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Advancing Renewable Energy Transition for Economic Sustainability: Insights from Global Practices and Local Adaptation Strategies

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Abstract
Renewable energy in Ukraine accounts for 9 per cent. Renewable energy is planned to be developed in the post-war reconstruction. The Swedish experience is suitable for this purpose and it is advisable to apply it. The biggest problem is the conversion of old enterprises to renewable energy sources. The article presents a methodology for assessing the possibility of transition to renewable energy sources

Keywords: energy, renewable energy, economic sustainability, energy system energy strategy

1. Introduction

In most countries of the world, the share of renewable energy in the total volume is steadily increasing. In Ukraine, it is 9 percent. After the collapse of the Soviet Union, Ukraine will still have 55 percent of nuclear power. But nuclear power units need to be reconstructed. A possible development scenario is to increase the percentage of renewable sources or to switch completely to this type of energy resources.

Under martial law, the energy sector is transformed into a system with elements of distributed generation, i.e., power plants are created. Power plants in a distributed generation system can range from several kilowatts to several tens of MW. These can be solar panels on a house, small windmills, as well as combinations of these and other technologies, small and medium-sized modular nuclear reactors, etc.

In other words, changes in the energy system are gradually taking place, including an increase in renewable sources. However, this process is slow.

At the same time, the transition to renewable energy sources is one of the priorities in the fight against global warming. Due to the rejection of Russian gas after the full-scale invasion of Ukraine, Europe is currently focused on rapidly reducing its demand.

At the same time, there is a gradual abandonment of coal, also due to the war in Ukraine - on August 1, 2022, the EU imposed an embargo on coal imports from Russia. The share of Russian coal in the EU consumption structure was as high as 45%.

Ukraine also needs to focus on the construction of generation: basic and shunting. The results of Ukrenergo's modeling of the further development of the power system,

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published in early 2024, show that the country needs 8 GW of solar and wind generation, up to 1.5 GW of gas shunting capacities, up to 1.5 GW of biomass power plants, and 1 GW of energy storage systems.

2. Previous research

Reforming the Ukrainian energy sector is and will remain a key factor for the growth and harmonious development of the country's economy. After all, the development of energy, especially renewable energy, in Ukraine was in line with the previous long-term energy development strategy of Ukraine (until 2035) (Decree of the Cabinet of Ministers of Ukraine, 2017) and the current one (until 2050) (Decree of the Cabinet of Ministers of Ukraine, 2023).

This is stated in the long-term energy modeling, forecasting in Ukraine, research and forecasting of scenarios, plans, measures for the implementation of the energy strategy of Ukraine in the work of O. Dyachuk (2019), R. Podolets (2019), R. Yukhymets (2019), V. Pekkoev (2019) (Decree of the Cabinet of Ministers of Ukraine, 2023).

Ukraine is a strategic player in energy transit and is one of the largest hydrocarbon producers in the region. Therefore, an important aspect of Ukraine's energy policy should be reforming the energy sector by using the best international (including European) experience and adapting it to domestic conditions. The topic of renewable energy is relevant for the Ukrainian economy, as well as for the economies of other countries. This is stated in the works and studies of I. Sotnyk (2019), I. Klopov (2017), O. Sukhodol (2020) and many other energy scientists.

The strategic development of the energy sector is the subject of the works of I. Klopov (2017), Zh. Chernousova (2022) and K. Stepanchuk (2022). O. Dyachuk (2019), R. Podolets (2019), R. Yukhymets (2019), and V. Pekkoev (2019) conducted a detailed study of long-term energy modeling and forecasting in Ukraine. However, it is clear that after February 24, 2022, the situation in the country's energy sector has changed significantly, and completely different problems and needs have come to the fore.

The need (demand) for transformation of the energy sector is noted in the works of O. Kambur (2022), K. Tulkina (2022), T. Panova (2022) and V. Mazurenko (2020), E. Panchenko (2020), O. Yatsenko (2020). The problems of increasing the level of energy efficiency of the Ukrainian economy with the help of renewable energy are discussed in the works of I. Sotnyk (2019), P. Makarenko (2019), O. Kalinichenko (2019), V. Aranchii (2019). After all, Ukraine's competitive advantages depend on the level of energy intensity.

A number of foreign and domestic scholars have studied the development of renewable energy. R. Vakulchuk (2020), I. Overland (2020), D. Scholten (2020) in their studies stated that renewable energy has advantages over fossil fuels for international security. The impact of renewable energy consumption on economic growth has been studied (M. Shahbazab, C. Rahutland, K. Reddy, J. Chitedie, Y. Xuan, V. Vog, 2020).

M. Perea-Moreno (2018), C. Hernández-Escobedo (2018), A. Perea-Moreno (2018) studied the contribution of international institutions to the production of renewable energy in cities as a key element for achieving sustainability. According to the research, energy production from renewable sources is in line with the energy policies adopted by most developed countries to mitigate the effects of climate change (M. Perea-Moreno, C.

Hernández-Escobedo, A. Perea-Moreno, 2018). In their study, M. Perea-Moreno (2019), E. Sameron-Monzano (2019), A. Perea-Moreno (2019) analyzed the trends in the use of biomass for renewable energy sources. On the basis of cooperation between countries, eight clusters have been identified in biomass research, which are concentrated in three countries (USA, India, and the UK).

The problem of renewable energy has been actively studied for a long time in Europe (L. Romo-Fernandez, C. Lopez-Puyalte, 2011), as the leading continent in the production of energy by alternative means. Intensifying the transition of economies to renewable energy sources is important for decarbonizing the world economy and mitigating global climate change (A. Levenda, I. Behrsinb, F. Disanok, (2021). The authors evaluate renewable energy technologies based on the environmental justice of their distribution and capabilities. Based on empirical analysis, scientists have confirmed the long-term relationship between renewable energy consumption and economic growth of countries (C.-W. Su, H. Han, M. Umar, W. Zhang, 2021).

