УДК 33.021.658.264(477) DOI 10.20535/1813-5420.1.2025.324272

D. Karpenko[1], Cand. Sc. (Eng.), ORCID 0000-0002-8022-9782
T. Yevtukhova[1], Cand. Sc. (Eng.), Assoc. Prof, ORCID 0000-0003-4778-2479
O. Novoseltsev[1], Dr. Sc. (Eng.), ORCID 0000-0001-9272-6789
[1]**General Energy Institute of the National Academy of Sciences of Ukraine**

IMPROVING THE COMPETITIVE STRUCTURE OF THE DISTRICT HEATING MARKET THROUGH ENERGY STORAGE DEVICES

This research article explores the modernization of structural frameworks in district heating systems (DHSs) operating under competitive market conditions by integrating energy storage devices (ESD). Recognizing the necessity to enhance operational flexibility and reliability, particularly with the increasing share of intermittent renewable energy sources like wind and solar, the study investigates the role of ESD in optimizing DHS functionalities. The primary objectives include conducting a literature review to identify effective technologies for DHS integration and proposing an upgraded structural interaction scheme tailored to competitive environments. The literature review highlights the potential of various thermal energy storage (TES) solutions, each contributing to enhanced energy management despite inherent economic and technical challenges. The proposed modernization of structural schemes redefines the roles of multiple actors in the DHS, including energy producers, transportation networks, and consumers, alongside operations management. By facilitating demand response and adapting pricing structures, the competitive DHS environment aims to reduce reliance on fossil fuels and enhance the viability and resilience of energy networks. In conclusion, this research underscores the transformative impact of integrating ESD into DHSs, promoting sustainable urban energy infrastructures that align with global sustainability objectives. Continued innovation, coupled with strategic policy support, is essential to overcome existing barriers and fully exploit the potential of ESD in modernizing district heating frameworks for resilient and economically viable energy solutions.

Keywords: *district heating, DH market, energy storage, renewable energy sources, grid stability.*

Introduction

The ongoing evolution of energy systems worldwide is driven by the imperative to enhance efficiency, minimize environmental impacts, and integrate a greater proportion of renewable energy sources into existing infrastructures. This transformation is particularly relevant to district heating systems (DHSs), which are crucial components of urban energy distribution networks. DHSs stand poised for significant modernization reforms, especially under competitive market conditions where the integration of energy storage devices (ESD) emerges as a critical enabler [1]. The drive for such modernization stems from an urgent need to address the challenges posed by the growing share of intermittent renewable energy sources (RES) like wind and solar power [2, 3]. Fig. 1 illustrates the trend in the increasing share of renewable energy sources in the European Union [4].

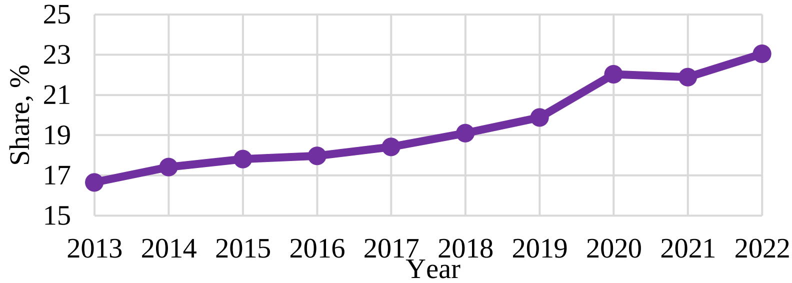

Figure 1 - *Share of energy from renewable sources (European Union - 27 countries)*

The integration of ESD into DHSs facilitates greater operational flexibility and reliability by enabling these systems to store surplus energy generated during peak periods of renewable energy production for use during demand peaks or low production phases. This capability addresses the inherent variability and intermittency associated with renewable energy, thus ensuring a stable and reliable energy supply [5, 6]. As urban centers transition towards a more sustainable energy landscape, exemplified by initiatives striving for 100% renewable energy, the strategic role of DHSs equipped with advanced energy storage cannot be overstated [7]. Structured approach of understanding the use of energy storage within a DHSs presented in Fig. 2.

