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INTRODUCTION OF RENEWABLE ENERGY SOURCES INTO THE SOCIAL INFRASTRUCTURE. REVIEW OF RESEARCH

Abstract. *The article examines the integration of renewable energy sources (RES) into Ukraine's social infrastructure as a key factor in ensuring energy independence, the stable functioning of public institutions, and achieving sustainable development goals. In light of current challenges − particularly the ongoing war, widespread infrastructure damage, and energy instability − special emphasis is placed on the urgent need for decentralized energy supply and a transition to environmentally friendly energy sources. The study examines the potential for utilizing solar, wind, bioenergy, and geothermal resources in educational institutions, healthcare facilities, social services, and administrative and municipal establishments. The article also outlines the main technical, organizational, and economic aspects of RES integration into the social infrastructure. It presents an overview of current legislation, as well as national and international funding programs that support such initiatives. Furthermore, particular attention is given to the analysis of successful case studies of energy efficiency projects implemented at the local community level. The study identifies key barriers hindering the widespread adoption of renewable technologies, including insufficient technical preparedness of facilities, lack of qualified personnel, limited awareness among local authorities, and difficulties in accessing financial resources. As a result, the research justifies the need for a comprehensive strategy for renewable energy deployment in the social sector, taking into account both national priorities and regional specifics. The paper concludes with practical recommendations for integrating RES into local-level energy policies in Ukraine.*
Keywords: renewable energy, social infrastructure, decentralization of electricity supply, energy efficiency, energy security, sustainable development.

1. Introduction

The necessity of integrating renewable energy sources (RES) into Ukraine's social infrastructure stems from a combination of current challenges, most notably energy instability caused by the military aggression of the Russian Federation, the significant wear and tear of traditional energy systems, and the intensification of global climate change. Social infrastructure − which includes educational institutions, healthcare facilities, kindergartens, and cultural centers − plays a critical role in ensuring the continuity of daily life. Its uninterrupted operation is particularly vital during times of crisis. Indeed, the reliable energy supply of such facilities directly affects social stability, community well-being, and the preservation of human capital [1].

Given that Ukraine is a net importer of energy resources, its energy strategy, priorities, and implementation mechanisms differ from those of energy-producing countries. In order to secure stable imports of the required energy volumes from global markets, Ukraine must remain competitive in the global economy. This competitiveness is crucial for winning the price competition over scarce energy resources with other consumer countries [2].

Therefore, the issue of energy independence and the modernization of energy supply systems within the social sector is of national significance. Transitioning to renewable energy technologies represents not only an environmental imperative but also a strategic necessity for increasing resilience and reducing dependency on external energy supplies. As such, this topic requires comprehensive research and the development of practical, scalable solutions tailored to Ukraine's socio-economic and geopolitical realities.

According to data from the Kyiv School of Economics, between February 2022 and May 2024, Russian attacks resulted in damage or total destruction of 18 large combined heat and power plants (CHPs), 815 boiler houses, 152 central heating substations, and 354 kilometers of heating networks. The direct financial losses from these attacks are estimated at $2.4 billion USD, with more than half of the damage attributed to assaults on CHPs specifically [3].

In this context, where Ukraine's centralized energy systems are under considerable stress and at constant risk of disruption, the implementation of decentralized and environmentally sustainable energy sources becomes not only a technical or economic challenge but also a matter of national security. The deployment of solar photovoltaic systems (PV), heat pumps, and other renewable energy technologies contributes significantly to strengthening regional energy independence, reducing greenhouse gas emissions, and supporting sustainable development.

Given these circumstances, a systematic analysis of the effectiveness of integrating RES into Ukraine's social infrastructure is crucial − particularly in facilities such as hospitals and schools. These institutions serve as vital components of public safety and social welfare. Therefore, the research aims to assess both the economic and ecological benefits of applying PV systems and heat pumps, their role in enhancing the reliability of local energy grids, and to identify the primary obstacles hindering their large-scale adoption. This comprehensive approach is essential for formulating effective strategies for the resilient transformation of the country's energy infrastructure.

