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Low-carbon management in selecting resources for energy production of enterprises

Abstract: Climate risks are driving changes in the economy towards low-carbon energy development. The article is devoted to exploring low-carbon management in selecting resources for energy production of enterprises. The households' willingness to use low-carbon technologies through the transition to consume energy from renewable resources is clarified. The article has proposed a methodological approach to low-carbon management in selecting resources for energy production of enterprises. The specificity of this methodological approach lies in assessing the energy consumption system efficiency based on the low-carbon management in selecting resources for energy production of enterprises. The results obtained for all types of harmful substances indicate the adequacy of the low-carbon management in selecting resources for energy production of enterprises giving preference to solar and wind power. The scientific value of such a methodological approach lies in the ability to forecast the potential of low-carbon management in selecting resources for energy production of enterprises in the energy supply chain. The results is the basis for creating climate energy clusters

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in the regions to diversify the resources for energy production of enterprises, and to increase of the efficiency of transportation of production waste as renewable energy sources by transport for strengthening the resilience of climate security.

Keywords: climate change, low-carbon innovation, low-carbon management, low-carbon energy supply chain, renewable energy sources

Introduction

To reduce greenhouse gas emissions, the European Commission revised the “Clean Energy for all Europeans” package in 2019. This package was originally published in 2015, and the main objectives of this package are energy efficiency of buildings, renewable energy, energy efficiency, establishing control over the energy system of the European Union, and the development of a contemporary European electricity market (Clean energy for all Europeans package).

The formation of an environmental taxation system as low-carbon tool is considered (Koziuk et al. 2020; Zatonatska et al. 2024). The motivational tool for building loyalty to this kind of taxation in the countries of the European Union is “to reduce the tax on labor, increase investment in innovation, increase the level of employment, the transition to renewable energy, the greening of transport, the strengthening of environmental well-being and the increase in environmental awareness of the population” (Brych et al. 2023a).

In this context, the development of transnational cooperation together with the strengthening resilience of global and national climate security towards the optimisation of the energy supply chain using renewable energy sources, and the low-carbon management in selecting resources for energy production of enterprises is clearly important. As part of the implementation of “The Mediterranean Action Plan of the United Nations Environment Programme” (UNEP/MAP), the Mediterranean Sea Program (2020–2024) was launched, aimed at improving environmental security. It also included a project to manage the relationship of water, energy, food, and ecosystems (Mediterranean Coastal Zones: Managing the Water-Energy-Food and Ecosystems Nexus) (The Mediterranean Sea Programme). Being a part of the EU Regional Policy, “The MED Program” was developed as part of the EU Regional Policy, which included projects for marine renewable energy and renewable energy in coastal areas (Bluene and Enercoast; Caldés, 2016). In addition, the application of the EU Strategy for the Baltic Sea Region is the basis for the implementation of transnational cooperation programs in renewable energy (Studzieniecki and Palmowski 2022).

In this context, the effectiveness of a green energy transition is determined by the level of development and use of low-carbon energy technologies, such as the introduction of hydrogen technologies, the production of carbon-free steel, the use of seaweed and energy crops as biomass for the production of biofuels, testing a prototype of a concrete road capable of charging electric cars on the go, the use of biomethane in energy, the use of infrared cameras, drones, satellites for monitoring carbon dioxide emissions, the transition to electric vehicles, the use of heat pumps, solid fuel boilers in the thermal power industry, cogeneration and trigeneration technologies, the development of solar and wind power.

On this way, it is needed to develop low-carbon management system of enterprises through the integration of low-carbon technologies in the energy production processes. In addition, it is necessary to assess the energy consumption system efficiency based on the low-carbon management in selecting resources for energy production of enterprises. Accordingly, the purpose of article is to explore of the low-carbon management in selecting resources for energy production of enterprises, in particular to propose a methodological approach to low-carbon management in selecting resources for energy production of enterprises.

