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ДЕЦЕНТРАЛІЗАЦІЯ - МАГІСТРАЛЬНИЙ ШЛЯХ ПЕРЕТВОРЕННЯ ЕНЕРГЕТИЧНОЇ ГАЛАЗІ УКРАЇНИ

Актуальність. Події листопада 2022 року показали абсолютну нестійкість централізованої енергетичної системи України. До 40% централізованої енергетичної інфраструктури було виведено з ладу за два дні. Мільйони людей на тривалий термін залишилися без електрики, тепла та води. Тому дуже важливим є розвиток у майбутньому енергетичної сфери держави з урахуванням потреб політики децентралізації України, зокрема місцевих громад.

Мета та завдання. Метою дослідження є визначення імперативів децентралізації енергетичної галузі України. Головним шляхом розбудови енергетичної системи держави є перехід від централізованої систем до розподіленої. Розташування систем генерації в об'єднаних громадах дає можливість перейти до систем когенерації електричної та теплової енергії підвищити ККД встановлених потужностей та суттєво до 40% економити паливо.

Матеріали та методи. Методологічним базисом формування регіональної політики повинні стати найкращі світові та європейські практики щодо розвитку енергетичного сектору країни. Активне впровадження методів системного аналізу, експертної оцінки щодо впровадження систем децентралізації енергетичної галузі є запорукою досягнення пріоритетів національної безпеки України у повоєнний період. Приоритетна підтримка з боку ЄС та інших міжнародних донорів стосується тих проектів та програм, які спрямовані на децентралізацію, декарбонізацію, місцеву економічну стійкість та енергетичну незалежність.

Результати. У дослідженні обґрунтовано, що місцеві Громади мають великі можливості для використання альтернативних поновлювальних ресурсів для генерації електричної та теплової енергії. Насамперед це біомаса, біогаз, сонячна енергія, енергія вітру та геотермальна. Зокрема, авторами доведено, що за рахунок встановлення засобів акумуляції електричної енергії можливо підняти рівень використання встановлених потужностей сонячних та вітряних електростанцій ще на 50% та досягти загальний рівень використання встановлених енергетичних потужностей до 70%.

Висновки. Активне впровадження в господарську практику альтернативних джерел енергії може стати основою національної безпеки держави в повоєнний період. Пропонується Громадам замість виконного імпортованого палива використовувати, як паливо близько розташовані відходи сільськогосподарської діяльності та тверди побутові відходи. Також пропонується в рамках об’єднаних громад створювати локальні електричні мережі об’єднанні у віртуальні електростанції, включаючи туди не тільки всі види генерації, що є на території, а й системи короткострокового і довгострокового накопичення електричної енергії. Для тривалого накопичення великих обсягів електричної енергії пропонується використовувати вугілля та нафтопродукти, які допоможуть відновити енергосистеми України на відновлюваних джерелах та передових енергоєфективних технологіях.

Ключові слова: децентралізація, зелена енергетика, розподілені енергетичні системи, віртуальні електростанції, відходи сільськогосподарської діяльності, системи криогенного накопичення.
The events of November 2022 showed the absolute instability of Ukraine's centralized energy system. Up to 40% of the centralized energy infrastructure was disabled in two days. Millions of people were left without electricity, heat and water for a long time. Therefore, it is very important to develop the energy sector of the state in the future, taking into account the needs of Ukraine's decentralization policy, in particular, local communities.

Topicality. The events of November 2022 showed the absolute instability of Ukraine's centralized energy system. Up to 40% of the centralized energy infrastructure was disabled in two days. Millions of people were left without electricity, heat and water for a long time. Therefore, it is very important to develop the energy sector of the state in the future, taking into account the needs of Ukraine's decentralization policy, in particular, local communities.

Aim and tasks. The purpose of the research is to determine the imperatives of decentralization of the energy sector of Ukraine. The main way of developing the energy system of the state is the transition from a centralized to a distributed system. The location of generation systems in united communities makes it possible to switch to systems of cogeneration of electric and thermal energy to increase the efficiency of installed capacities and save fuel significantly by up to 40%.

Materials and Methods. The methodological basis for the formation of regional policy should become the best of the world and European practices of the country’s energy sector development. Active use of the methods of system analysis, expert assessment on the implementation of decentralization systems of the energy industry is a guarantee of achieving the priorities of national security of Ukraine in the post-war period. Priority support from the EU and others international donors refers to those projects and programs aimed at decentralization, decarbonization, local economic sustainability and energy independence.