In his report, V.P. Babak proposes a conceptually new approach to the integration of RES into district heating systems by electrifying centralized thermal networks through the use of electric boilers. This approach utilizes the unstable generation from wind and solar power plants (WPPs and SPPs) without incurring significant costs for maintaining frequency stability, as electric boilers can operate across a wide range of electricity inputs. The proposed structure incorporates autonomous subsystems of WPPs/SPPs combined with energy storage systems, ensuring self-sufficiency and stability of the energy network. Implementing this model would reduce energy market costs, significantly decrease natural gas consumption (by more than 7 billion cubic meters annually), and reduce carbon dioxide emissions. Furthermore, this system facilitates the efficient integration of RES generation, enhancing the economic attractiveness and competitiveness of renewable energy in Ukraine [4].

Artur Zaporozhets focuses his research on minimizing the environmental impact of energy facilities, along with the strategic and practical aspects of integrating renewable distributed generation into Ukraine's energy supply system − a system currently facing the dual challenges of global decarbonization and military threats. In one of his studies, co-authored with H.P. Kostenko, he emphasizes the importance of distributed generation in enhancing energy resilience, reducing dependence on centralized sources, and improving the flexibility of energy resource management. The study analyzes successful examples of distributed RES projects implemented abroad and explores their potential adaptation in Ukraine, particularly in the domains of solar, wind, and small-scale hydropower. Zaporozhets further underscores the need for a comprehensive integration approach that includes technical, economic, legal, and regulatory dimensions, as well as the implementation of innovative management and energy storage systems. The integration of RES is expected to increase the reliability, safety, and efficiency of Ukraine's energy system while offering substantial economic and environmental benefits [5, 6].

Volodymyr Derii explores the integration of Power-to-Heat technologies − namely electric boilers and heat pumps − into thermal networks and energy systems. His research focuses on enhancing the resilience of energy systems during periods of excess renewable energy production (from solar and wind sources) by using thermal storage units as a means of load balancing. These technologies enable more flexible energy consumption and contribute to the stability of energy supply under fluctuating generation conditions [7].

In a 2019 study, Oleksandr Teslenko analyzed three modernization scenarios for boiler houses − progressive, traditional, and conservative. All scenarios anticipate a significant reduction in nitrogen oxide (NO_x) emissions by 50–60 %, in compliance with the environmental requirements of the EU Directive 2010/75/EU. The objective of this modernization is to improve both the efficiency and environmental performance of centralized heating systems [8].

The outcomes of these studies provide a scientifically substantiated foundation for the development of effective policies aimed at integrating renewable energy sources into Ukraine's social infrastructure. These efforts align with the country's strategic objectives of energy security and environmental sustainability.

2. Main Part

The primary goal of this article is to evaluate the feasibility of implementing renewable energy sources in social infrastructure facilities, with a focus on solar photovoltaic systems (PVs) and heat pumps. This evaluation considers technical, economic, environmental, and social aspects, and aims to formulate conclusions regarding their potential impact on the overall resilience of Ukraine's energy system.

Analysis of Recent Research and Publications Addressing the Problem

The issue of integrating RES into social infrastructure is actively addressed in both Ukrainian and international academic and professional publications. Ukrainian studies, particularly the reports from the "Energy Act for Ukraine" [9] and "RePower Ukraine" [10] projects, emphasize the potential of hybrid solar installations for ensuring autonomous power supply to healthcare facilities during electricity outages.

A notable example is the Mykolaiv Regional Children's Hospital, where a solar power plant (PV system) with a capacity of 58.24 kW and a battery storage system of 112 kWh was installed. This case illustrates a new approach to strengthening the energy security of social institutions through the decentralization of energy supply. Rather than relying solely on centralized power grids, the system combines autonomous and hybrid energy solutions based on RES.

The photovoltaic system supplies the hospital with electricity during daylight hours, while the storage system accumulates excess energy for use at night or during outages. This ensures uninterrupted operation of critical medical equipment, which is particularly vital during wartime conditions, emergency situations, or periods of unstable power supply.

Beyond enhancing energy independence, the implementation of such a system also contributes to reducing electricity costs. As a result, budgetary resources can be allocated more efficiently to other priority areas. Moreover, this initiative demonstrates environmental responsibility and serves as a scalable model for replication in other healthcare and social infrastructure facilities. It lays a practical foundation for sustainable development and improving energy efficiency within the public sector [11].