1. Literature review

In the context of limited natural energy resources, an urgent issue is the introduction of low-carbon technologies into the diversification of renewable energy sources. In this context, it is vitally important to consider the possibilities of circular use of renewable resources by developing intersectoral partnerships, creating climate energy clusters with a circular energy resource management system based on smart management (Borysiak et al. 2022c), establishing environmentally friendly technologies (Konovalyuk et al. 2023), assessing environmental risks (Poberezhna et.al. 2022), and thoroughly scrutinising the impact factors on production of renewable energy (Borysiak et al. 2022a). In Muhammed et al. (2023), the possibilities of using solar energy photovoltaic in households are substantiated. In the context of the development of the renewable energy market and the development of entrepreneurship in the field of renewable energy, it is of particular importance to determine the influence of internal factors (the influence of the owner/managers and the characteristics of the company) on the stable growth of renewable energy enterprises (Yadav and Pradhan 2016), as well as the need for "green" financing of renewable energy enterprises to promote the overall growth of the economy (Wang and Fan 2023; Zatonatska et al. 2024).

On the way to the transition to low-carbon energy, scenarios of the global warming impact on investment in construction and a decrease in the need for district heating are considered (Ziemele et al. 2023). In the context of integrating climate policy into the environmental and energy management system, appropriate measures to improve energy efficiency, for example, at thermal power plants, such as cogeneration, trigeneration, installation of heat pumps and heat fuel boilers, waste heat processing, etc. in their essence have not only a socio-economic direction, but also an environmental one, namely ensuring the decarbonisation of energy (a component of environmental policy). In Stevens et al. (2023), the attention is drawn to the need to implement technology-push policies that promote the development of supplementary technologies of renewable energy production of enterprises, which can stimulate innovation in solar photovoltaic and wind technologies and the development of technologies in other areas.

Finally, renewable energy sources alone are not enough to ensure a safe supply of energy, they must be combined with nuclear energy or gas. Taking this into account, for the development of a low-carbon and energy-efficient economy, it is valuable to introduce eco-innovations to ensure economic growth (Madaleno et al. 2020; Santos et al. 2019), analyze the financial and economic potential of energy enterprises to integrate renewable resources into the energy supply chain (Borysiak et al. 2022b), take into consideration the peculiarities of forming an investment portfolio for implementation of environmentally friendly projects based on sustainable economic development (Brych et al. 2022; Halysh et al. 2021; Brych et al. 2023b).

To ensure sustainable energy development of enterprises and households based on climate neutrality, there is a need to identify opportunities for applying a diversified approach to using low-carbon technologies for renewable energy production. Moreover, integrating low-carbon management into the general management system for selecting resources for energy production of enterprises plays an urgent role. Accordingly, the contribution of the research performed is to propose a methodological approach to low-carbon management in selecting resources for energy production of enterprises. The specific of this methodological approach lies in assessing the energy consumption system efficiency based on the low-carbon management in selecting resources for energy production of enterprises.

2. Methodology and research methods

The methodology for implementing the research consists of the following steps:

1. Determining the level of household awareness of the transition to low-carbon energy in the context of strengthening the resilience of climate security.

1.1. Conducting a sociological survey "Adaptation to climate change and strengthening energy security: using European experience".

1.2. Analysing the results of the survey "Adaptation to climate change and strengthening energy security: using European experience" and dedicating the importance of measures to introduce critical low-carbon technologies in the energy sector through the diversification of renewable energy sources, decarbonisation of the energy supply chain and the development of "green" local energy networks based on smart management and inter-industry.

2. Developing a methodological approach to low-carbon management in selecting resources for energy production of enterprises.

2.1. Defining the indicator of environmental decarbonisation.

2.2. Using multiple regression models for the determine of the functions for the main types of pollutants, which will establish causal relationships between energy production and environmental decarbonisation.

2.3. Analysing the results obtained for all types of harmful substances indicate. Dedicate the adequacy of the low-carbon management in selecting resources for energy production of enterprises. Note the preference for solar and wind energy to ensure the decarbonisation of the environment.

1. Determining the level of household awareness of the transition to low-carbon energy in the context of strengthen resilience of climate security

To determine the level of awareness of households about the threats and consequences of climate change, the use of the European experience of adaptation to climate change based on the digital transformation of energy management and the transition to the use of renewable energy sources, we conducted a sociological survey "Adaptation to climate change and strengthening energy security". The survey was conducted in December 2022 in an online format using a Google form based on West Ukrainian National University (Ternopil, Ukraine). 300 respondents (representatives of households) took part in the survey, including:

- a type of settlement in which they live: 41.3% – regional center; 22.7% – district center; 18.3% – rural settlement; 17.7% – the center of a territorial society; 25.7% apartment building (lack of condominiums – an association of co-owners of apartment buildings);
- a type of household in which they live: 40.7% – an individual private house; 33.7% – an apartment building (the presence of condominiums – an association of co-owners of apartment buildings).