Furthermore, the modernization of DHSs through energy storage solutions aligns with the global emphasis on sustainability as outlined in international accords like the Paris Climate Agreement. By reducing reliance on fossil fuels and enhancing energy efficiency, DHSs contribute not only to reduced greenhouse gas emissions but also to more resilient and economically viable energy networks [8]. This broader transition is supported by comprehensive research efforts focusing on the development of innovative techno-economic models designed to integrate energy storage technologies effectively into DHS frameworks, thus optimizing their interaction with various entities within the microgrid system under competitive settings [9].

The drive towards integrating ESD within DHSs is further motivated by the need to enhance energy security and economic efficiency across European electricity markets, particularly in balancing services sectors where DHSs can serve as pivotal contributors [10, 11]. Technologies such as combined heat and power (CHP) systems and power-to-heat (P2H) systems can extend the role of DHSs beyond traditional heat delivery, enabling them to provide valuable balancing services that maintain grid stability amid increased RES penetration. However, achieving these objectives requires strategic advancements in energy storage technologies and structural modernizations that address the unique needs of competitive DHS environments [12, 13].

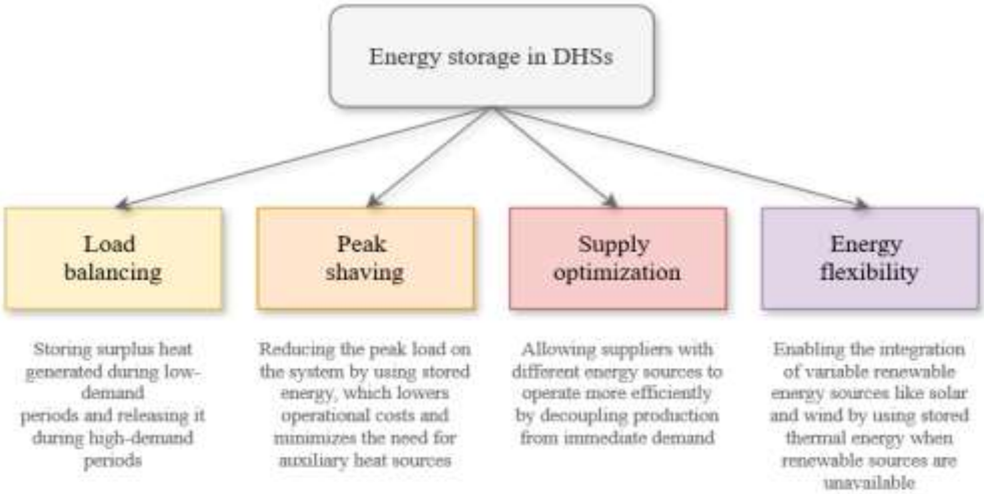

Figure 2 - *Structured approach of understanding the use of energy storage within a DHSs*

Research [10] highlights that regions with advanced district heating infrastructure hold significant untapped potential for integrating ESD to facilitate energy balancing services, although this prospect is often underestimated due to data limitations and country-specific implementations. Overcoming such challenges requires not just technological innovation but also comprehensive reviews and adaptations of energy service frameworks, ensuring these systems cater to the diverse and evolving requirements of modern energy markets [9, 13].

The modernization of structural schemes in DHSs through the incorporation of ESD is a pivotal aspect of current research focused on transforming urban energy systems to meet the demands of a sustainable future. This integration promises not only to enhance operational efficiency and reduce emissions but also to redefine service delivery frameworks in competitive environments, aligning local urban systems with broader global efforts towards renewable and resilient energy infrastructures. This research aims to significantly contribute to the development of modern DHS structures, leveraging storage technologies to foster innovative solutions for sustainable urban energy management [8, 13].

The purpose of this research is to improve the competitive structure of the district heating market through energy storage devices. To achieve this goal, the following tasks must be completed:

1. Conduct a literature review on the application of ESDs to identify the most effective technologies for integration into DHSs.

2. Propose upgraded structural scheme of interaction among entities in the competitive DHS using energy storage.

1.Overview of promising energy storage technologies in DHSs. Modern DHSs face the dual challenges of increasing efficiency and reducing environmental impact. As the energy landscape shifts towards sustainability, integration of ESDs has emerged as a pivotal strategy in enhancing the flexibility, reliability, and efficiency of DHSs. This literature review encapsulates various studies focusing on the application and integration of advanced energy storage solutions in DHSs to address these challenges.