L. Ionescu (2022) studied sustainable economic growth and CO2 emission reduction. In particular, the author pointed out the role of carbon accounting in achieving carbon neutrality.

Energy experts also paid attention to adapting the experience of leading European countries in the energy sector of Ukraine. The possibilities of using regenerative energy sources in Ukraine and the EU countries are highlighted in the work of M. Rozheliuk (2023). Due to the significant level of pollution of traditional energy, the large scale of destruction by Russia (the energy sector suffered the most), it is necessary to effectively restore the energy sector, in particular its renewable segment.

It is clear that, in addition to the environmental factor, the security factor has come to the fore after Russia's full-scale invasion. The problems of Ukraine's energy security are highlighted in monographic studies by O. Sukhodol (2020), Y. Kharazishvili (2020), D. Bobro (2020), A. Smenkovskyi (2020), H. Riabtsev (2020), S. Zavhorodnia (2020). M. Rozheliuk (2023) identifies the development of renewable energy sources as a key factor in strengthening Ukraine's energy security.

Experts have assessed the impact of new renewable electricity generating capacities in Ukraine (in particular, according to the pessimistic scenario, 21% of electricity from renewable energy sources will be produced by 2030, while according to the optimistic scenario, this figure is expected to reach 30%). The key problems of renewable energy development in Ukraine and existing barriers are also analyzed (G. Trypolska, O. Kryvda, T. Kurbatova, O. Andrushchenko, S. Suleymanov, E. Brydun, (2021).

A significant number of scientific works by foreign and domestic scientists are devoted to the development of renewable energy.

Among foreign researchers, it is advisable to highlight the works of the following specialists: R. Vakulchuk (2020), I. Overland (2020), D. Scholten (2020), M. Shahbazab (2020), C. Rahutland (2020), K. Reddy (2020), J. Chitedie (2020), Y. Xuan (2020), V. Vog (2020). The study of the impact of renewable energy on economic development and climate is devoted to the works of M. Perea-Moreno (2018, 2019), C. Hernández-Escobedo (2018), A. Perea-Moreno (2018, 2019), E. Sameron-Monzano (2019). Scientific studies (based on empirical analysis) have confirmed the long-term relationship between

renewable energy consumption and economic growth (C.-W. Su, H. Han, M. Umar, V. Zhang, 2021).
For Ukraine, the high potential for renewable energy lies in the European integration direction of development (L. Romo-Fernandez, C. Lopez-Puyalte, 2011).
In addition, the transition of Ukraine's economy to renewable energy sources is important for decarbonizing the economy and mitigating global climate change (A. Levenda, I. Behrsinb, F. Disanok, 2021, L. Ionescu, 2022).
It is also necessary to note a galaxy among domestic renewable energy researchers. S. Kudria (2020) in his monographic study analyzed the processes of converting energy from various types of renewable sources (wind, solar, geothermal, small rivers, biomass) into electricity and heat. The author also substantiates effective ways/means of developing various types of renewable sources. It is noteworthy to consider the peculiarities of the use of each type of renewable energy source (wind, solar, geothermal, small rivers, biomass) by different sectors of the Ukrainian economy, as well as by the private sector, as one of the priorities for reform in our country. The study presents the results of scientific research on renewable energy by specialists of the Institute of Renewable Energy of the National Academy of Sciences of Ukraine (S. Kudria, 2020).
The key problems of renewable energy development in Ukraine were analyzed by G. Trypolska, O. Kryvda, T. Kurbatova, O. Andrushchenko, S. Suleymanov, and E. Brydun (2021).
A visual analytical model based on statistical information on electricity generation from renewable sources was developed for Ukraine (O. Kambur, K. Tulkina, T. Panova, 2022).
The issues of economic, social and environmental effects of the development of domestic renewable energy have been studied by such domestic researchers as O. Akimenko (2020), I. Kostiuchenko (2020), Zh. Chernousova (2022), K. Stepanchuk (2022), Y. Dziadykevych (2019), O. Sohatska (2019), I. Liubezna (2019), M. Kuzmina (2020), P. Makarenko (2019), O. Kalinichenko (2019), V. Aranchii (2019), V. Omelchenko (2020), N. Ryazanova (2017) and many others.
A small number of works have been devoted to the problems of the formation and development of renewable energy in Ukraine during the war and post-war periods (M. Rozheluk, 2023), given that Russia's full-scale invasion took place relatively recently. However, solving the existing problems in the energy sector is a priority task facing Ukraine's economy.
For Ukraine, these studies are useful because the replacement of traditional sources with renewable ones and the modernization of the energy sector is lagging behind industrialized countries. In addition, this is happening in the context of war and the constant threat from Russia. An important aspect of this is to determine the percentage of enterprises that simply cannot be technically converted to renewable sources.
The purpose of the article is to develop a methodology for assessing the possibility of switching Ukrainian enterprises to renewable energy sources, and to identify prospects and ways of developing renewable energy.

3. Materials and methods

We can formulate the following hypotheses:
1. The level of energy consumption in the countries of the world (including Ukraine) will steadily increase.
2. Increased consumption of various types of energy will lead to the desire to improve energy efficiency, including the level of energy efficiency of exploited energy resources, in order to increase the level of competitive advantages, energy and economic security.

These hypotheses will determine the society's desire to introduce and actively exploit new renewable energy capacities with high efficiency.

At the same time, if we compare the markets of traditional (hydrocarbon raw materials and products of their processing) and renewable energy in recent years, the former is less volatile, and the latter is more competitive in terms of price parameters. Although prices for traditional energy resources (oil, liquefied natural gas, coal) fluctuate, they are ultimately cheaper than renewable ones Goldthau, , etc. 2009, Moran, etc. 2009).

In particular, Ukraine has significant coal deposits. The only concern today is a Russian invasion.

Given the above, there is an urgent need to develop a methodology for assessing the processes of replacing traditional energy with renewable sources.