According to the results of the survey, respondents noted the shift of the seasons (76.7% of respondents), as well as drought and heat (50.3% of respondents) as the factors due to which climate change is most experienced, and climate change is the most experienced due to a general deterioration in well-being (68.3% of respondents), changes in crop and livestock production (53.3% of respondents) and an increase in complaints of cardiovascular disease (52% of respondents). In turn, according to Fig. 1 and Fig. 2, we monitor the positive dynamics of public involvement in climate prevention, adaptation, and mitigation measures at the household level introducing climate-neutral and energy-efficient technologies. At the same time, 91.7% of respondents answered that they needed to obtain additional knowledge, develop skills in energy management, and implement measures to prevent, mitigate, and adapt to climate change, which indicates the relevance of applying an integrated approach to the implementation of climate innovation, climate management in the field of energy supply through the interaction of all participants in the energy market, both energy enterprises, energy service companies, and stakeholders with households, to enhance energy security and promote the "green" recovery of Ukraine.

This transitivity of socio-economic development causes a change in the approach to positioning "green" energy as a climate-neutral product in the market, namely, a combination of resource-saving and climate-neutral approaches. This indicates the importance of measures to introduce critical low-carbon technologies in the energy sector through the diversification of renewable energy sources, decarbonisation of the energy supply chain, and the development of "green" local energy networks based on smart management and inter-industry.

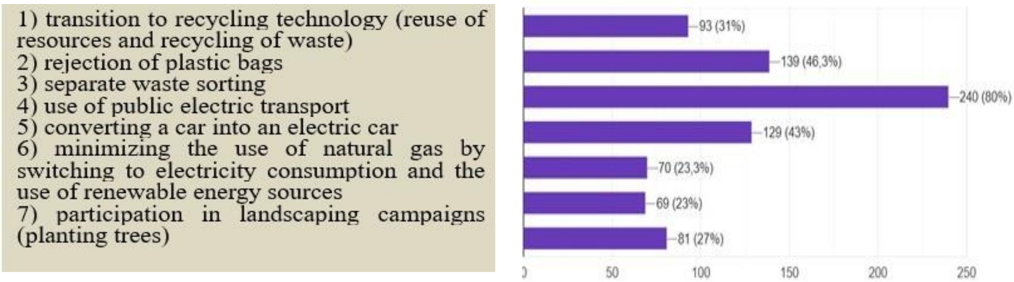

Fig. 1. The results of respondents' answers to the question "What measures do you use to prevent, mitigate and adapt to climate change?"
Source: obtained by the authors

Rys. 1. Wyniki odpowiedzi respondentów na pytanie „Jakie środki podejmujesz, aby zapobiegać, łagodzić i dostosowywać się do zmian klimatu?"

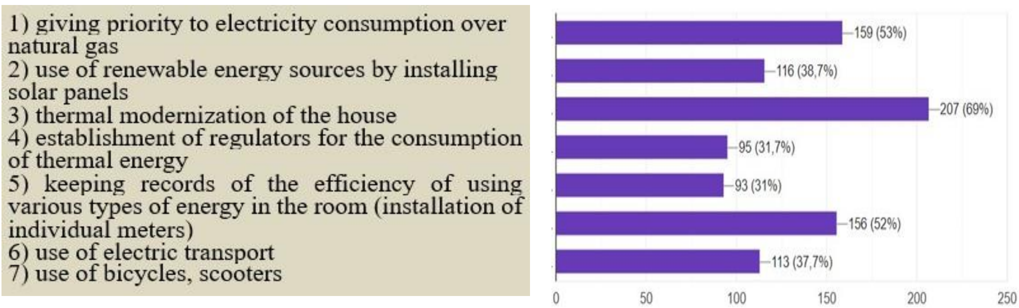

Fig. 2. The results of respondents' answers to the question "Which of the following tasks, by the developed regulatory documents, are acceptable for you to implement at the level of your household to prevent, mitigate and adapt to climate change and implement an energy management system?"
Source: obtained by the authors

Rys. 2. Wyniki odpowiedzi respondentów na pytanie „Które z poniższych zadań, na podstawie opracowanych dokumentów regulacyjnych, są dla Ciebie akceptowalne do wdrożenia na poziomie Twojego gospodarstwa domowego w celu zapobiegania, łagodzenia i adaptacji do zmian klimatu oraz wdrożenia systemu zarządzania energią?"