One of the primary focuses in the field is on improving energy storage methodologies, particularly through various forms of thermal energy storage (TES) systems. Borehole thermal energy storage (BTES) is recognized for its potential to integrate with fifth-generation district heating and cooling systems, offering cost-effective and environmentally friendly solutions that help in balancing the time gap between energy supply and demand [14]. Underground Thermal Energy Storage (UTES), which includes aquifer, borehole, reservoir, and ground heat exchangers, is emphasized for its capacity to optimize load sharing and enhance system flexibility, contributing significantly to the decarbonization of heating and cooling processes [15]. Similarly, large-scale thermal ESDs, such as pit and tank TES, are crucial in capitalizing on renewable energy potential while reducing curtailment [16].

The coupling of biomass-fueled Combined Heat and Power (BCHP) systems with DHSs, augmented by thermal energy storage, represents an optimization pathway for energy systems, promising enhanced reliability and reduced environmental footprint, specifically under competitive market conditions [17]. The integration of power-to-heat technologies, including electric boilers combined with TES, facilitates enhanced flexibility in CHP plants, reducing reliance on fossil fuels while supporting smoother load balancing within 4th generation district heating frameworks [18, 19]. Furthermore, the implementation of photovoltaic thermal (PVT) systems along with TES infrastructures presents a promising advancement in urban heating solutions, underscoring both current applicability and future prospect potentials as discussed by recent reviews [16, 20].

Decentralized storage solutions, particularly innovative control strategies for domestic hot water (DHW) needs demonstrate energy savings and reduced thermal losses, marking significant advancements in distributed storage technologies [21, 22]. In parallel, short-term TES solutions help district heating networks provide flexibility and ancillary services to the electricity grids, thereby harnessing potential benefits in fluctuating energy markets in regions like Europe and China [23]. The integration of building-induced demand response strategies alongside centralized TES further indicates avenues for optimization, economizing on peak loads and heating generation costs [24].

A techno-economic evaluation of hybrid TES geometries has shown promising results in optimizing cost and performance, offering guidelines on the economic viability of large-scale TES applications in DHSs [25]. The integration of thermal storage with building-scale photovoltaics and ground source heat pumps further affirms the importance of storage in optimizing energy management and cost-efficiency under market-based conditions [26]. Moreover, the combination of TES with strategic demand-side management approaches helps address uncertainties, reducing operational costs and emissions, thus enhancing system performance under market constraints [27].

Recent reviews and analyses underline the importance of strategic TES integration with HVAC systems, comparing various configurations and emphasizing the management of thermal distribution networks to maximize system efficiency and renewable integration [28, 29]. The deployment of water tank TES, specifically for prosumer economic performance, further illustrates significant cost savings and operational optimization potential, thereby underlining the competitive edge TES can provide within DHSs [30].

Based on the reviewed literature, the most promising energy storage technologies for DHSs were classified and their features, pros and cons were defined and presented in Table 1.

Table 1. *Promising ESD technologies for competitive DHSs.*

ESD type	Features	Pros	Cons
Borehole thermal energy storage (BTES)	Utilizes the ground's subsurface for storing thermal energy via deep boreholes	Environmentally friendly, long-term storage capabilities, and reduces greenhouse gas emissions.	High initial setup costs and site-specific dependency on geological conditions
Pit thermal energy storage (PTES)	Utilizes insulated, large-scale pits to store heat, often as water or gravel-water mixtures	Economically viable on a large scale and efficient for seasonal storage	Large land use footprint and high initial construction costs
Aquifer thermal energy storage (ATES)	Stores and retrieves heat from groundwater in aquifers	Large capacity potential and minimal surface disruption	Site-specific limiting factors due to geological requirements and potential environmental impacts
Sensible heat storage (SHS)	Stores thermal energy by changing the temperature of a liquid or solid media, commonly water or rocks	Cost-effective and reliable with ease of use	Requires significant space for large storage volumes
Phase change materials (PCM) storage	Uses materials that absorb or release heat during phase transitions, such as melting or solidification	High energy density and reduced storage volume	Higher costs and technical complexity during installation
Battery energy (BES)	Stores electrical energy by creating a potential difference between lithium ions	High energy density, fast response times, long cycle life, and scalability	Costly and power limited compared to thermal solutions
Chemical energy storage (CES)	Involves storing energy through reversible chemical reactions	High energy density and long-term storage without energy losses	Low technology maturity and high operational costs

Overall, the integration of ESDs in district heating frameworks not only addresses immediate operational efficiencies but also lays a foundation for future advancements in sustainable urban energy networks. The consistent theme across the literature echoes the critical role that TES technologies play in enhancing the adaptability and eco-friendliness of modern DHSs while navigating complex market and competitive environments. This body of work serves as a reference point for ongoing research and development aimed at fine-tuning these storage integrations to meet future energy demands efficiently and sustainably.