Domestic Research. Over the past five years, Ukraine has witnessed a significant increase in scientific and applied research focused on the use of RES, particularly in the context of social infrastructure. Recent green reconstruction initiatives in Ukraine illustrate the practical benefits of combining solar photovoltaics and heat pump technologies in healthcare facilities. For example, in Horenka hospital near Kyiv − damaged during recent military actions − a heat pump coupled with a solar power system was installed, enabling the hospital to restore heating even during blackouts, reduce heating costs by approximately 80 %, and have up to 60 % of its annual energy consumption supplied by the hybrid solar installation. Greenpeace Similarly, in Zviahel (Zhytomyr Oblast), a rooftop solar installation was deployed at the city hospital; in its first month of operation, it generated about 800 kWh of electricity, enough to power life-support equipment, thereby helping to buffer operational disruptions and reduce energy costs under wartime conditions [12, 13].

Practical energy audit case studies conducted in healthcare facilities in the Cherkasy, Sumy, and Lviv regions have revealed high potential efficiency gains from the implementation of hybrid systems combining photovoltaic installations (PV) and heat pumps. These findings are especially relevant for regions where heat supply remains unstable [14, 15].

However, many studies are limited by a narrow geographical focus and often fail to account for regional climatic and infrastructural differences. In addition, there is a lack of long-term operational data, making it difficult to assess the reliability and sustainability of these systems over time. Another shortcoming is the limited coverage of social aspects, such as the acceptance of new technologies by school staff and parents, which is essential for the successful scaling of such initiatives.

A noteworthy example supported by the EU and NEFCO involved the modernization of a school building in the village of Susk, attended by approximately 200 students and staff. Previously, the school relied on solid fuel for heating and electric water heaters, resulting in high energy consumption. The modernization project improved the building's thermal insulation, upgraded the heating system to reduce fossil fuel use, and introduced mechanical ventilation to enhance indoor air quality. These measures are expected to save about 61 tons of solid fuel and 45 MWh of electricity annually, while reducing CO_2 emissions by 148 tons per year. The resulting financial savings are projected to range from €25,900 to €30,500 annually. Thus, the project not only boosts energy efficiency and reduces operational costs but also improves the overall learning environment [16].

The issue of ensuring the energy security of Ukraine's social infrastructure − particularly hospitals, schools, and other essential institutions − has become increasingly urgent in light of ongoing military conflict and the instability of centralized electricity supply networks. In this context, RES, when combined with battery storage systems, represent a key solution for enhancing the autonomy and resilience of such facilities.

Ukrainian researchers and practitioners are actively developing and implementing innovative energy solutions tailored to the specific needs of the social sector amid current national challenges.

One notable contribution comes from Kilnitska O. [11], who presents a comprehensive analysis of energy management in Ukraine's social sphere. Her work focuses especially on the difficulties faced by medical institutions located in remote and frontline regions.

Kilnitska O. emphasizes the necessity of introducing decentralized RES systems as a viable strategy to ensure energy security and increase the flexibility of energy supply. In particular, he highlights that the integration of PV and battery storage allows hospitals to reduce their dependence on centralized power grids − which may be unreliable under crisis conditions − and simultaneously establish backup capacity for critical medical equipment.

This approach not only contributes to technical stability but also plays a vital role in improving the level of social protection for communities during emergencies. Ultimately, such solutions underscore the importance of sustainable and adaptable energy systems in safeguarding public health and welfare.

UNDP Ukraine (2023) [15] highlights the practical implementation of projects involving the installation of photovoltaic stations and battery storage systems in hospitals across the country. The report emphasizes that such initiatives ensure the uninterrupted operation of critical medical equipment, even during frequent disruptions in the centralized power grid − disruptions that have intensified amid the ongoing conflict. It presents specific case studies where the use of RES has proven crucial for maintaining essential healthcare services, particularly in areas with unstable electricity supply.

Moreover, UNDP draws attention to the broader social impact of these projects. This includes the promotion of energy literacy among local communities, the creation of new jobs in the green energy sector, and the development of a culture of energy efficiency. These initiatives not only improve the energy resilience of medical institutions but also contribute to the sustainable development of entire communities.

A comprehensive review of recent research confirms the critical importance of implementing solar PV and heat pumps in social infrastructure, especially in hospitals and schools. In his work "Formation of Technological Structures of Energy-Independent Communities", V.V. Kaplun stresses the potential of RES to reduce community dependence on centralized energy supply and to lower greenhouse gas emissions [17].

Practical examples from Ukraine clearly demonstrate the effectiveness of these solutions. For instance, a solar power station installed at a hospital in Kharkiv significantly reduced reliance on grid electricity and improved both economic and environmental performance. Similarly, in Kostopil, the introduction of a 16 kW geothermal heat pump in a medical facility helped reduce heating costs and enhance the reliability of energy supply.