2. Developing a Methodological Approach to Low-Carbon Management in Selecting Resources for Energy Production of Enterprises

The entire energy system as a part of critical infrastructure, regardless of the type of energy, can be divided into the following blocks: obtainment of primary energy from natural or alternative sources; production of an appropriate type of secondary energy (transformation into electricity, heat energy), distribution of such energy by the kind of consumers and direct supply of energy to consumers.

In this context, the development of a methodological approach to low-carbon management in selecting resources for the energy production of enterprises is vital. The innovative value of developing such a methodological approach lies in the ability to forecast the potential of low-carbon management in selecting resources for energy production of enterprises in the energy supply chain, including the definition of optimization criteria for the effectiveness of the management system.

The indicator of environmental decarbonisation is the volume of emissions of pollutants into the atmosphere from stationary sources of pollution $D_i^E, i = 1, \ldots, p$, where p is the number of pollutants whose emissions are considered. At the same time, we consider that the production and distribution of energy from renewable and traditional sources in energy services to consumers affects the decarbonisation of the environment with a certain regularity $f\left(\vec{\alpha}^B, \vec{B}\right)$, where $\vec{B}$ is the vector of values of energy volumes from renewable and traditional sources, $\vec{\alpha}^B$ is the vector of weight coefficients. Consequently, it is necessary to determine the functions $f\left(\vec{\alpha}^B, \vec{B}\right)$, of the main types of pollutants, which will establish causal relationships between energy production and environmental decarbonisation:

$$D_i^E = f_i\left(\vec{\alpha}^B, \vec{B}\right), i = 1, \ldots, p \tag{1}$$

For this, as a rule, multiple regression models of the following form are used:

1) linear:

$$D^E\left(\vec{\alpha}^B, \vec{B}\right) = \sum_{i=1}^{m} \alpha_i \cdot B_i \tag{2}$$

2) non-linear:

$$D^E\left(\vec{\alpha}, \vec{B}\right) = \sum_{i=1}^{2m} \alpha_i \cdot B_i^{\alpha_{i+1}} \tag{3}$$

where:

$D^E\left(\vec{\alpha}^B, \vec{B}\right)$ – is an indicator of environmental decarbonisation based on the assessment of emissions of pollutants into the atmospheric air from stationary sources of pollution,

$\vec{B}$ – vector of values of impact factors (production and distribution of energy from renewable and traditional sources in energy services),

$\vec{\alpha}^B = \left(\alpha_1, \ldots, \alpha_i, \ldots, \alpha_m\right), i = 1, \ldots, m$ – regression model parameters,

m – the number of factors (types of energy).

By minimising the carbonisation level of the energy service used from renewable and traditional sources, we achieve the maximization of the environmental effect from the use of critical low-carbon technologies for renewable energy production.

This optimisation criterion (minimisation of emissions of pollutants) is given by the objective function of the optimisation model for the management of the promotion of "green" energy:

$$D_i^E\left(\vec{\alpha}^B, \vec{k}^B\right) = f_i\left(\vec{k}_i^B, \vec{\alpha}^B\right) \xrightarrow{\vec{k}^B} min \tag{4}$$

$$\sum_{j=1}^{m} k_{i,j}^{B} = 1$$

$$0 \le k_{i,j}^{B} \le K_{j}^{B}$$

$$i = 1,\ldots,p, j = 1,\ldots,m$$

where:

D_i^E – an indicator of the level of decarbonisation from energy consumption for the i-th pollutant,

$\vec{\alpha}^B$ – the vector of weight coefficients for the share of energy use from renewable and traditional sources,

$k_{i,j}^B$ – the share of use of the j^{th} type of energy in the system of total energy consumption for the indicator of the level of decarbonisation based on the i^{th} pollutant,

K_j^B – restriction on the use of the j^{th} type of energy in the system of general energy consumption,

p – the amount of pollutants to determine the level of decarbonisation from the use of energy services,

m – the number of types of energy in the system of general energy consumption.

To build a model for optimising the energy consumption system based on the use of critical low-carbon technologies for renewable energy production, we identify the general form of the objective function (1). To do this, we use statistical data on emissions of pollutants (Table 1) and the amount of energy from renewable and traditional sources in Ukraine (Table 2) from 2011 to 2020.