2.Modernization of structural scheme of interaction among entities in a competitive DH market based on ESDs. The need for modernization of the structural scheme of competitive DHS presented in [31, 32] arises from several factors. The integration of renewable energy is increasingly essential in today's DHS, as sustainability goals call for cleaner energy sources. Advanced demand response capabilities and energy storage are increasingly necessary to efficiently handle fluctuating demand, especially with the rise of intermittent RES. Enhancing these features in the previous scheme would improve energy efficiency and system stability, supporting a more dynamic balance between supply and demand. Decentralized management aligns well with the growing complexity of modern energy networks. Such a structure allows the system to distribute responsibilities across multiple operators, making it easier to respond to changes in demand and balance loads efficiently. This approach also supports a consumer-centric model by giving end-users more influence over their energy consumption and costs. Modernizing the DHS to focus on consumer engagement and adaptable pricing could encourage energy-saving behavior and boost satisfaction.

The proposed basic scheme in Fig. 3 illustrates a competitive DHS in which multiple actors are involved in producing, transporting, consuming, and managing energy. The system is divided into four main groups: the energy production group, the energy transportation group, the energy consumption group, and the DHS operations group.

The energy production group consists of several entities that generate thermal and electric energy. The CHP producer plays a dual role by supplying both electric and thermal energy. Electricity produced by the CHP is directed to the electricity market, facilitating the balancing of electric supply and demand. Independent energy producers, including RES and other independent thermal energy producers, contribute thermal energy to the system, which is essential in a competitive environment. A major player in this group is the main thermal energy producer, who supplies significant amounts of thermal energy to the network.

The energy transportation group is primarily managed by the thermal energy network organization, which serves as the central entity for distributing thermal energy across the network. This organization receives thermal energy from various producers, including both independent and main thermal energy producers. It ensures efficient distribution to meet consumer demand and works in close collaboration with energy storage to balance supply and demand fluctuations. Energy storage plays a critical role by absorbing excess energy during low-demand periods and releasing it when demand peaks, thereby stabilizing the network and optimizing resource utilization.

Consumers are represented in the energy consumption group, where buildings or other end-users receive thermal energy through the thermal network. Consumers rely on this energy for heating and other applications, making them the final link in the energy flow chain. Cash flows from consumers to the DHS operations group, highlighting the financial transactions necessary to sustain the energy supply chain.

The DHS operations group encompasses several crucial roles that ensure the stability and efficiency of the system. The system operator is responsible for maintaining overall network stability, overseeing the smooth operation of the energy flows and balancing them as needed. The energy storage operator manages the energy storage facilities, collaborating closely with the thermal energy network to help balance demand and supply. This group also includes the market operator, who oversees the trading of thermal energy, creating a competitive environment that benefits both producers and consumers. Finally, the demand response coordinator is tasked with managing demand response mechanisms, encouraging consumers to adjust their energy consumption patterns based on system conditions. This helps alleviate demand peaks and prevents potential strain on the system.

Thermal energy flows from various producers to the thermal network organization, which distributes it to consumers, representing the core functionality of the DHS. In parallel, the CHP supplies electric energy to the electricity market, adding value and efficiency to the system. Cash flows indicate the financial interactions between consumers and the DHS operations, while system control and management flows reflect the communication and coordination among different operators and the network organization. These management flows are essential for ensuring that the system operates in a synchronized manner.

In competitive conditions, multiple energy producers vie to supply thermal energy to the network, incentivizing efficiency and potentially lowering energy costs for consumers. The integration of energy storage adds flexibility, allowing excess thermal energy to be stored and used during periods of high demand. The market operator plays a key role in maintaining a fair and efficient trading environment, while the demand response coordinator's involvement helps manage peak loads and prevent system overload. The system operator oversees these interactions, ensuring that the DHS remains stable and reliable despite the complexities of competition and varying energy demands.