Research results. The research substantiates that local communities have great opportunities for using alternative renewable resources for the generation of electricity and thermal energy. First of all, it is biomass, biogas, solar energy, wind energy and geothermal energy. In particular, the authors proved that due to the installation of means of electric energy accumulation, it is possible to raise the level of use of the installed capacities of solar and wind power plants by another 50% and to bring the total level of use of the installed energy capacities to 70%.

Conclusions. The active implementation of alternative energy sources into economic practice can become the basis of the national security of the state in the post-war period. It is suggested that Communities use nearby agricultural waste and solid household waste as fuel instead of imported fossil fuel. It is also proposed to create local electric networks combined into virtual power plants within the framework of united communities, including not only all types of generation available on the territory, but also systems of short-term and long-term storage of electric energy. For the long-term storage of large amounts of electrical energy, it is suggested to use accumulators based on cryogenic liquids. It has been proven that due to the installation of means of electric energy accumulation, it is possible to raise the level of use of the installed capacities of solar and wind power plants by another 50% and to bring the total level of use of the installed energy capacities to 70%. Virtual power plants make it possible to significantly increase the amount of generated (consumed) electricity without additional investment costs. Such technologies meet the requirements of the European Union for candidate countries to join the Union and open the possibility of financing projects related to the restoration of the energy system of Ukraine based on renewable sources and advanced energy-efficient technologies.

Keywords: decentralization, green energy, distributed energy systems, virtual power plants, agricultural waste, cogeneration, cryogenic storage systems.

Problem statement and its connection with important scientific and practical tasks. Ukraine has been a member of the European Energy Community since 2011. The legal basis of the Energy Community consists of the Treaty on its establishment (the European Energy Charter), which refers to the acts of European legislation that must be implemented by the participants in the
framework of the implementation of the European energy policy. A Memorandum of Understanding on cooperation in the energy sector is also in force between Ukraine and the European Union. The memorandum entered into force on 12.05.2005. He determines that Ukraine and the EU can benefit from the integration of their energy markets, thereby increasing the level of energy security of the European continent.

The events of November 2022 showed the absolute instability of Ukraine's centralized energy system. Up to 40% of the centralized energy infrastructure was disabled in two days. Millions of people were left without electricity, heat and water for a long time. Therefore, it is very important to develop the energy sector of the state in the future, taking into account the needs of Ukraine's decentralization policy, in particular, local communities.

Particular importance should be attached to the sustainable development of non-traditional and renewable energy sources. It should be noted that the ways and directions of the strategic development of non-traditional and renewable energy sources in the country should contribute to the European Community's joint efforts in the field of energy and comply with the main principles of the Green Book "European Strategy for Sustainable, Competitive and Secure Energy" (Brussels, 8.3.2006. COM (2006) 105).

Analysis of recent publications on the problem.

To general issues of implementing the policy of sustainable business development into domestic practice devoted works of a number of scientists (Burkynskyi et al., 2021). Theoretical and applied aspects of determining the determinants of innovation and investment policy of rational nature management is highlighted in the study (Burkinsky et al., 2021), but considering the specifics of energy development sector in conditions of decentralization, taking into account Green Deal priorities in Ukraine, is absolutely absent. At the same time, let us emphasize that the modern policy of the European Union today pays special attention namely to the development of Green Deal policy, an important element of which is the implementation of the principles of circularity economy and the introduction of the alternative energy sources as a basis for ensuring economic and environmental security of the state and individual territories. The organizational and legal principles of the transition to a "green" economy are reflected in the strategic documents of the EU – «The Europe 2020 Strategy» (Communication from the commission Europe, 2020) and «The Circular Economy package» (Circular Economy Package, 2020) which are aimed at increasing the share of use of renewable energy sources and reducing the level of greenhouse gas emissions.

Allocation of previously unsolved parts of the general problem.

The President of European Commission in her closing speech at the International Expert Conference on the Recovery, Reconstruction and Modernization of Ukraine emphasized that the decentralization reform makes Ukraine stronger and local communities should be the driving force for the implementation of economic recovery plans. In practice, this means that the European Commission will actively work with the Ukrainian municipalities and communities, as well as allocate funds for local decentralized solutions for energy supply.