As the main pollutants, the reduction of emissions of which will determine the level of decarbonisation of the environment in Ukraine, it is customary to measure (Table 1):

- sulfur dioxide (SO_2),
- nitrogen oxide (NO_2),
- carbon monoxide (CO_2).

The list of renewable and traditional sources, which form the system of general energy consumption in Ukraine, and energy volumes are given in Table 2.

Based on the data of Table 1 and Table 2, regression models are given for the main types of pollutants, which will establish causal relationships between using critical low-carbon technologies for renewable energy production and environmental decarbonisation in the following form:

$$D^E\left(\vec{\alpha}^B, \vec{B}\right) = \alpha_0 + \alpha_1 \cdot B_1 + \alpha_2 \cdot B_2 + \alpha_3 \cdot B_3 + \alpha_4 \cdot B_4 + \alpha_5 \cdot B_5 + \alpha_6 \cdot B_6 + \alpha_7 \cdot B_7 + \alpha_8 \cdot B_8 + \alpha_9 \cdot B_9 + \alpha_{10} \cdot B_{10} \quad (5)$$

where:

B_1 – energy from coal and peat,

B_2 – raw oil,

B_3 – oil products,
B_4 – natural gas,
B_5 – nuclear energy,
B_6 – hydropower,
B_7 – wind and solar energy,
B_8 – biofuels and waste,
B_9 – electric power industry,
B_{10} – thermal power industry.

Table 1. Emissions of pollutants into the atmospheric air from stationary sources of pollution in Ukraine from 2011 to 2020 [thousand tons]

Tabela 1. Emisje zanieczyszczeń do powietrza atmosferycznego ze stacjonarnych źródeł zanieczyszczeń na Ukrainie w latach 2011–2020 [tys. ton]

Pollutant	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020[1]
Sulfur dioxide (SO_2)	1,333.1	1,399.2	1,381.8	1,133.3	830.3	1,076.4	726.2	698.1	676	601
Nitrogen oxides (NO_2)	333	332.5	333.3	288.1	233.8	240.2	215.5	215.3	205.1	181.2
Carbon monoxide (CO_2)	1,066.1	1,004.6	1,007.2	828.4	764.1	802.8	728.4	744.3	748.4	707.3

[1] Real-time data.
Source: based on (Emissions of certain pollutants and carbon dioxide).

Table 2. The volume of energy from renewable and traditional sources in Ukraine [thousand tons of oil equivalent]

Tabela 2. Wolumen energii ze źródeł odnawialnych i tradycyjnych na Ukrainie [tys. ton ekwiwalentu ropy naftowej]

	2011	2012	2013	2014	2015	2016	2017	2018	2019[1]	2020
Coal and peat	41,490	42,718	41,427	35,576	27,344	32,450	25,757	28,055	26,076	22,847
Raw oil	9,100	5,050	3,978	3,043	2,851	2,806	3,351	3,635	3,786	4,196
Oil products	3,360	6,559	5,928	7,645	7,700	8,387	9,345	9,637	9,690	9,947
Natural gas	46,841	43,018	39,444	33,412	26,055	25,603	24,554	25,739	23,383	23,844
Nuclear energy	23,672	23,653	21,848	23,191	22,985	21,244	22,449	22,145	21,771	19,994
Hydropower	941	901	1,187	729	464	660	769	897	560	650
Wind and solar energy, etc.	10	53	104	134	134	124	149	197	426	794
Biofuels and waste	1,563	1,522	1,875	1,934	2,102	2,832	2,989	3,209	3,349	4,243
Electricity	–541	–987	–851	–725	–116	–323	–445	–522	–348	–208
Thermal energy	1,020	980	1,000	745	571	599	546	534	667	56

[1] Real-time data.
Source: based on (Total primary energy supply).