Discussion

The integration of ESD into competitive DHSs presents significant potential to enhance operational efficiency, increase system flexibility, and reduce environmental impact, aligning with broader sustainability goals. One of the primary technological advancements outlined is the strategic integration of TES systems, such as BTES, PTES, and ATES. These technologies offer substantial promise in addressing the inherent variability of RES, such as solar and wind, by providing reliable energy storage solutions that bridge supply-demand gaps. However, challenges such as high initial costs and site-specific geological dependencies present barriers that necessitate further innovation and refinement. The incorporation of PCM also highlights an innovative avenue for enhancing energy density and reducing required storage volumes, albeit with associated technical complexities. Moreover, BESS and CES add a new dimension by enabling electrical energy storage, although they are often costly and require advancements in technology maturity to be viable on a larger scale. These systems, in conjunction with TES, broaden the scope of energy storage options available to DHSs, potentially enabling more nuanced and efficient energy management strategies.

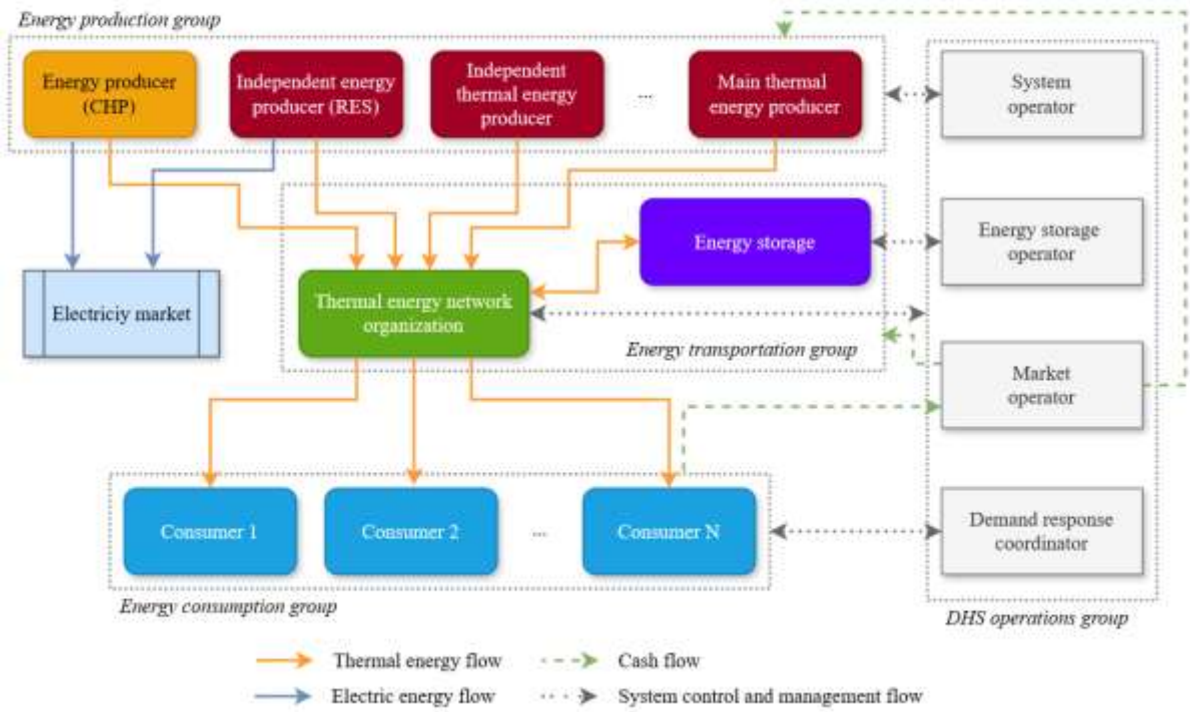

Figure 3 – *Basic modernization of the structural scheme of the competitive DHS with ESD*

From an economic standpoint, utilizing ESD in competitive DHSs promises to reduce operational costs and enhance grid stability. The proposed structural scheme fosters a multi-actor competitive environment where various energy producers contribute to a dynamic energy marketplace. By facilitating demand response and allowing for a more decentralized system management approach, DHSs can better optimize pricing structures and encourage energy-saving behaviors among consumers. Strategically, the integration of ESD supports a shift towards a consumer-centric model, enhancing end-user engagement and satisfaction. Additionally, by capitalizing on technologies like CHP, DHSs can extend their roles within energy networks, providing valuable balancing services that maintain grid reliability amidst increased RES penetration. This, in turn, enhances energy security and bolsters the economic viability of DHSs in competitive settings, where efficient energy management is crucial.