Despite this, the authorities again declare their intention to start construction of small modular reactors (hereinafter - SMR). This was announced by the President of Ukraine, and the Minister of Energy of Ukraine and the Special Representative of US President has already announced a pilot project for the construction of the SMR for the generation of electricity. The key word in this abbreviation is the word small, because the capacity of these power plants is 300 MW against 1000 MW at nuclear power plants (for information, the capacity of the Kakhovskaya hydro power plant was 334.8 MW). The size of territory necessary for accommodation is up to 40 000 sq. m. Based on this, it is again a movement to a centralized energy system. Such approach makes it impossible to support the development of the alternative sources of "green" energy in the state.

Formulation of research objectives (problem statement).

The aim of the research is the determination of imperatives for the decentralization of the energy sector of Ukraine. Significantly, the main way of developing the energy system of the state is the transition from a centralized to a distributed system. The location of generation systems in united communities makes it possible to switch to systems of cogeneration of electric and thermal energy to increase the efficiency of installed capacities and save fuel by up to 40%. Electricity storage system is one of the fastest growing energy sectors. Over past 10 years, the mentioned above sector has grown by 48 times, the average annual growth rate was 47%.

Analysis of today’s market of accumulative electricity systems in Ukraine indicates that in this sector there is no great progress in the field of technology. At the same time it should be noted
that on 15 February 2022 Ukraine has adopted the Law “On amendments to certain laws of Ukraine regarding the development of energy storage systems”. The Law regulates energy storage activities and defines the status of energy storage systems and energy storage system operator. This determines the legal relations of accumulation storage systems in the distributed energy system of Ukraine. Very important in the future is the determination of imperatives, the creation of an institutional basis and competitive prerequisites of alternative sources of “green” energy (Law of Ukraine, 2022).

**Materials and Methods.**

The methodological basis for the formation of regional policy should become the best of the world and European practices of the country’s energy sector development. Active use of the methods of system analysis, expert assessment on the implementation of decentralization systems of the energy industry is a guarantee of achieving the priorities of national security of Ukraine in the post-war period. Priority support from the EU and others international donors refers to those projects and programs aimed at decentralization, decarbonization, local economic sustainability and energy independence. In this context, the proper reconstruction of the energy sector of Ukraine will require the implementation of reforms, provided by the EU legislative package “Clean energy for all Europeans”, which aims to drive the transition to more cleaner, decentralized and more sustainable solutions in favor of local communities. In 2019 the European Union approved the 4th energy package “Clean energy for all Europeans”. The package consists of the following tools:

1. **Renewable energy.** The obligatory aim is to achieve a share of 32% for RES (renewable energy sources) in the total amount of EU generation by 2030.

2. **Energy efficiency.** The obligatory goals are to increase energy efficiency by at least 32.5% until 2030.

3. **Climate.** Achieving the status of a climate-neutral Europe by 2050, that is one that doesn’t affect climate change.

4. **Electricity market’s design.** The energy package envisages the creation of a modern market of EU electricity adapted to new realities: easier conditions for the integration of renewable energy sources, greater independence of the household consumer, wider application of IT technologies.

5. **Coordination of actions to achieve the aims of the Energy Union.** Every member state of the EU draws up a national plan for achieving climate and energy goals that meets the aims of the Energy Union.

EU member states are obliged to bring their legislation in line with the new provisions of the Energy package.

In the case, if Ukraine doesn’t apply the legislation of the package “Clean energy for all Europeans”, the state will suffer losses of an economic nature, since the products that won’t meet EU environmental standards, will be uncompetitive in the EU markets (Andrienko S. Yu., Stepaniuk V. K., Korbut M. B.).

**An outline of the main results and their justification.**

Local communities have great opportunities to use alternative renewable resources of electric and thermal energy generation. First of all, it is biomass, biogas, solar energy, wind energy and geothermal energy. The work (Geletukha, September 14, 2022) shows that the potential of the use of various biomasses in the energy sector is 21 million tons. The largest resource, that is at the level of 40% of the theoretical potential of biomass, falls on various residues of agricultural production such as straw, plant stems, husks and sunflower baskets.

For example, Shabivska UTC (united territorial community) is located in the village Shabo, Belgorod-Dnistrovsky District of Odesa oblast, includes 13 settlements with a total population of 14 321 people and with a total area of 580.91 sq. km. On average, each villager consumes up to 100 kW electricity per month. Then the total monthly consumption of the population of Shabivska UTC will be 1400 MW. There are no large industrial enterprises in the community. The main industrial consumption of electricity determined by winemaking enterprises, as well as processing and drying of agricultural products enterprises. You can calculate this consumption on average per month estimate 5000 MW. The total monthly electricity consumption of Shabivska UTC can be estimated in 6400 MW or 76800 MW per year. The installed capacity of generation systems in the community should be at least 5 MW per year. At the same time, thermal energy will be produced at least 15 MW per year.