Using the application package MATLAB tools for constructing regressions, we obtained linear regression models of the following form:

1) sulfur dioxide (SO_2):

$$D^E_{SO^2}\left(\vec{\alpha}^B,\vec{B}\right) = -0,015\cdot B_1 - 0,236\cdot B_2 - 0,139\cdot B_3 + 0,103\cdot B_4 - 0,039\cdot B_5 - 1,0002\cdot B_6 - 1,169\cdot B_7 + 0,752\cdot B_8 - 0,059\cdot B_9 + 0,412 B_{10} \quad (6)$$

2) nitrogen oxide (NO_2):

$$D^E_{NO^2}\left(\vec{\alpha}^B,\vec{B}\right) = -0,00057\cdot B_1 - 0,022\cdot B_2 - 0.0199\cdot B_3 + 0.0078\cdot B_4 + 0.0063\cdot B_5 - 0,0379\cdot B_6 - 0,038\cdot B_7 + 0,0517\cdot B_8 - 0,022\cdot B_9 + 0,0485\cdot B_{10} \quad (7)$$

3) carbon monoxide (CO_2):

$$D^E_{CO}\left(\vec{\alpha}^B,\vec{B}\right) = -0,0099\cdot B_1 - 0.0548\cdot B_2 + 0.0274\cdot B_3 + 0.048\cdot B_4 - 0.0295\cdot B_5 - 0.0879\cdot B_6 - 0.2644\cdot B_7 + 0.153\cdot B_8 + 0.33\cdot B_9 + 0.344\cdot B_{10} \quad (8)$$

The resulting models were used as objective functions to build models for optimising the energy consumption system.

The solution to an optimisation problem (4) is a vector containing the optimal distribution of particles by type of energy in the energy consumption system from the point of view of environmental decarbonisation. For the model of using critical low-carbon technologies for renewable energy production, based on the target function of reducing carbon monoxide (CO_2) emissions into the environment, the following vector was obtained:

$$\vec{k}^B = (0,2;0,05;0,12;1,25\cdot 10^{-5};0,33;0,15;0,157.39\cdot 10^{-7};9,17\cdot 10^{-7};3,598\cdot 10^{-7}) \quad (9)$$

The results obtained for all types of harmful substances indicate the adequacy of low-carbon management in selecting resources for energy production of enterprises. It should also be noted that the solution to this problem without restrictions on the use of the *j-th* type of energy in the system of general energy consumption for all cases completely gave preference to the use of solar and wind energy as the most appropriate way to ensure the decarbonisation of the environment.

Results

The vulnerability of the energy sector to climate change exists due to the influence of "natural factors (dependence on natural processes (lighting rhythms, air temperature) of station load rhythms; the impact of climatic conditions on energy resource consumption schedules;

energy resource consumption planning (according to long-term average factors) which, in turn, significantly depends on the variability of natural conditions, the configuration of weather characteristics (temperature, wind speed, insolation)" (Ivanenko and Sas 2011). According to this, the following are among the possible consequences of climate change for the energy industry in (Climate change 2020) "allocation of a reduction of up to 5% of the heating season; the influence of climatic conditions (temperature and humidity) on the working conditions and equipment of power facilities, the influence of weather phenomena (snow, ice, strong gusty wind) on the operation of power lines and the reliability of power supply, etc." (Climate change 2020). This indicates the importance of applying an integrated approach to the prevention of climate risks in the energy sector.

As part of implementing climate action by the United Nations, the Sustainable Development Solutions Network was launched, which directs its activities towards providing the communication support to accelerate climate-neutral transition in various areas. Among the priority areas of research is climate and energy ("Climate and Energy"). In particular, in this direction, the Sustainable Development Solutions Network has developed the Climate and Energy Program and a series of Roadmaps to 2050 (in 2019, the "Roadmap to 2050: A Manual for Nations to Decarbonize by Mid-Century"; in 2021, "Roadmap to 2050: The Land-Water-Energy Nexus of Biofuels") (Roadmap to 2050; Climate and Energy).

The diversification of renewable resources and their integration into the energy supply chain is of great importance. Given this, the proposed methodological approach to low-carbon management in selecting resources for the energy production of enterprises has an innovative scientific value, which involves forecasting the potential of low-carbon management in selecting resources for the energy production of enterprises in the energy supply chain, including the definition of optimization criteria for the effectiveness of the management system. According to the results of the study, the advantage of solar and wind energy for ensuring the decarbonisation of the environment and the transition to low-carbon energy has been established. Instead, we should note that the complexity of integrating the climate component into the energy sector is in the combination of obtaining an economic and low-carbon effect. Accordingly, the analysis of the selected resources for energy production, and, in particular, the usage of renewable energy sources for the example of the energy system of Poland and Ukraine of a greater role for the integration of low-carbon management into the general management system of enterprises.