Despite the clear benefits, several challenges must be addressed. The complex interplay between different technological components requires careful coordination and management, demanding robust control systems and strategic planning. The financial implications, particularly concerning initial investment costs and economic feasibility in diverse geographical contexts, need in-depth analysis.

Looking towards future research directions, the scheme laid out can be explored through various alternative structural configurations. Given the diverse potential interactions between energy storage, producers, and consumers, further studies could focus on optimizing these relationships to maximize efficiency, economic, and environmental outcomes. Additionally, advanced modeling and simulation techniques could be applied to analyze the impact of various ESD integration strategies under different market and regulatory scenarios, providing critical insights for policymakers and industry stakeholders.

Additionally, ongoing advancements in smart grid technologies and real-time data analytics will play pivotal roles in refining these systems. As DHS operations become more data-driven, integrating advanced analytics and machine learning could lead to more accurate forecasts and better demand-supply matching, thereby enhancing overall system performance.

Conclusions

The modernization of competitive DHSs through the integration of ESD represents a critical advancement towards achieving a sustainable, efficient, and flexible urban energy infrastructure. This research confirms that the incorporation of promising energy storage technologies, such as TES and other advanced storage solutions, significantly enhances the operational capacity and adaptability of modern DHSs. By enabling more effective management of the variability and intermittency associated with RES, ESDs are essential for ensuring a stable and reliable energy supply.

Through a comprehensive literature review, this study identified key technologies that stand out for their potential to improve DHS performance. TES solutions like BTES, PTES, and ATES emerge as particularly effective, though initial costs and geological dependencies pose challenges that need strategic consideration.

The proposed structural scheme illustrates a dynamic interaction model among various entities within a competitive DHS, encompassing energy producers, transportation networks, and consumption sectors, alongside robust operations management facilitated by a market operator and a demand response coordinator.

The shift towards a decentralized and consumer-centric model promotes energy-saving behaviors and enhances user engagement, aligning with global sustainability efforts and reducing greenhouse gas emissions. Energy storage, particularly in conjunction with CHP technologies, offers the dual benefit of maintaining energy security and providing valuable balancing services to the electrical grid, thereby reinforcing the critical role DHSs play in modern energy networks.

In summary, this research underscores the transformative capacity of ESD in DHSs, positioning these systems at the forefront of sustainable urban energy solutions. Continued innovation and strategic integration of these technologies will be vital in catering to evolving energy demands and meeting stringent environmental targets globally.

References

1.I. Buratynskyi, T. Nechaieva, and I. Leshchenko, 'Assessment of the economic efficiency of battery energy storage systems in the electricity market segments', in *Studies in Systems, Decision and Control*, Cham: Springer Nature Switzerland, 2024, pp. 37–50.

2.V. Derii, T. Nechaieva, and I. Leshchenko, 'Assessment of the effect of structural changes in Ukraine's district heating on the greenhouse gas emissions', *Sci. Innov.*, vol. 19, no. 4, pp. 57–65, Aug. 2023.

3.V. Babak and M. Kulyk, 'Increasing the efficiency and security of Integrated Power System operation through heat supply electrification in Ukraine', *Sci. Innov.*, vol. 19, no. 5, pp. 100–116, Oct. 2023.

4.Eurostat. doi:10.2908/NRG_IND_REN.

5.V. Denysov, V. Babak, A. Zaporozhets, T. Nechaieva, G. Kostenko, Energy System Optimization Potential with Consideration of Technological Limitations (August 23, 2024). Available at SSRN: https://ssrn.com/abstract=4936175.

6.Hotra O, Kulyk M, Babak V, Kovtun S, Zgurovets O, Mroczka J, Kisała P, 'Organisation of the structure and functioning of self-sufficient distributed power generation', *Energies*, vol. 17, no. 1, p. 27, Dec. 2023.

7.J. Z. Thellufsen *et al.*, 'Smart energy cities in a 100% renewable energy context', *Renew. Sustain. Energy Rev.*, vol. 129, no. 109922, p. 109922, Sep. 2020.