On the other hand, the farmers of Shabivska UTC all the years show stable high indicators with harvesting of grain corps. The average yield consistently exceeds 40 centners per hectare. This means that even with a ratio 1/0.7 of the volume of straw remaining after harvesting, there are at least 28 centners per hectare (2.8 tones). Of the entire area of 580 910 hectares, 70 % are used as agricultural land. If 30% of the yield to use for energy purposes, it would be 341 575 tons of
waste. Taking into the account that for the production of 1 MW of electrical energy it is necessary to burn 1.5 tons of straw, then this amount is enough to produce 228,000 MW of electrical energy, which is 2.9 times greater than the required amount of fuel. It should be noted that the main thing is that biomass burning is in the balance with release/sequestration of CO₂ and doesn’t affect climate change. But despite of this, Ukraine is the only country in the world that doesn’t provide tax benefits, but on the contrary collects taxes from producers of thermal and electrical energy from biomass.

At the local level in the communities there is an opportunity also to install electricity storage systems with the aim to increase the efficiency of wind and solar power plants. Electrical energy storage systems primarily ensure the stability work of the system as a whole and increase the utilization rates of solar and wind power plans. The work (Kulyk et al., 2019) provides data on actual utilization rates of installed capacities of solar and wind power plants in different countries. The average utilization rate of installed capacities for solar and wind power plants is 20%. We offer to raise the level of use of the established capacities by another 50% and bring the total level of use of the installed capacities up to 70% at the expense of installation in power systems the means of long-term accumulation of electrical energy. For long-term large scale accumulation of electrical energy it is necessary with its help to make substances that can be stored for a long time without significant changes in their characteristics. Modern technologies today include compressed air, liquefied air, hydrogen, liquefied nitrogen, as well as synthetic neutral gas. Table 1 shows the characteristics of the most common methods of accumulation.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Lithium-ion batteries</th>
<th>Hydrogen accumulation</th>
<th>Cryogenic accumulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Need of electricity, kW/kg</td>
<td>-</td>
<td>50</td>
<td>1.2</td>
</tr>
<tr>
<td>Cost of production, kg/$</td>
<td>41</td>
<td>3.0</td>
<td>0.07</td>
</tr>
<tr>
<td>Amount of accumulation, kg/kW</td>
<td>150</td>
<td>8.33</td>
<td>97</td>
</tr>
<tr>
<td>Conversion efficiency on gas for generation, %</td>
<td>98</td>
<td>55</td>
<td>70</td>
</tr>
<tr>
<td>Overall efficiency technology, %</td>
<td>98</td>
<td>55</td>
<td>70</td>
</tr>
<tr>
<td>The cost of accumulation of 1 MW, $</td>
<td>282000</td>
<td>6548</td>
<td>1030</td>
</tr>
</tbody>
</table>

For the accumulation of electrical energy we offer to use technologies for the accumulation in cryogenic liquids (Highview Power Cryo battery). In 2022 in the United Kingdom to the network was connected the electric storage system with the capacity of 100 MW per year. The incentive for development of project was a large-scale power outage in 2020. To prevent recurrence of incident, large energy storage systems became a priority. According to the forecasts of Blumberg NEF, up to 2040 the total storage capacity will exceed 1 TW and one of the reasons for the increase of interest to the electricity storage system became the rapid growth of the share of renewable energy sources. The production and storage of electricity distributed by communities allows significantly increase reliability of energy supply, and the use of alternative sources to reduce the impact on the environment. In fact, we are talking about the creation of a distributed energy system in Ukraine. Distributed energy generation is fundamentally different from the traditional model of central generation, because it can be located next to the end consumers, next to locality, on the building. More than 12 million installations of small distributed generation are operated in the USA with total installed capacity of over 220 GW. In a number of industrialized countries (EU, USA, Australia) recently have been adopted the conceptual documents regarding the development of industry with an increased emphasis on small distributed energy. Typical composition of distributed energy systems that are combined into virtual power plants are schematically presented in Figure 1.
Figure 1 shows various types of electrical energy generation that can be included in the local network combined into a virtual power plant: solar batteries, wind power plants, solid fuel power plants. The system is filled with accumulative elements. Management of all elements of the distributed system is carried out from a single dispatch center. Advantages of distributed energy systems is the reduction of electricity losses in the transportation system and distribution, increase of reliability, reduction of voltage fluctuations, improvement the quality of electricity, reduction of energy costs. A big advantage of distributed systems is the ability to use the heat received at production of electrical energy for heating. Cogeneration is a method used at the facilities of distributed energy (mini thermal power plants) – own power plants at enterprises, infrastructure and residential facilities. The heat produced in the process of obtaining electricity by centralized stations doesn’t reach consumers and is released into the atmosphere (Sposoby otrymannya elektroenerhiyi y tepla za dopomohoyu koheneratsiyi). Cogeneration installations in distributed systems are physically placed directly on the object therefore there are no losses during the time of transferring. In addition, the placement of cogeneration stations on the territory of the communities provides an opportunity to use thermal energy all the year round (for example, in summer for drying).