These examples illustrate the real-world potential of RES technologies in strengthening the autonomy, efficiency, and sustainability of Ukraine's social infrastructure.

An important factor in the transition to renewable energy is its economic viability. Studies indicate that initial investment costs can account for up to 70 % of the total project cost. However, in the long term, energy savings can fully offset these expenses, particularly in the presence of favorable tariff policies and state support mechanisms [17]. This makes renewable energy not only an environmentally conscious choice but also a financially sound strategy for public institutions and municipalities.

Before the full-scale war, the share of renewable energy sources in Ukraine's energy balance amounted to 8.1 %, with an installed capacity of 9.9 GW (including 6 GW of solar, 2 GW of wind, and 0.2 GW of biomass). In 2019, the country ranked 6th globally in terms of investment attractiveness in the renewable energy sector, with total investments exceeding USD 12 billion. As of 2023, the share of renewable energy, including large hydropower plants, reached 22 %, compared to 42 % in the European Union [18].

The war resulted in a reduction of installed capacity to 8.7 GW, the destruction of approximately 13 % of industrial solar power plants and 80 % of wind power facilities, as well as the loss of nearly 2.5 GW of hydropower capacity (including the Kakhovka HPP). Despite these challenges, more than 1,400 new facilities were commissioned in 2023, adding 182.3 MW of wind and around 500 MW of solar generation. In August 2024, the government approved an investment plan of USD 20 billion aimed at increasing the share of renewable energy to 27 % of the national energy balance by 2030, while international assistance (USA, EU, G7) provided over USD 1 billion in support for the recovery of the sector [18].

The study by Kostenko H., and Zaporozhets A. focuses on enhancing the resilience of energy systems through the integration of microgrid systems with distributed renewable energy generation. The authors emphasize that approximately 90 % of power outages occur in distribution networks. Thus, the use of local microgrids powered by RES significantly improves the reliability and stability of electricity supply. Their proposed solution involves creating autonomous local energy systems capable of operating in both normal and emergency modes, ensuring uninterrupted power for critical infrastructure. Key advantages of microgrids include their ability to self-recover quickly, reduce emergency response time, and decrease reliance on centralized power networks. Consequently, the deployment of RES-based microgrids emerges as an effective strategy to enhance energy resilience and security amid modern challenges such as military threats and environmental crises [19].

Regarding international experience, Germany stands out as one of the global leaders in the use of renewable energy. A widely adopted model there is the energy cooperative, which unites citizens to jointly invest in solar and wind power installations. By 2022, approximately 25 % of the energy used in the country's social infrastructure was generated through cooperative renewable energy projects. As a result, hospitals and schools benefited from stable, cheaper, and environmentally friendly electricity, enhancing their resilience to external crises [20].

In Lithuania, the government actively supports the installation of photovoltaic systems integrated with smart energy platforms. Over the past three years, more than 100 social institutions have achieved partial energy autonomy through these systems, resulting in a 40 % reduction in energy consumption from the centralized grid. This shift has strengthened both energy security and the financial sustainability of public facilities [21].

In Israel, where frequent power outages are linked to geopolitical tensions, mobile solar power stations equipped with battery storage are widely used. These mobile systems can be rapidly deployed to hospitals, schools, and social service centers. In 2023 alone, over 50 such deployments were recorded in critical regions, ensuring uninterrupted operation of essential medical equipment and communication infrastructure even during total power failures [22].

These international examples highlight that decentralized renewable energy solutions not only contribute to energy independence but also offer high levels of environmental safety, cost efficiency, and social resilience.

For Ukraine, adapting such models in line with national circumstances, financial resources, and technical capacities is crucial for the sustainable development of social infrastructure amid ongoing challenges.

A particularly promising solution for enhancing the energy efficiency of public buildings is the combination of solar panels and heat pumps with loop heat pipe (LHP) systems. Experimental results demonstrated that the PV/LHP hybrid system achieved an electrical efficiency of 9.13 %, thermal efficiency of 39.25 %, and an overall efficiency of 48.37 %, with COP_th = 5.51 and COP_PV/T = 8.71—substantially outperforming conventional technologies. The economic analysis revealed annual savings of 364 kWh of heat and 85 kWh of electricity in Shanghai, yielding a payback period of 16 years; in London, the payback period falls to 9 years. Over 25 years of operation, the system reduces CO_2 emissions by 12.06 tonnes in Shanghai and 2.94 tonnes in London, underscoring its high environmental effectiveness [23].