As the study shows, the processes of replacing traditional energy with renewable sources and their dynamism are mainly characterized by the following three key indicators: the level of economic efficiency, the level of rationality and the level of substitution effectiveness.

So, as for the first indicator, the level of economic efficiency of the process of replacing traditional energy with renewable energy sources should be calculated by the ratio of revenues received from the sale of energy resources to the costs (current, capital) associated with the creation of infrastructure and generation of energy resources from renewable energy sources.

However, it should be understood that the replacement (gradual substitution) of traditional energy with renewable energy sources should bring not only exclusively direct economic benefits, but also indirect effects. The indirect effects are to reduce the environmental burden on the national and world (global) natural system.

Therefore, it is proposed to supplement the mechanism for calculating the level of efficiency with a coefficient that characterizes the level of environmental load when operating certain energy sources ((Report on the implementation of the research work., 2024).

$$К_{ec} = 1 - \frac{DE}{EB} R_{eco} = 1 - \frac{ED}{EAB}, \quad , \tag{1}$$

$К_{ec}$ – the level of environmental load during the operation of various energy sources, ED – the level of environmental damage from the exploitation of certain energy resources, EAB – economic advantages (benefits) from the processes of selling energy resources obtained from different energy sources.

It is recommended to calculate the indicators of the level of economic efficiency of replacing traditional energy with non-traditional (renewable) energy sources using the following calculation formulas (2, 3):

$$\mathrm{IN_{e1}} = \frac{\mathrm{R_r}}{\mathrm{E_r}} * \mathrm{k_r} \bigg/ \frac{\mathrm{R_a}}{\mathrm{E_a}} * \mathrm{k_a} \quad I_{\mathrm{e1}} = \frac{D_t}{C_t} * k_t \bigg/ \frac{D_\mathrm{a}}{C_\mathrm{a}} * k_t, \tag{2}$$

$$\mathrm{I_{e1}} = \frac{\mathrm{D_t}}{\mathrm{C_t}} * \mathrm{k_t} \bigg/ \frac{\mathrm{D_a}}{\mathrm{C_a}} * \mathrm{k_t}$$

where Dt, Da are the current revenues (received, respectively, from the operation of traditional (index r) and renewable (alternative, index a) energy sources);;
Cr, Ca – current costs associated with the operation of traditional/renewable energy sources (respectively);
kt, ka – coefficients of environmental load reduction by traditional/renewable energy sources.

$$I_{\mathrm{e2}} = \frac{NPV_t}{KB_t} * k_t \bigg/ \frac{NPV_\mathrm{a}}{KB_\mathrm{a}} * k_\mathrm{a}, \tag{3}$$

NPVt , NPVa – is the net present value of the operation of traditional/renewable energy sources; KBt, KBa are capital costs associated with the creation of traditional/renewable energy sources infrastructure.

The second most important indicator that will characterize the processes of replacing domestic (Ukrainian) traditional energy with renewable energy sources and their dynamism is the indicator of the rationality of this replacement (Report on the implementation of the research work., 2024).
Some authors (Connollya, et al. 2016) propose to assess the rationality of replacing some energy sources with other sources by calculating (formula 4) the indicator of the level of efficiency (ER):

$$RE = \frac{\mathrm{MP}*Q}{\sum \mathrm{CP}}, \tag{4}$$

where MP is the market price of a unit of the substituted energy resource (e.g., a standard ton, etc.); Q is the volume of the substituted energy resource; ΣCP is the cost of total costs (current, capital) associated with the processes of this substitution.

In this case, the reverse indicator of the level of economic efficiency is used in the form of the profitability of this substitution. However, it should be noted that this approach will not allow to fully assess the rationality of replacing traditional energy with renewable (alternative) energy sources. Therefore, it is advisable (Connollya, et al. 2016) to use the following refined calculation of the rationality of substitution indicator (5):

$$REU = \frac{EEC_r}{EEC_a} - \Delta k_{ra}, \tag{5}$$

where EECr is the level of energy intensity of the country's economy, ECCa is the level of energy intensity of the social and household sector when using traditional/renewable energy sources, respectively; Δkra is the difference between the average efficiency of renewable and traditional energy sources.

The level of effectiveness (efficiency) of the dynamism of processes in replacing traditional energy with renewable energy sources should be assessed taking into account the level of energy security. This is especially relevant for the economy and energy sector of Ukraine in wartime, when the Russian occupiers (cynical invaders) systematically destroy the country's energy infrastructure, despite the fact that it provides for the innocent civilian population (including hospitals, kindergartens, schools, universities, etc.) (Report on the implementation of the research work., 2024).

In practice, there are a number of approaches to calculating energy security indicators. It is optimal to analyze the state of energy security of a particular region (area, country, territory, administrative unit, etc.) using an integrated approach. This approach should include the calculation of three indicators (coefficients): the level of energy security of the region, the level of sufficiency of energy supply, and the level of quality of development of the region (Table 1).

We propose to calculate the coefficient (indicator) of energy supply as follows (Table 1).

Based on the calculations (Table 1), it is recommended to calculate an integrated indicator of the effectiveness of the processes of replacing traditional energy resources with renewable resources (IR). The calculation will be based on the level of energy security of the region (country, territory, administrative unit, etc.). It will have the following form (6) (Report on the implementation of the research work., 2024, Alam, etc. 2024).

$$IR = SUFF * \sqrt[2]{AU * QUAL}, \tag{6}$$

Taking into account the structural and logical sequence of the proposed calculation tools, we can distinguish three potentially possible states of the dynamics of the processes of replacing traditional energy with renewable sources.

1. The dynamics of the processes of replacing traditional energy with renewable sources will be characterized by extensiveness. This will happen when the growth rate of performance indicators is lower than the growth rate of economic efficiency and rationality indicators. In other words, renewable energy will not contribute to the potential growth of socio-economic benefits from the development of its infrastructure and generation of energy resources.

2. The dynamics of the processes of replacing traditional energy with renewable energy sources is characterized by intensity. This will occur when the growth rate of the performance indicator is higher than the growth rate of the economic efficiency and

rationality indicators. That is, renewable energy will generate socio-economic benefits from its development and operation.