Among the measures to prevent climate change in the European Union, it is considered to reduce the methane concentration in the atmosphere due to its processing into biogas. "The research by the Global Carbon Project has shown that the methane concentration in the atmosphere is 150% higher than in the pre-industrial period. More than half of methane emissions into the atmosphere are connected to the activities in three sectors: extraction and transportation of fossil fuels (35% of methane emissions), agriculture (40% of methane emissions), and waste (20% of methane emissions). To reduce methane emissions in the energy sector, the European Commission introduces obligations to improve methods for detecting and eliminating leaks in gas infrastructure (gas pipelines, storage facilities, compressor stations)" (Savytskyi 2021). "Within the limits of primary energy, the energy of solar rays, the energy of falling water, the energy of waves, the energy of tides, the energy of ocean currents, the energy of biomass, the energy of the earth (heat transfer and geothermal sources), and the energy of anaerobic decomposition are emitted. Secondary energy includes nuclear fuel energy, solar thermal energy, biofuel energy, and energy obtained by burning primary fuels (natural gas, oil, coal, peat, etc.)" (Zaverbnyi 2019; Marinas 2018).

"The Polish generation system is based mainly on fossil fuels, which makes it sensitive to climate policy and rising coal prices. In 2020, 70% of electricity was produced using coal. In February 2021, the Council of Ministers of Poland adopted "Poland's Energy Policy until 2040" (EPP2040), indicating support for the European policy to reduce emissions from 30% to 55%, included in the Fit for 55 packages. "Poland's Energy Policy 2040" presents a holistic approach to energy issues, considering the fundamentals of a just transition, an energy reconstruction system, and clean air, which involves a complete reconstruction of power generation sources, heating systems and distributed heating sources, and electrification of heating and transport. EPP2040 provides a forecast of technological directions the reconstructing generation sources and mixing primary energy sources. It implies basing electricity production on wind (sea) energy, solar power, and nuclear power plants. Prosumers, being producers and consumers of energy, play a unique role. During the transition period, natural gas will be the fuel that provides controlled energy generation" (Borysiak et al. 2022a).

The range consideration of raw materials (primary energy) used by Ukrainian energy enterprises for producing heat and electricity is essential. In the context of the data in Table 3, in 2020, wind and solar stations provided only electricity production, unlike other stations.

Table 3. Source of energy supply of Ukraine in 2020

Tabela 3. Źródła zaopatrzenia energetycznego Ukrainy w 2020 r.

Source of energy supply	Supply of electrical energy [million kWh]	Thermal energy supply [thousand Gcal]
Thermal power plants	36,300	1,125
Combined heat and power plants	12,837	25,517
Nuclear power plants	71,249	1,387
Wind power plants	3,271	–
Solar power plants	5,684	–
Hydroelectric power plants, including pumped storage power plants	7,415	–
Heat generating installations, boiler rooms	–	52,954
Other power generating installations	441	7,971
Total	137,197	88,954

Source: formed on the basis of (Statistical Yearbook of Ukraine 2020, 2021).

According to (Statistical Yearbook of Ukraine 2020, 2021), "in 2020, for conversion into other types of fuel and energy in Ukraine 92.6% of non-glomerated fuel peat, 89.1% of coal, 83.6% of fuel briquettes and pellets from wood and other natural raw materials, 81% fuel oil, 44.4% briquettes, pellets and similar types of solid fuels from coal, 38.9% natural gas, 38.2% firewood for heating, 0.3% propane and liquefied butane, 0.2% gas oil (diesel fuel) were used" (Statistical Yearbook of Ukraine 2020, 2021). Such data indicate that, along with natural primary sources (coal, peat, natural gas), also in the production process of other types of fuel and energy, a high percentage fell on the use of biomass (from wood), while other alternative primary energy sources are not listed.

Within the European integration of Ukraine, it is of particular importance to consider the aspect of the competitiveness of energy enterprises in the European energy market. In this context, to understand the correspondence of the energy policy to the European energy challenges, Table 4 presents summary data on the structure of energy resources in the energy system of Poland from 2018 to 2020 by the source of electricity generation. In particular, in Poland (Borysiak et al. 2022a).