Currently there are about 1500 plants in the world producing electricity and heat from solid household wastes (SHW). Annually due to SHW processing Europe produces more than 28 billion KWh of electricity and 69 billion KWh of thermal energy. This allows to save an organic fuel and prevent greenhouse gas emissions of more than 37 million tons per year (Derkach, 2012).

On 23 November 2022, during the consideration of the question regarding options for stabilizing the energy system of Ukraine, the profile committee of Verkhovna Rada of Ukraine proposed to mass-implement cogeneration mini thermal power plants. At the first stage, these mini thermal power plants can have an “island” character, i.e. to serve the objects located inside the one district, community. At the second stage, these mini thermal power plants should be connected to local networks. Saving of fuel energy when using a single cogeneration system will be about 40%.

Today the market of Ukraine presents
automatic thermal power plants, mini thermal power plants with the capacity from 500 kW up to 100 MW (GRNYOV kom and Partners LLC), operating on various secondary raw materials, various types of biomass: wood chips, cake, straw, husks, rubber and polymers, wood waste and household waste. Costs of raw materials are from 0.3 kg/kW. The use of such mini thermal power plants allows the united communities to decide three tasks at the same time: to produce electricity and heat; dispose of solid household waste.

The practical implementation of our proposals requires:

- Immediately stop subsidizing fossil fuels and redirect these funds to efficient ones renewable technologies. Boilers that use only fossil fuels must be replaced or modernized to use alternative energy sources.
- Create equal conditions for all participants of the modern energy system. Existing system of taxation due to the use of fossil fuels covers only large installations, living out its scope of application the majority of small producers of heat for individual systems heating.
- Stimulate the use of sustainable waste heat. Waste heat can provide more than 25% of future demand in the energy sector.
- Introduce mandatory energy planning at the local level. Mandatory planning on the level of communities is needed to assess the potential and make the best use of local energy sources, reducing dependence on energy imports.

Conclusions and perspectives of further research.

1. One of the main tasks for Ukraine is to transform the centralized energy system of the country into a distributed one.

2. The location of the generation systems in the united communities makes it possible to switch to cogeneration systems and thereby significantly increase the efficiency of the installed equipment.

3. It is suggested to use waste from agricultural activity and solid household waste for the cogeneration systems.

4. Within the framework of the united communities to create the local electric networks combined into the virtual power plants, including not only all types of generation available on the territory, but also short-term and long-term storage systems of electrical energy. For long-term storage of large amounts of electrical energy it is proposed to use accumulators based on the cryogenic liquids.

5. Distributed systems must necessarily include long-term storage systems of large amount of electrical energy.

Summarizing all of the above, we should note that active implementation of alternative sources of “green energy” into economic practice can become a basis component of the national security of the state in the post-war period. The authors proved that due to the installation of means of electric energy accumulation it is possible to increase the level of use of the installed capacities of solar and wind power plants by another 50% and to bring the total level of use of the installed energy capacities to 70%. Virtual power plants allow significantly increase the volume of generated (consumed) electricity without additional investment costs. Such technologies meet the requirements of the European Union for candidate countries to join the Union and open the possibility of financing projects related to the restoration of the energy system of Ukraine on renewable energy sources and advanced energy efficient technologies.

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На жаль, зображеньки, які показані, є непридатними для відображення тексту. Будь ласка, надайте текст у вигляді текстового поля, щоб ми могли його читати і аналізувати.