Moreover, international studies consistently highlight the broad applicability of heat pump − solar hybrid systems, particularly across EU countries. For instance, in the United Kingdom, governmental schemes for installing solar panels on school buildings mandate integration within the educational process, where students learn principles of sustainable development [14]. A systematic review [24] further emphasizes the adaptability of hybrid systems combining heat pumps and solar energy to different climatic conditions and their superior energy efficiency.

International studies increasingly utilize modeling tools such as EnergyPLAN, HOMER Pro, and TRNSYS, which allow for the consideration of a wide range of technical, economic, and climatic parameters. For example, Weiss and Spörk-Dür [25] conducted a study on the effectiveness of solar energy deployment in municipal institutions.

Based on a systematic analysis of both Ukrainian and international research on the integration of RES into social infrastructure, several critical shortcomings have been identified. First and foremost, there is insufficient attention paid to the comparative efficiency of photovoltaic systems and heat pumps, especially when considering the diverse energy consumption profiles of social institutions. Educational establishments such as schools typically operate predominantly during the colder months, resulting in high thermal loads, whereas hospitals maintain a stable energy demand throughout the year. This heterogeneous energy usage pattern necessitates the development of flexible and context-specific energy solutions, which remain underexplored in current literature.

Secondly, there is a lack of comprehensive and systematic analysis of the impact of RES integration on local energy networks under conditions of unstable electricity supply, which is particularly relevant for Ukraine during the ongoing military aggression and numerous technical challenges in the energy sector. Underestimating such factors may lead to system failures and reduce the overall reliability of energy supply to social facilities.

Thirdly, current research insufficiently considers the social aspects of RES implementation, particularly the readiness level of institution administrations to adopt new technologies, the availability of qualified personnel to maintain the equipment, and the involvement of local communities in funding and supporting projects. This highlights the need for a comprehensive approach that encompasses not only technical and economic parameters but also socio-cultural factors that determine the success of RES integration into the social support system [26, 27].

Nevertheless, even within the European Union, certain challenges persist. These include insufficient coordination between local energy planning and educational policies [28], as well as complicated licensing procedures for small-scale energy systems.

Given the above, it should be emphasized that the implementation of RES in social facilities is not solely a technical or economic issue but represents an essential component of national energy policy and security, contributing to the decentralization of energy systems and the strengthening of social stability in the country.

The results of the conducted research confirm the high potential of hybrid systems combining photovoltaic (PV) systems and heat pumps in reducing energy consumption in social infrastructure facilities. An analysis of practical case studies indicates that such technologies enable significant energy savings − ranging from 35 % to

65 % depending on the type and energy consumption profile of the institution. For example, in a rural school, the integration of a 15 kW solar power plant together with an air-to-water heat pump led to a 42 % reduction in electricity consumption from the grid and a 58 % decrease in thermal energy use. In healthcare facilities with higher thermal loads, a ground-source heat pump proved to be the more effective solution, achieving up to 63 % reduction in heat consumption and ensuring more stable system performance despite its higher initial cost [15].

Beyond quantitative energy savings, qualitative benefits of RES should also be highlighted: improved indoor thermal comfort, reduced noise and vibration compared to traditional gas or diesel boilers, and more reliable energy supply in the event of central grid disruptions.

The integration of RES into local energy networks contributes to lowering peak loads, increasing overall energy resilience, and consequently reducing the risk of emergency power outages. This is especially critical for socially significant facilities amid the ongoing military conflict [29].

Thus, a comprehensive analysis of current scientific publications and real projects − both Ukrainian and international − provides a complete picture of the current state of renewable energy implementation in social infrastructure. At the same time, identified shortcomings and limitations highlight key areas for further research and practical action aimed at improving the effectiveness, adaptability, and scalability of these technologies in Ukraine.

An important aspect of integrating PV and heat pumps into social infrastructure facilities is their economic efficiency. Cost-Benefit Analysis (CBA) makes it possible to determine actual payback periods and assess the financial impact of these technologies on institutional budgets.

The economic evaluation of heat pump installations in public buildings shows the financial attractiveness of such projects. The Simple Payback Time (SPBT) ranges from 4.1 to 7.8 years depending on the previously used heat source and the size of the building. Furthermore, the calculated Levelized Cost of Heat (LCOH) for heat pumps is significantly lower compared to other traditional energy sources, such as electric heating, LPG, and oil products, offering additional savings for institutional budgets [30].