Table 1. Indicators of energy security of replacing traditional energy sources with renewable (alternative) ones and their calculation.

Indicator names	Calculation formulas	Explanation of formula elements	Essence of indicators
Indicator of energy security	$AU = \frac{(AU_{fr} - AU_{minr}) + (AU_{fa} - AU_{mina})}{(AU_{max} - AU_{min})}$	AUfr is the actual level of provision of the region with renewable energy resources, AUfa is the actual level of provision of the region with traditional energy resources, AUmint, AUmint are the minimum permissible levels of self-sufficiency of the region with renewable, traditional energy resources, AUmin, AUmax are the total minimum possible and maximum established levels of self-sufficiency of the region with all types of energy resources (regardless of sources)	It shows the level of energy supply in the region, availability of all types of energy sources (traditional, renewable)
Indicator of the level of energy supply sufficiency,	$SUFF = \frac{PR_t + PR_a}{C_t + C_a}$	PRt - primary production of conventional energy resources, PRa - primary production of renewable energy resources, Ct , Ca - final consumption by each source	Reflects whether the level of energy supply in the region is sufficient (including production (generation) and consumption)
Indicator of the quality of development of a given region	$QUAL = \frac{GPIND}{GDPU}$	GPIND - General Progress Indicator, GDPU - Gross Domestic Product of Ukraine indicator	Indicates the level of correlation between the general progress indicator and the gross domestic product indicator for the region

Source: (Report on the implementation of the research work, 2024).

3. The dynamics of the processes of replacing traditional energy with renewable energy sources will be characterized by a clear balance. This will happen under conditions when the growth rate of the performance indicator is equal to the growth rate of the indicators of economic efficiency and rationality. Under these conditions, there will be a proportional transformation of the efficiency and rationality of substitution processes into socio-economic benefits in the form of an increase in energy security.
Thus, the proposed methodology takes into account three key indicators (the level of economic efficiency, rationality and effectiveness) in the context of energy security.
The current experience of organizing the structures of territorial communities in the context of the global transition to "green" energy and decentralization of energy supply systems indicates a return to the management of resource assets related to their own energy production through the introduction of local generating capacities and renewable energy sources.
Due to the rational allocation of resources, coordination of energy generation, transmission, storage, distribution and consumption processes, it becomes possible to create local high-tech infrastructure facilities within a separate territorial community to form an independent (island) energy sector.

4. Results and discussion

For comparison, the structure of energy consumption in the world is shown (Fig. 1). In the case of transition of Ukraine according to the scenario of transition to renewable energy sources, a situation may arise where there is no possibility of transition of the majority of enterprises to renewable sources of energy. Since most enterprises use outdated technological processes.

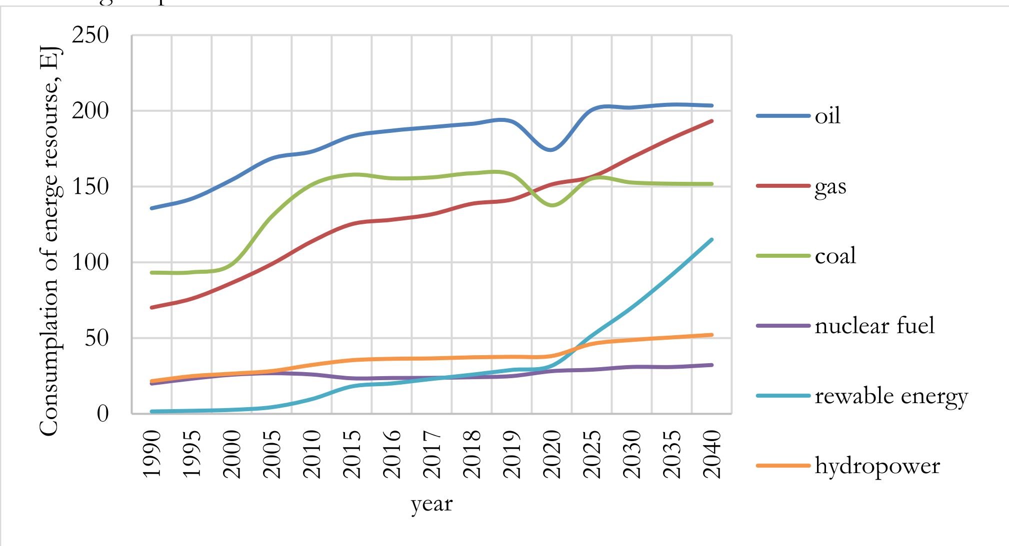

Fig 1. The dynamics of changes in the structure of the resource-based public transport system of Ukraine
Source: (Statistical Review of world Energy, 2021).

The basis of the electric power industry of Ukraine is the unified energy system of Ukraine - a set of nuclear, thermal, hydroaccumulative power plants, thermal power plants, as well as power plants based on renewable energy sources (wind, solar, etc.), main electric networks of Ukrenergo and distribution electric networks, which are united by a common method of production, transmission and distribution of electric and heat energy. Centralized dispatching management of the energy system of Ukraine is carried out by Ukrenergo. Communication with power systems of other countries is carried out by interstate power transmission lines [Abdullah, Iqbal, Hyder, Jawaid, 2020, Osadcha, 2024]. The main components of the energy system of Ukraine are given in Table 2. In 2020. Ukraine produces, buys, and partially imports energy resources [Osadcha, 2024].
In Ukraine, since the 1990s, a model of the wholesale electricity market has been operating, the basis of which was the experience of Great Britain. The basis of this model is the preservation of the country's unified electric power system and its centralized management. At the end of the 90s of the last century, the liberalization of the electricity industry of Ukraine began.