8.T. T. Sebestyén, M. Pavičević, H. Dorotić, and G. Krajačić, 'The establishment of a micro-scale heat market using a biomass-fired district heating system', *Energy Sustain. Soc.*, vol. 10, no. 1, Dec. 2020.

9.H. Bielokha, L. Chupryna, S. Denisyuk, T. Eutukhova, and O. Novoseltsev, 'Hybrid Energy Systems and the Logic of Their Service-Dominant Implementation: Screening the Pathway to Improve Results', *Energy Eng.*, vol.120, no.6, 2023, pp.1307-1323. https://doi.org/10.32604/ee.2023.025863

10.A. Boldrini, J. P. Jiménez Navarro, W. H. J. Crijns-Graus, and M. A. van den Broek, 'The role of district heating systems to provide balancing services in the European Union', *Renew. Sustain. Energy Rev.*, vol. 154, no. 111853, p. 111853, Feb. 2022.

11.V. O. Derii, V. D. Bilodid, 'Limiting possibilities of the accumulation of thermal energy in centralized heat supply systems', *Probl. Gen. Energy*, vol. 2019, no. 2, pp. 41–45, Jun. 2019.

12.V. V. Horskyi, O. Y. Maliarenko, N. Y. Maistrenko, O. I. Teslenko, and H. O. Kuts, 'Modified three-stage model for forecasting the demand for energy resources at various hierarchy levels of the economy', *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1049, no. 1, p. 012054, Jun. 2022.

13.E. Guelpa, A. Bischi, V. Verda, M. Chertkov, and H. Lund, 'Towards future infrastructures for sustainable multi-energy systems: A review', *Energy (Oxf.)*, vol. 184, pp. 2–21, Oct. 2019.

14.H. Sadeghi, R. Jalali, and R. M. Singh, 'A review of borehole thermal energy storage and its integration into district heating systems', *Renew. Sustain. Energy Rev.*, vol. 192, no. 114236, p. 114236, Mar. 2024.

15.N. Fry, P. Adebayo, R. Tian, R. Shor, and A. Mwesigye, 'A review of district energy technology with subsurface thermal storage integration', *Geotherm. Energy*, vol. 12, no. 1, Aug. 2024.

16.I. Sifnaios, D. M. Sneum, A. R. Jensen, J. Fan, and R. Bramstoft, 'The impact of large-scale thermal energy storage in the energy system', *Appl. Energy*, vol. 349, no. 121663, p. 121663, Nov. 2023.

17.M. Rezaei, M. Sameti, and F. Nasiri, 'Biomass-fuelled combined heat and power: integration in district heating and thermal-energy storage', *Clean Energy*, vol. 5, no. 1, pp. 44–56, Mar. 2021.

18.K. Lepiksaar, V. Mašatin, E. Latõšov, A. Siirde, and A. Volkova, 'Improving CHP flexibility by integrating thermal energy storage and power-to-heat technologies into the energy system', *Smart Energy*, vol. 2, no. 100022, p. 100022, May 2021.

19.N. Javanshir, S. Syri, S. Tervo, and A. Rosin, 'Operation of district heat network in electricity and balancing markets with the power-to-heat sector coupling', *Energy (Oxf.)*, vol. 266, no. 126423, p. 126423, Mar. 2023.

20.A. Kang, I. Korolija, and D. Rovas, 'Photovoltaic Thermal District Heating: A review of the current status, opportunities and prospects', *Appl. Therm. Eng.*, vol. 217, no. 119051, p. 119051, Nov. 2022.

21.D. Wang, J. Carmeliet, and K. Orehounig, 'Design and assessment of district heating systems with solar thermal prosumers and thermal storage', *Energies*, vol. 14, no. 4, p. 1184, Feb. 2021.

22.E. Bellos *et al.*, 'Dynamic investigation of centralized and decentralized storage systems for a district heating network', *J. Energy Storage*, vol. 56, no. 106072, p. 106072, Dec. 2022.

23.J. Hennessy, H. Li, F. Wallin, and E. Thorin, 'Flexibility in thermal grids: a review of short-term storage in district heating distribution networks', *Energy Procedia*, vol. 158, pp. 2430–2434, Feb. 2019.

24.D. Romanchenko, E. Nyholm, M. Odenberger, and F. Johnsson, 'Impacts of demand response from buildings and centralized thermal energy storage on district heating systems', *Sustain. Cities Soc.*, vol. 64, no. 102510, p. 102510, Jan. 2021.