Table 4. The structure of energy resources in the energy system of Poland from 2018 to 2020 by source of electricity generation [TWh]

Tabela 4. Struktura zasobów energii w systemie energetycznym Polski w latach 2018–2020 według źródła wytwarzania energii elektrycznej [TWh]

	31.12.2018	31.12.2019	31.12.2020	Difference between 2020 and 2018
Total	45,939	46,799	49,238	+3,299
Commercial power plants	36,638	36,674	36,364	–274
Commercial hydropower	2,341	2,346	2,356	+15
Commercial thermal power plants:	34,296	34,328	34,008	–288
on coal	23,215	23,159	22,747	–468
on brown coal	8,752	8,382	8,478	–274
on gas	2,330	2,788	2,782	–452
Wind and other renewable energy sources	6,621	7,490	10,229	+3,608
Industrial power plants	2,680	2,634	2,645	–35
District/centralised power generation	29,128	29,333	29,429	+301
Non-centralised energy generation	16,811	17,466	19,810	+2,999

Source: formed on the basis of (Borysiak et al. 2022a).

Such results of the analysis of electricity production in Poland testify to the competitiveness of Ukrainian energy enterprises to integrate into the European energy policy. In addition, the applied justification for this was that Ukraine joined the European electricity network ENTSO-E in March 2022.

Conclusions

The research has proposed a methodological approach to low-carbon management in selecting resources for energy production of enterprises. The specificity of this methodological approach lies in assessing the energy consumption system efficiency based on low-carbon management in selecting resources for energy production of enterprises. The scientific value of the methodological approach proposed lies in forecasting the potential of low-carbon management in selecting resources for energy production of enterprises in the energy supply chain, including the definition of optimisation criteria for the effectiveness of the management system. In particular, for the determining the indicator of environmental decarbonisation, the volumes of emissions of pollutants into the atmospheric air from stationary sources of pollution were studied.

The results obtained for all types of harmful substances indicate the adequacy of the low-carbon management in selecting resources for energy production of enterprises giving preference to solar and wind power. The scientific value of such a methodological approach is presented by the ability to forecast the potential of low-carbon management in selecting resources for energy production of enterprises in the energy supply chain.

This indicates the intensification of transition to low-carbon energy and the need to forecast the choice of low-carbon technologies for renewable energy production. The results stand as the basis for creating climate energy clusters in the regions to diversify the selecting resources for energy production of enterprises, and to increase the efficiency of transportation of production waste as renewable energy sources by transport for strengthening the resilience of climate security.

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Zarządzanie niskoemisyjne w doborze zasobów do produkcji energii przedsiębiorstw

Streszczenie

Zagrożenia klimatyczne wymuszają zmiany w gospodarce w kierunku niskoemisyjnego rozwoju energetycznego. Artykuł poświęcony jest badaniu zarządzania niskoemisyjnego w doborze zasobów do produkcji energii w przedsiębiorstwach. W artykule wyjaśniono gotowość gospodarstw domowych do korzystania z technologii niskoemisyjnych poprzez przejście do konsumpcji energii ze źródeł odnawialnych. W pracy zaproponowano podejście metodologiczne do zarządzania niskoemisyjnego w doborze zasobów do produkcji energii w przedsiębiorstwach. Specyfika tego podejścia metodologicznego polega na ocenie efektywności systemu zużycia energii w oparciu o zarządzanie niskoemisyjne w doborze zasobów do produkcji energii w przedsiębiorstwach. Wyniki uzyskane dla wszystkich rodzajów substancji szkodliwych wskazują na adekwatność zarządzania niskoemisyjnego w doborze zasobów do produkcji energii w przedsiębiorstwach, preferując energię słoneczną i wiatrową. Wartość naukowa takiego podejścia metodologicznego polega na możliwości prognozowania potencjału gospodarki niskoemisyjnej w doborze zasobów do produkcji energii przez przedsiębiorstwa w łańcuchu dostaw energii. Uzyskane wyniki stanowią podstawę do tworzenia klastrów energii klimatycznej w regionach w celu dywersyfikacji zasobów do produkcji energii w przedsiębiorstwach oraz zwiększenia efektywności transportu odpadów produkcyjnych jako odnawialnych źródeł energii w transporcie w celu wzmocnienia odporności bezpieczeństwa klimatycznego.

Słowa kluczowe: zmiany klimatu, innowacje niskoemisyjne, zarządzanie niskoemisyjne, niskoemisyjny łańcuch dostaw energii, odnawialne źródła energii