Table 2. Energy system by component, thousand tonnes of oil equivalent

Components	**Values for the years**								
	2008	2009	2010	2015	2016	2017	2018	2019	2020
generation	84,260	79,339	78,712	61,614	66,323	58,863	60,883	60,452	57,017
consuption	134,562	114,420	132,308	90,090	94,383	89,462	93,526	89,359	86,363
import	65,263	48,506	51,260	31,575	29,152	35,145	33,795	34,708	30,655
export	1,462	7,081	9,278	1,447	1,427	1944	1,462	1,841	1,246
losses	-	-	11614	-	-335	-	316	-	63

Source: (State Statistics Service, 2023)

Producers of electric energy are business entities that legally own or use generating capacities, produce electric energy for the purpose of selling it on the electric energy market and/or provide auxiliary services. Among them: the old enterprise "Energoatom" - the operator of 4 operating nuclear power plants of Ukraine, on which 15 nuclear power units are operated. The company provides about 55% of Ukraine's electricity needs, in the autumn-winter period this indicator reaches 70%. According to the indicator of the installed capacity of nuclear power plants, Ukraine ranks seventh in the world. At the same time, it should be noted that renewable energy has a low share. In general, the share of renewable energy (solar and wind) is within 7 percent of the country's total energy balance. Until 2022, the share of renewable energy sources was growing, but the share remained insignificant.
In Ukraine, there is a trend of declining energy consumption in connection with the country's economic decline and the closure of a number of enterprises (Fig. 2).

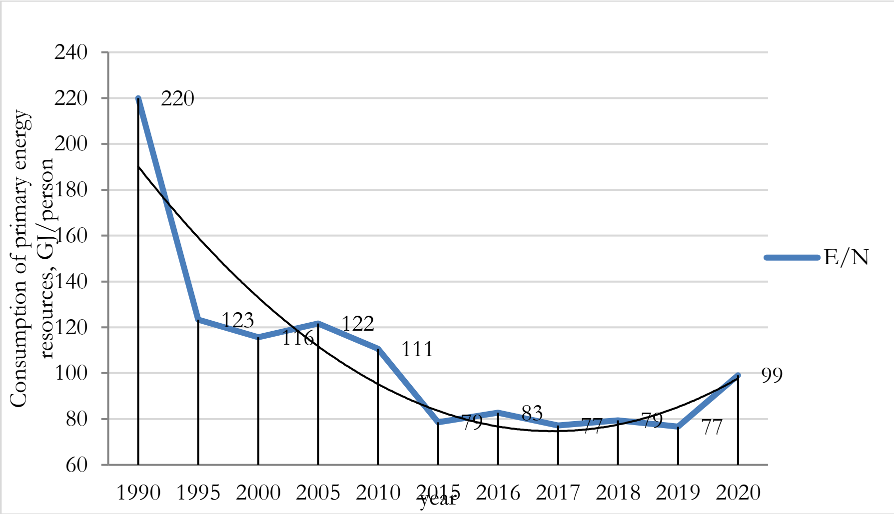

Fig. 2. Dynamics of changes in consumption of primary energy resources, GJ/person
Source: (Statistical Review of world Energy, 2021)

At the same time, there is a tendency to increase the energy intensity of the gross domestic product of Ukraine, as enterprises have outdated production processes (Fig. 3).

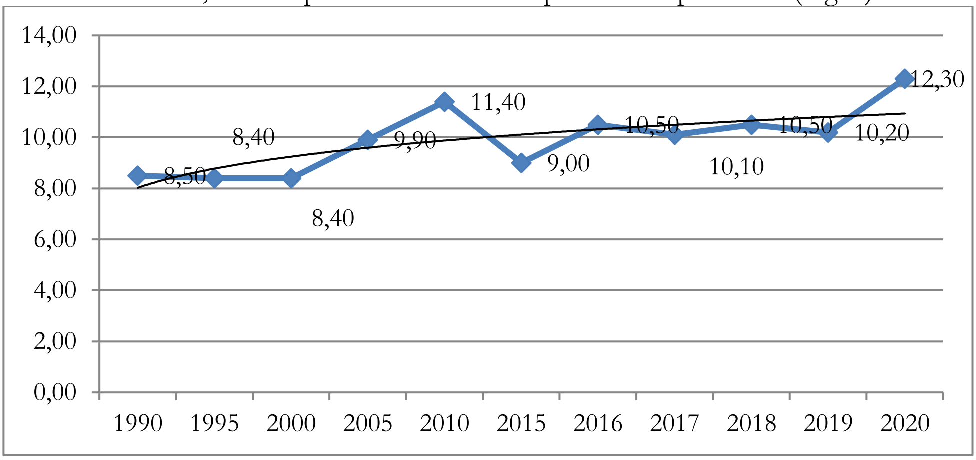

Fig. 3. Dynamics of the energy intensity of the gross domestic product of Ukraine, MJ/dollar
Source: (Statistical Review of world Energy, 2021)

It is clear that the indicators will be much worse in 2022. Therefore, in the following periods, it is advisable to restore the destroyed capacities and return the share to the level of the pre-war period.
It is also necessary to take into account the need to disclose reliable information about the real state of affairs in Ukraine's energy sector, including the renewable sector during the