In the context of the growing share of renewable energy sources in Ukraine's energy balance and the increasing need for decentralized, environmentally sustainable heating, Power-to-Heat (PtH) technologies are gaining particular significance. These solutions enable the efficient use of intermittent solar and wind power by converting it into thermal energy for heating, hot water supply, and support of critical infrastructure. Implementing such technologies in social infrastructure − schools, hospitals, kindergartens, and administrative buildings − paves the way for reducing dependence on imported energy carriers, cutting greenhouse gas emissions, and forming a sustainable energy model during and after wartime.

The study on the implementation of Power-to-Heat (PtH) technologies in Ukraine's district heating systems analyzes the potential of using surplus electricity from RES (solar and wind power plants) for thermal energy production. The main problem this technology addresses is the instability of RES generation and nighttime consumption "valleys," which require load reduction in the energy system. Using PtH helps reduce energy losses, lower fossil fuel consumption, and contribute to the decarbonization of the energy sector [31].

The study identifies the economic indicators of the feasibility of implementing PtH, specifically:

– at a surplus electricity price of €10–20/MWh, feasible use is possible with a capacity utilization factor of at least 10–15 %;

– at €30/MWh – at least 25 %;

– investment attractiveness arises when the cost of ancillary services at night is around €25–30/MWh [31].

It is also found that the economic efficiency of PtH primarily depends on the cost of natural gas, surplus electricity, and equipment utilization rates. Heat pumps included in PtH systems have low operating costs, are autonomous, versatile, environmentally safe, and durable.

Thus, PtH technology is appropriate for integration into Ukraine’s heating systems, especially under the development of RES and the need to balance the power system.

The decentralization of energy production through local systems based on solar power plants (PV systems) and heat pumps has significant potential to improve the stability and efficiency of local energy networks, particularly in social infrastructure. The use of these technologies helps to offload energy grids, which is critically important during peak loads, especially in the winter season when demand for thermal and electrical energy is at its highest.

Researchers in the United States have calculated that, on a national scale, heat pumps reduce average household energy consumption by 31 % to 47 %, depending on efficiency level, and by 41 % to 52 % when combined with building upgrades such as improved insulation. Heat pumps reduce greenhouse gas emissions in the residential sector by 36–64 %, including emissions from additional electricity generation. These findings may also be relevant for Ukraine [32].

At the same time, despite the clear advantages, the implementation of local RES systems faces several significant barriers that hinder the scaling of such projects:

1. High initial investment costs limit the capacity of many social infrastructure institutions and local communities in Ukraine, especially in the context of economic instability and tight budgets.
2. A lack of qualified specialists at the community level for installing, operating, and maintaining RES systems poses risks of technical failures and reduces equipment longevity.
3. An imperfect regulatory framework complicates the connection procedures of local generation capacities to central power grids. Lengthy and complex approvals, along with the lack of unified standards and regulatory norms, significantly delay project implementation.

A positive sign is the high level of interest from local communities in transitioning to RES. According to sociological surveys, 64 % of amalgamated territorial communities already have experience cooperating with donors in the field of energy efficiency, indicating readiness and capacity to implement such projects. Furthermore, 82 % of surveyed ATCs expressed their willingness to join RES programs if adequate financial support is available, emphasizing the importance of creating accessible funding tools and state incentives.

Additional research by the Institute of General Energy of the National Academy of Sciences of Ukraine indicates significant economic benefits of implementing heat pump units (HPUs) in district heating systems. Specifically, financial modeling has shown that HPUs utilizing waste heat from boiler houses and CHPs have the highest economic efficiency, providing an internal rate of return (IRR) of up to 49.7 % and a payback period of up to 3.2 years, allowing such projects to be implemented even without state financial support. However, systems using other low-grade heat sources − wastewater, ground, air, and river water − require comprehensive state support, as their payback period may exceed 10 years without it [33].

Thus, decentralizing energy production through local solar power plants and heat pumps not only helps to relieve local grids and enhance the energy resilience of social infrastructure but also opens up prospects for forming a more flexible, adaptive, and secure energy system. Overcoming the existing barriers requires joint efforts from government authorities, local communities, donor organizations, and businesses to ensure the financial, technical, and regulatory conditions necessary to scale the implementation of RES in Ukraine's social sector [34].