25.A. Dahash, F. Ochs, and A. Tosatto, 'Techno-economic and exergy analysis of tank and pit thermal energy storage for renewables district heating systems', *Renew. Energy*, vol. 180, pp. 1358–1379, Dec. 2021.

26.R. Savolainen and R. Lahdelma, 'Optimization of renewable energy for buildings with energy storages and 15-minute power balance', *Energy (Oxf.)*, vol. 243, no. 123046, p. 123046, Mar. 2022.

27.R. Egging-Bratseth, H. Kauko, B. R. Knudsen, S. A. Bakke, A. Ettayebi, and I. R. Haufe, 'Seasonal storage and demand side management in district heating systems with demand uncertainty', *Appl. Energy*, vol. 285, no. 116392, p. 116392, Mar. 2021.

28.E. Borri, G. Zsembinszki, and L. F. Cabeza, 'Recent developments of thermal energy storage applications in the built environment: A bibliometric analysis and systematic review', *Appl. Therm. Eng.*, vol. 189, no. 116666, p. 116666, May 2021.

29.E. Guelpa and V. Verda, 'Thermal energy storage in district heating and cooling systems: A review', *Appl. Energy*, vol. 252, no. 113474, p. 113474, Oct. 2019.

30.H. Li, J. Hou, Z. Tian, T. Hong, N. Nord, and D. Rohde, 'Optimize heat prosumers' economic performance under current heating price models by using water tank thermal energy storage', *Energy (Oxf.)*, vol. 239, no. 122103, p. 122103, Jan. 2022.

31.V. I. Deshko, National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», D. S. Karpenko, and National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», 'Analysis of conditions for the creation of the local thermal energy market in Ukraine', *Komunalne gospodarstvo mist*, vol. 7, no. 146, pp. 68–76, 2018.

32.D. Valeriy and K. Dmytro, 'Functional structure of the local thermal energy market in district heating', in *2019 IEEE 6th International Conference on Energy Smart Systems (ESS)*, Kyiv, Ukraine, 2019.

Д.С. Карпенко[1], канд. техн. наук, ORCID 0000-0002-8022-9782
Т.О. Євтухова[1]**,** канд. техн. наук, доцент, ORCID 0000-0003-4778-2479
О.В. Новосельцев[1]**,** д-р техн. наук, ORCID 0000-0001-9272-6789
В.О. Ходаківський[1]**,** аспірант, ORCID 0009-0007-3237-3476
[1]**Інститут загальної енергетики НАН України**

УДОСКОНАЛЕННЯ КОНКУРЕНТНОЇ СТРУКТУРИ РИНКУ ЦЕНТРАЛІЗОВАНОГО ТЕПЛОПОСТАЧАННЯ ЧЕРЕЗ ЕНЕРГОНАКОПИЧУВАЧІ

У цій статті досліджується модернізація структурних схем у системах централізованого теплопостачання (СЦТ), що працюють в конкурентних умовах з використанням накопичувачів енергії. Визнаючи необхідність підвищення робочої гнучкості та надійності, особливо зі збільшенням частки відновлюваних джерел енергії, таких як вітер і сонце, в роботі досліджується роль накопичувачів енергії в оптимізації функціонування СЦТ. Основні завдання дослідження включають проведення огляду літератури для визначення ефективних технологій для інтеграції в СЦТ та визначення оновленої схеми структурної взаємодії, адаптованої до конкурентного середовища. Огляд літератури підкреслює потенціал різних рішень для зберігання теплової енергії, кожне з яких сприяє покращенню управління енергією, незважаючи на властиві економічні та технічні проблеми. Запропонована модернізація структурних схем переосмислює ролі багатьох учасників у СЦТ, включаючи виробників енергії, транспортні мережі та споживачів, а також сторони державного контролю та управління. Підсумовуючи, це дослідження підкреслює трансформаційний вплив інтеграції енергонакопичувачів у СЦТ, сприяння стійкій міській енергетичній інфраструктурі, яка відповідає глобальним цілям сталого розвитку.

Ключові слова: *централізоване теплопостачання, ринок теплової енергії, зберігання енергії, відновлювані джерела енергії, стабільність мережі.*

Надійшла: 19.02.2025
Received: 19.02.2025