war, in order to achieve the required level of energy, and, accordingly, economic and national security.
Therefore, future scientific research will be based only on "open" information. But this will last only until Ukraine wins the war.
Experts who say that the situation with the shutdowns will be tense for the next two years are being realistic. This is the period during which large-scale generation - solar, wind, and gas - is being built. During this period of time, companies need to actively build it. Yes, the state has a plan to build nuclear power units, but these are long-term projects with implementation periods of at least five to seven years.
In the short and medium term, wind generation is the best way to make up for lost capacity. It is the cheapest in terms of total cost per kilowatt among other generators and is relatively quick to build.
The construction period for a wind farm is one year. Large facilities are built in two years. There are enough projects in Ukraine that have passed the development stage and are ready for construction.
According to the Ukrainian Wind Energy Association, 4-5 GW can be built in Ukraine in the coming years. The potential for launching new distributed wind power generation in Ukraine is enormous. To meet demand and reduce imports, we need to build gigawatts of wind power across the country.
Of course, wind power generation can be called basic generation conditionally. However, all generation gaps should be covered by shunting gas piston or gas turbine generation. The cost of such a kilowatt-hour is higher and such facilities take longer to build than wind power. This is well demonstrated by the global benchmark LCOE (net present value of electricity for the period of operation of a power plant).
According to Bloomberg NEF, onshore and offshore wind and solar generation is the cheapest. Moreover, they are the fastest to build: solar - up to two years, wind - two to three years. Bloomberg NEF does not calculate the LCOE for nuclear. It lacks real information because few such projects are being implemented. Approximately, the LCOE for nuclear is $230-432 per MWh.
The government is moving forward with the development of distributed and renewable generation by liberalizing the market and changing the regulatory framework. However, there are still several important tasks that can accelerate the start of wind farm construction by investors.
Ukraine does not have a corporate PPA mechanism (long-term contracts for the purchase and sale of renewable electricity by private companies). Renewable electricity producers cannot raise international money because there is no guaranteed sale price for electricity for a long period, say, ten years.
It is much easier to do this when banks see that a renewable energy project will have a certain contractual yield for a certain period after commissioning. The development of renewable energy fits perfectly into the European integration processes that Ukraine is expecting and is in line with the Paris Climate Agreement. Moreover, after signing the Association Agreement with the EU, our country committed itself to greening the domestic energy sector.
At the end of July 2021, the Ukrainian government approved the Updated Nationally Determined Contribution of Ukraine to the Paris Agreement, according to which

Ukraine's current climate goal is to reduce greenhouse gas emissions by 35% by 2030 compared to 1990. However, it is clear that this plan will need to be updated to reflect the new realities brought about by the full-scale war.

One of the solutions discussed by industry players could be the creation of a fund by the state and international government organizations. It will guarantee the payment of a minimum electricity price to players in exchange for a certain portion of the income from the implementation of new projects by market players being transferred to the fund. This is an interesting idea that could significantly improve the prospects for new construction.

The advantage of this proposal is that the minimum price to be guaranteed for banks is significantly lower than all existing electricity tariff forecasts. Neither the state nor the IFIs will bear any real costs, but investors will receive an effective price guarantee mechanism by deducting part of their income.

Investors are not starting renewable energy projects because of uncertainty about war risk insurance mechanisms for equity investments and the limited mechanism for insuring debt capital risks.

The issues of war risk insurance and contracts are being worked out. The state has launched an insurance mechanism with limited amounts - up to UAH 200 million for new projects. However, addressing the energy capacity shortage requires higher limits, as we have billions to invest.

The solution to this problem is also to involve international financial institutions, which, in partnership with the state, can create a more powerful fund to insure war risks. In my opinion, the state can open a dialogue with international financial institutions and donor countries to launch projects that will help create infrastructure for new construction.

Mostly companies that are already present on the Ukrainian market and understand the route of project implementation are now ready to build wind farms. However, these market participants have been experiencing liquidity problems over the past three years.

The level of payment by the Guaranteed Buyer for renewable energy produced since the beginning of 2024 is about 60%. There is still a problem of old debts, which is about UAH 18 billion. If the state sees the need to build prepared projects, it should give this process an impetus in the form of a financial resource.

This is money previously earned by companies that will be paid back at some point, instead of working to strengthen Ukraine's energy security by investing in construction right now.

The problem is not in the Guaranteed Buyer, it is a general problem of the electricity market with a chain of debts that begins with the insufficiency of Energoatom's resources to finance preferential tariffs for the population.

At present, Energoatom's debt to the Guaranteed Buyer is approximately equal to the amount of the Guaranteed Buyer's debt to RES. Under these circumstances, the state could find a tool to solve the problem. For example, by providing a loan or issuing bonds to Energoatom, the entire debt problem could be solved.

Through the chain of Guaranteed Buyer - suppliers - grid companies - Ukrenergo, this money would go to “green” generation, and then the lion's share of this resource would go to the development and construction of generation. Fulfillment of the state's obligations to market participants would strengthen their belief that they have not developed new projects in vain, and this would stimulate new construction.

We are convinced of the critical need to build energy capacities every time we experience a power outage in our own homes or hear generators roaring in the streets. It is already clear that the country needs to build new energy. And we need to build a lot of it: both basic and maneuvering capacities.
We need the government to get involved in solving investors' problems: debts, corporate PPAs, and investment insurance. These issues will not be resolved on their own.
If the problems can be overcome jointly, renewable energy projects and maneuvering capacities will be built during the war. This is not only an urgent social issue, it concerns the country's economy - everyone suffers. Both the welfare of citizens and the economy depend on how quickly we build the facilities.
According to experts from the Institute of Industrial Economics, the integrated indicator of the effectiveness of the processes of replacing traditional energy resources with renewable resources (IR) is 0.6. This means that it is not advisable to switch 40 percent of enterprises to renewable sources.
Sweden's experience in developing renewable energy: The first instrument of influence: carbon payment. Sweden was one of the first countries in the world to test a carbon tax back in 1991. Any company pays a certain amount for each liter of fossil fuel it burns (and, accordingly, for each ton of CO2 emitted into the atmosphere). Private consumers also pay the tax in the form of a surcharge included in the price of gasoline. And vice versa: the combustion of fuel from sources classified as renewable (for example, biofuels based on wood waste, household waste, peat) is not taxed.
The result: this tax policy has "fundamentally changed the country's energy sector and made energy consumers Second step-: additional tax advantages. The wind energy sector and, since the beginning of this year, the solar energy sector have enjoyed impressive benefits in Sweden. For example, solar energy producers are exempt from almost all taxes: payments to the budget have been reduced by 98% since January 2017.
The third is green certificates. In this case, for each megawatt-hour of electricity generated by a wind turbine, you receive a certificate that you can later resell. The certificate is of interest to large energy companies or serious industrial energy consumers, which, according to Swedish law and EU regulations, must regularly and gradually reduce their greenhouse gas emissions. Large enterprises are included in the European Trading System and are required to obtain annual quotas (permits) for these emissions. In order to comply with the regulations, many companies not only apply a policy of reducing these indicators "internally", but can also purchase permits "externally" - for example, by purchasing a certificate from you. This mechanism helps to redirect finances from traditional large fossil fuel businesses to the new renewable energy sector, i.e. to support small producers.
But in addition to electricity, we also need to solve the problem of heat: in a cold country, people need to be warm. And here, too, renewable sources play an important role in Sweden. As a rule, either biomass energy (from processing waste from the forestry sector) or energy extracted from household waste is used for this purpose. Yes, a number of cities still receive heat based on energy from waste incineration plants, which is also seriously criticized by environmentalists who call for recycling rather than burning waste. In contrast, the residential urban sector uses a lot of heat pumps, which are essentially "refrigerators in reverse": they transfer heat energy from a low-temperature source to the

