand tons	400	455	750	210	1815	1992.3
Number of households supplied with electricity WPP, per thousand	127	191	233	44	595	1141.4
Amount of investment required to install 1 MW of additional WPP generating capacity, per million EUR/MW	1.31	1.50	1.61	1.51	1.51	1.51
The amount of investment required to produce one additional kWh. of WPP electricity, per EUR/kWh	0.34	0.43	0.46	0.39	0.42	0.42
The level of reduction of emissions of harmful substances per 1 thousand kWh. of produced electricity WPP, per t/thousand kWh	1.05	0.79	1.07	0.79	0.95	0.95
Amount of investment per 1000 households supplied with electricity by WPP, per million EUR	1.031	1.283	1.378	2.341	1.345	1.345
Estimated optimal investment in WPP development that will provide the required level of WPP electricity generation to meet the needs of households, per million EUR	3808					
Estimated installed capacity of WPP required to meet household electricity demand, per MW	2530					
Estimated WPP electricity production required to meet household needs, per million kWh	1586					

Source: Calculated by the authors according to the data [38].

5. Discussion and Conclusions

The study allowed us to contribute theoretical, methodological, and practical foundations and implementation.

As a result of the study, we managed to achieve the following theoretical and methodological results:

An algorithm for monitoring the study of innovation and investment processes in the electricity sector in the south-eastern region of Ukraine that provides the analytical part of the research in several interrelated stages: analysis of the current state, trends, and features of the electricity sector in terms of the industrial sector and renewable sources energy; assessments of the dynamics of attraction and use of investment and innovation resources in the electricity sector of industry in the south-eastern region; diagnostics of the effectiveness of investment and innovation processes in the research area in the context of reforming the electricity sector; and determining the prospects of innovation and investment development (which complements the study [16]).

The sources of information supporting the statistical estimation of processes in the electric power complex in the south-eastern region of Ukraine are generalized. The primary and derivative indicators of assessing the state, tendencies, and potential of the electric power complex development at the macro- and regional levels are systematized and characterized. Particular attention is paid to calculating relative indicators that reveal the productivity of production and the environmental efficiency of capital and foreign direct investment.

A thorough analysis of the state and trends of changes in the values of the leading indicators of the electric power complex of Ukraine and its regions allowed for grouping the areas of Ukraine by the level of production, use of electricity for electricity deficit, and surplus. It is determined that the south-eastern region has traditionally been a leader in the production of electricity, has the significant natural potential of wind and solar energy, and records the highest needs and levels of consumption due to the concentration of large industrial enterprises and relatively high population density.

The list of the largest industrial power plants of traditional energy in the south-eastern region is systematized, and their technical and economic indicators of activity for the period of 2018–2019 are generalized. In particular, almost 90% of the installed capacity of power plants in the study region is accounted for by the traditional power companies: NPP, HPP, TPP, HEPP, and HESPP. The five largest manufacturers trending in 2017–2019 allowed us to trace the trend of the rapid growth of the installed capacity of RES facilities.

It was concluded that the establishment of the green electricity industry was accompanied by an increase in investment in the installation and construction of solar power plants at the level of private households, which was reflected in an increase in the average capacity of one SES during 2015–2020 and a decrease of 20% in the cost of works on the purchase and installation of equipment to produce 1 MW of electricity (the result is supported by [20]).

As a result of the study, we managed to achieve the following practical results:

Mathematical calculations (using the example of the largest WPPs in the south-eastern region) revealed transparent relationships and dependencies between the critical technical and economic parameters of the WPP of South-Eastern Ukraine and investments in the wind energy sector. Among them: the installation of 1 MW of additional WPP generating capacity requires an average of EUR 1.51 million of investment resources, and the production of one additional kWh of electricity requires an investment of EUR 0.42 euros; therefore, providing an additional thousand households with WPP electricity is possible with an investment of EUR 1.345. This statement is supported by other studies in this area [47–49].

The results of a correlation analysis and calculation of indices of productivity and efficiency of investment allowed us to establish the regularity that the effectiveness of investment increases with an increasing production capacity of renewable energy sources (RES), while the operation of traditional power plants (thermal power plants), nuclear power plants (NPP), thermal power plant (HPP)) hurts it (which is a practical addition to the study [17]). This statement is supported by other studies in this area [21,50–53]. These studies, among others, provide evidence that investment in renewable energy is more effective when there is a larger production capacity of renewable energy sources and less dependence on traditional power plants.

Based on the above findings, we could propose several policy implications and recommendations can be made:

1. Encouraging investment in renewable energy. Given that the effectiveness of investment in the renewable energy sector increases with the increasing production capacity of RES, policymakers may want to incentivize investment in the renewable energy sector.

This can include tax incentives, subsidies, feed-in tariffs, and other mechanisms that provide financial support for renewable energy projects. Governments can also create favourable regulatory environments that promote renewable energy development, such as streamlined permitting processes, grid interconnection requirements, and net metering policies. Other approaches include setting renewable energy targets and standards, investing in research and development, and providing technical assistance to renewable energy developers. Encouraging investment in renewable energy is essential to accelerate the transition to a low-carbon economy and mitigate the impacts of climate change.

The article [21,54] concludes by emphasizing the need for policy support, research and development, and public–private partnerships to promote the growth of the bio-economy and its contribution to the knowledge economy. This aspect is a good subject for further research.

2. Reducing dependence on traditional power plants. To improve the efficacy of investments in renewable energy, policymakers may need to reduce their reliance on conventional power plants. This could be accomplished by gradually eliminating subsidies for traditional power plants, implementing policies that encourage the retirement of outdated and inefficient power plants, or establishing emissions standards that make it more challenging for conventional power plants to operate. By reducing dependence on traditional power plants, policymakers can promote the transition to renewable energy and accelerate the transition to a low-carbon economy.

6. Limitations

The presented calculations only roughly estimate the prospects of investment development. They do not consider several important factors influencing innovation and investment processes in the power industry (changes in equipment costs, features of other RES, government influence on the power complex).

The consequences of such limitations are that the estimated prospects of investment development may need to accurately reflect the real-world conditions and challenges the power industry faces. The calculation model does not account for changes in equipment costs, which can significantly impact the financial viability of renewable energy projects. Additionally, the model does not consider the impact of government policies and regulations on the power industry. Government subsidies, tax incentives, and other support measures can play a crucial role in promoting renewable energy development and influencing investment decisions. Ignoring these factors can lead to incomplete or inaccurate assessments of the investment potential of renewable energy projects.

Therefore, it is essential to recognize the presented calculations' limitations and use them as a starting point for further analyses that consider the broader context of the power industry and the specific market conditions of renewable energy.

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