3. Conclusions

The conducted study has demonstrated that the implementation of renewable energy sources, particularly solar PV and heat pumps, in Ukraine’s social infrastructure − namely hospitals and schools − holds substantial potential for reducing energy consumption, lowering greenhouse gas emissions, and achieving local energy independence. A systematic analysis revealed that the deployment of these technologies is associated with significant economic benefits, including reduced operational costs for institutions, enhanced energy stability, and long-term financial viability [11, 12, 24].

Moreover, the implementation of renewable energy projects in educational and healthcare institutions yields notable social impacts: it fosters energy literacy among the population, improves indoor environmental conditions, and stimulates the creation of new jobs in the green energy sector [26].

From a technical perspective, the integration of PV systems and heat pumps positively affects local energy networks by decreasing peak loads and enhancing the reliability of energy supply.

At the same time, the study identified several limitations, including uneven data availability across regions, technical barriers to integrating renewable energy systems into older buildings, and a shortage of qualified specialists for system maintenance. These findings highlight the need for further research into regional specifics and the development of financial and regulatory incentives to scale such solutions at the national policy level.

First, the use of decentralized renewable energy systems in hospitals, schools, and other social institutions enhances their energy security, particularly under conditions of armed conflict and unstable centralized power grids. Proposed solutions, such as solar power stations combined with battery storage systems, ensure uninterrupted electricity supply and reduce dependence on centralized sources.

Second, Ukrainian research and practical case studies confirm the effectiveness of such systems, demonstrated by reduced energy consumption, cost savings, and increased resilience of social infrastructure. At the same time, international experience − particularly in Germany, Lithuania, and Israel − illustrates broad opportunities for scaling and adapting innovative energy supply models based on community cooperatives, smart monitoring systems, and mobile solutions.

Third, the implementation of renewable energy sources has a positive impact on the environment by reducing harmful emissions and contributing to the sustainable development of cities and communities. This aspect is particularly significant for improving population health and overall quality of life [35].

Fourth, the successful application of such technologies in Ukraine requires consideration of local conditions, the regulatory framework, and the investment climate, as well as encouraging state support and international cooperation [25].

Thus, the integration of renewable energy sources into social infrastructure represents a promising direction that enhances energy resilience, reduces environmental impact, and establishes a reliable foundation for the development of society as a whole. Future research should focus on optimizing technical solutions and developing comprehensive strategies for the deployment of renewable energy across different regions of Ukraine.

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ВПРОВАДЖЕННЯ ВІДНОВЛЮВАНИХ ДЖЕРЕЛ ЕНЕРГІЇ У СОЦІАЛЬНУ ІНФРАСТРУКТУРУ. ОГЛЯД ДОСЛІДЖЕНЬ

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Анотація. *У статті розглядається впровадження відновлюваних джерел енергії (ВДЕ) у соціальну інфраструктуру України як один із ключових чинників забезпечення енергетичної незалежності, стійкого функціонування громадських об'єктів і досягнення цілей сталого розвитку. З огляду на сучасні виклики, зокрема війну, руйнування інфраструктури та енергетичну нестабільність, особлива увага приділяється потребі децентралізації енергопостачання та переходу на екологічно безпечні джерела енергії. У дослідженні проаналізовано потенціал використання сонячної, вітрової, біоенергетичної та геотермальної енергії в закладах освіти, охорони здоров'я, соціального обслуговування, а також в адміністративних і комунальних установах. Розкрито основні технічні, організаційні та економічні аспекти інтеграції ВДЕ у соціальну інфраструктуру, охарактеризовано чинне законодавче поле та надано огляд державних і міжнародних програм фінансування. Особлива увага приділена аналізу успішних кейсів реалізації енергоефективних проєктів на рівні територіальних громад. Виокремлено бар'єри, які перешкоджають широкому впровадженню ВДЕ, зокрема технічну неготовність об'єктів, брак кваліфікованих кадрів, низький рівень поінформованості місцевих органів влади та складнощі з доступом до фінансування. У результаті дослідження обґрунтовано необхідність формування комплексної стратегії розвитку відновлюваної енергетики у соціальній сфері з урахуванням національних і регіональних особливостей, а також запропоновано практичні рекомендації щодо інтеграції ВДЕ в енергетичну політику України на місцевому рівні.*

Ключові слова: відновлювана енергетика, соціальна інфраструктура, децентралізація джерел електропостачання, енергоефективність, енергетична безпека, сталий розвиток.

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