consumer. And in private homes, pellet boilers can often be found. Pellets are the same, but rammed into briquettes, forestry waste (mainly sawdust).
First of all, the semantic basis of the phrase "smart specialization" or "smart specialization" needs to be clarified. Today, the foreign-language component "smart" is widely used in the economic sphere in various combinations and meanings. The addition of the component "smart" to the word "specialization" in the context of the SS concept emphasizes the importance of a balanced consolidated search for priority areas that are promising for ensuring structural modernization of the economy based on knowledge and innovation. The authors of the original Guide on Research and Innovation Strategies for Smart Specialization (RIS3 Guide) [13] explain the "smartness" of smart specialization through: first, linking research and innovation to economic growth in the process of entrepreneurial discovery and setting policy priorities in cooperation with local actors; second, taking into account the situation in the external environment, which forces regions to be ambitious on the one hand, and realistic about the possibilities of achieving goals by linking local potential with external sources of knowledge and value chains.

5. Focusing the country's development on sustainable innovations in the energy sector

The importance of our study is confirmed by the focus of EU countries' development on sustainable innovation. This is one of the most popular goals (Eye@RIS3, 2023, S3 CoP Observatory, 2024) for the EU27 (Report on the implementation of the research work., 2024).
The focus of our study, ekj, is narrowed to smart priorities that focus on the most popular goal J - Sustainable Innovation. In total, as many as 507 priorities of national and regional smart specialization strategies were aimed at implementing sustainable innovations, which is 47% of their total number in the EU-27 countries/regions. Objective J includes the following 11 subject areas for creating innovations (Report on the implementation of the research work., 2024):
- Bioeconomy (J.61),
- Climate change (J.62),
- Eco-innovations (J.63),
- High-speed rail-road transport systems (J.64),
-Resource efficiency (J.65),
- Smart green and integrated transportation systems (J.66),
- Sustainable agriculture (J.67),
- Sustainable energy and renewable energy sources (J.68),
- Sustainable use of land and water resources (J.69),
- Sustainable production and consumption (J.70),
- Waste management (J.71).
The distribution of the shares of subject areas for creating innovations is shown in Table 2. At the same time (Eye@RIS3, 2023, S3 CoP Observatory, 2024) for the period 2014-2020, the percentages are slightly different from the period 2021-2027 (Report on the implementation of the research work., 2024).

But in both cases, it is the energy sector that is important J.61, J.62 J.63 and tangents to renewable energy: J.65, J.66, J.70. And, of course, directly "Sustainable energy and renewable energy sources" (J.68) (Report on the implementation of the research work., 2024).
Regions with a somewhat lower level of innovation development (moderate innovators and novice innovators) are trying to increase the number of priorities, the number of goals in each priority, and cover more target areas of smart prioritization in order to make the most of their geographical, climatic, and resource advantages and compensate for the immaturity of innovation ecosystems and the lag in technological development. A high share of digital transformations as a target for the development of start-up innovators seeking to bridge the digital divide in this way also seems natural (Report on the implementation of the research work., 2024).
To assess the effectiveness of the implementation of new approaches related to achievement in the new strategic period 2021-2027, a comparative analysis of smart priorities justified by the territories during the two strategic periods was carried out, and the content of current priorities with sustainable innovations was revealed (Table 3).

Table 3. The structure of sustainable innovation targets by area

Years	Share of sustainable innovation areas, %										
	J.61	*J.62*	*J.63*	*J.64*	*J.65*	*J.66*	*J.67*	*J.68*	*J.69*	*J.70*	*J.71*
2014-2020	9.6	4.8	16.0	0.8	15.2	9.6	5.6	13.6	4.8	14.4	5.6
2021-2027	9.4	8.2	12..0	3.0	14.2	7.7	7.7	8.6	8.2	13.3	7.7

Source: Eye@RIS3, 2023, S3 CoP Observatory, 2024, Report on the implementation of the research work.)

For further detailed analysis, the following countries were considered as reference for Ukraine countries of Central and Eastern Europe (CEE), which are neighboring and similar in terms of historical and socio-economic factors of development. According to the OECD (Eye@RIS3, 2023), this group includes the following countries: Albania, Bulgaria, Croatia, Czech Republic,
Hungary, Poland, Romania, Slovakia, Slovenia, and the three Baltic countries: Estonia, Latvia and Lithuania (all of which are close to Ukraine in terms of economic development). However, it is important for Ukraine it is important for Ukraine to adapt the best practices of these countries, as the proximity of development (Report on the implementation of the research work., 2024).
These countries have focused their smart strategies to varying degrees on sustainable innovations (Fig. 4), choosing 26 smart priorities under Goal J. The greatest Croatia, Poland, and the Czech Republic showed the greatest interest in its implementation.
The share of their priorities aimed at sustainable innovation exceeded the average for the EU27 countries. Regional RIS3s have been developed in three countries (Poland, Romania and the Czech Republic) (Report on the implementation of the research work., 2024).
The concentration of their regions on creating innovations for sustainable development is illustrated by the following indicators: 41%, 50% and 5%, respectively. The analysis of the RIS3 by CEE countries (Fig. 6) (S3 CoP Observatory, 2024) revealed their predominant focus on sustainable energy and the development of renewable energy sources. They also provide for a significant focus on achieving efficient use of resources, ensuring

sustainability in production, consumption and the development of the bioeconomy (Fig. 6) (Report on the implementation of the research work., 2024).

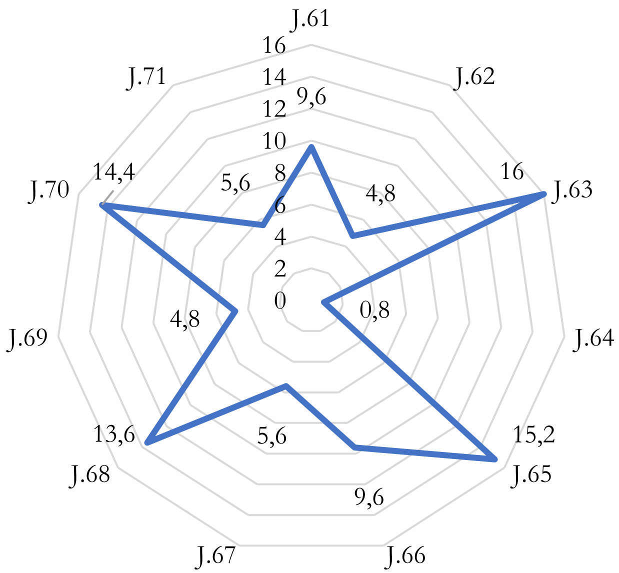

Figure 4. Choice of the Central and Eastern European countries of the subject innovation areas of the goal (J - Sustainable Innovation) for 2014-2020)
Source: (Eye@RIS3, 2023, (Report on the implementation of the research work., 2024).

Identifying the dominant areas of sustainable innovation in Central and Eastern Europe allows us to identify areas of potential cross-border/interregional partnership for Ukraine. In this regard, the situation with smart prioritization in our closest neighbors is of particular practical interest.
For example, Poland's RIS3 (one of Ukraine's largest partners, so it is extremely important) contains three priorities with the indication of Objective J: (1) Bioeconomy, including agri-food, forestry and environment; (2) Sustainable energy; (3) Natural resources and waste management. Sustainable innovation as a basis for regional development was chosen by 15 out of 16 Polish regions registered on the S3 Platform. Quantitative analysis of the choice of subject areas of innovation within the framework of Objective J (Fig. 5) showed that Polish regions are mainly focused on the realization of opportunities for efficient use of resources, creation of eco-innovations, and development and application of sustainable energy technologies (Report on the implementation of the research work., 2024).
Such a targeted focus correlates with the general innovation trends in the countries of Central and Eastern Europe.
To conclude our study, we should note the following positive changes and developments in the energy sector of Ukraine (Bojko, 2024).
At the COP29 climate conference in Baku, the United States and Ukraine announced the launch of three small modular reactor (SMR) projects (Bojko, 2024).

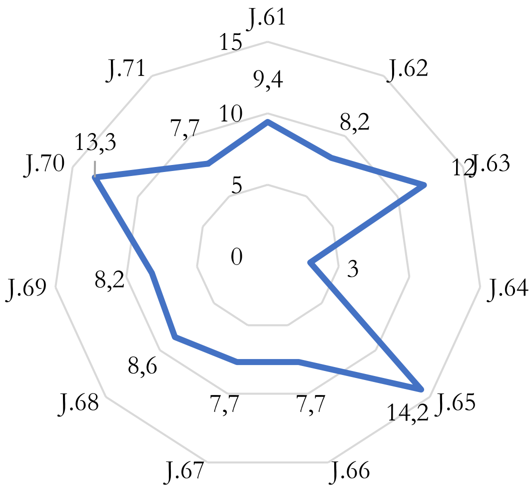

Figure 5. Choice of subject innovation areas of the target (J - Sustainable Innovation) for 2021-2027 by the countries of Central and Eastern Europe)
Source: based on (Eye@RIS3, 2023, S3 CoP Observatory, 2024, (Report on the implementation of the research work., 2024).

The initiatives are part of the international FIRST (Foundational Infrastructure for the Responsible Use of Small Modular Reactor Technology) program aimed at the responsible use of SMR technologies.
The projects include the construction of a pilot plant for the production of pure hydrogen and ammonia. The projects also envisage the conversion of coal-fired power plants to small modular reactors, as well as the development of a roadmap for the decarbonization of the steel industry using SMR.
Ukraine has committed to tripling its nuclear capacity by 2050 (according to the 2050 Strategy). This will promote the development of both large nuclear power units and small reactors for industrial needs (Decree of the Cabinet of Ministers of Ukraine, 2023).
The advantage of small modular reactors over traditional nuclear power plants is that they require lower capital costs, are more mobile, have an increased level of safety, and are adapted for integration with other energy solutions, including hydrogen energy.
Such projects will contribute to Ukraine's energy independence, economic recovery after the war, and carbon emissions reduction.
The initiatives will be implemented jointly with leading energy companies and academic institutions in the United States and Ukraine. The FIRST program will guarantee high standards of nuclear safety and non-proliferation (Boyko, 2024).

6. Conclusions

According to experts of the Institute of Industrial Economics, the integrated indicator of the effectiveness of the processes of replacing traditional energy resources with renewable resources (IR) is 0.6. That is, it is not advisable to convert 40 percent of enterprises to renewable sources. Ukraine's energy system is subject to destruction, and it is advisable to distribute energy risks and form energy hubs. It is necessary to attract investments to ensure the security of the energy system.

It is advisable to use the best European practices, for example, the experience of Sweden in stimulating the development of renewable energy. It is also advisable to adapt the experience of Central and Eastern European countries in renewable energy strategy in combination with other related innovations.

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