Diversification and Decentralization of Heat Energy Sources in the District Heating System of Tuzla

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Previous announcement
UDC: 621.311.22:697.34
697.34:502.131.1
DOI: 10.5937/tehnika2601055M

This paper investigates possibilities for the diversification and decentralization of heat energy sources in the district heating system of Tuzla, with the aim of increasing energy security, reducing CO_2 emissions and improving overall system efficiency. The existing model, which relies almost exclusively on the Tuzla Thermal Power Plant (TE Tuzla), is characterized by high dependence on fossil fuels, limited operational flexibility and hydraulic challenges in peripheral parts of the network. The study analyses potentials for integrating alternative heat sources, biomass cogeneration, waste-to-energy (RDF) and solar thermal systems, and assesses the role of thermal energy storage in optimizing operation and mitigating seasonal variability. Comparative scenario analysis demonstrates feasible transition pathways towards a sustainable heating model that reduces emissions and increases local control over energy supplies while accounting for Tuzla's specific technical and institutional context.

Key Words: *district heating system, alternative heat sources, heat storage*

1. INTRODUCTION AND REVIEW OF PREVIOUS RESEARCH

The „Tuzla“ Thermal Power Plant currently uses blocks 4 and 6 as the main sources of heat energy in the district heating system of Tuzla and Lukavac, while the older blocks have been phased out of operation [1]. The stability of heat energy consumption directly affects the efficiency and security of TE „Tuzla“, since fluctuations in heat demand create instability in the production process. These fluctuations cause frequent start-stop cycles, which increase equipment wear, reduce electricity production efficiency, and raise operating costs. Especially during the winter period, the peripheral parts of Tuzla face significant challenges in the continuity of heat supply. Due to fluctuations in the operation of the central heat sou rce, which may occur because of variations in demand or system failures, interruptions in heat delivery arise in more distant locations. This phenomenon is further intensified by the limited capacity of the existing distribution network, which is not optimally adapted to dynamic changes in consumer requirements on the periphery. Additionally, the use of coal as the primary fuel in the production of heat energy from the thermal power plant generates considerable CO_2 emissions, which is becoming an increasingly important economic factor due to the introduction or announced introduction of CO_2 emission taxes as part of the transition to a low-carbon economy.

The expected obligations from the CBAM (Carbon Border Adjustment Mechanism) and the growing pressure of European energy and environmental policies require the energy sector of Bosnia and Herzegovina [2], including Tuzla’s district heating system, to strategically shift towards renewable sources and reduce dependence on fossil fuels. In this context, the need for diversification of heat energy sources and gradual decarbonization of the system becomes not only an ecological imperative but also an economic priority that directly impacts the long-term sustainability and competitiveness of the district heating sys-

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Paper received: 19.11.2025.
Paper accepted: 14.01.2026.

tem in Tuzla. In recent years, research and technical proposals aimed at modernization, diversification, and potential decentralization of this system have intensified. In this regard, JP Elektroprivreda BiH has already been implementing a series of activities aimed at partial transition and substitution of fossil fuels. As part of development and decarbonization plans, projects have been launched for the integration of biomass cogeneration plants [1]. At the same time, local authors have analyzed the technological and ecological aspects of waste treatment and biomass utilization, with studies such as [3], [4] highlighting the significant potential of biomass and waste as alternative energy sources in the region. Furthermore, international organizations have developed strategic documents analyzing sustainable heating options for Tuzla [5]. Complementary local initiatives and operational insights, such as the report of JKP „Komunalac" Tuzla on waste management [6], additionally confirm the presence of local resources suitable for energy valorization. At the international level, numerous examples of integrating heat storage tanks into district heating systems [7–9] show how seasonal or decentralized heat storage can increase system flexibility, enable greater inclusion of renewable sources, and reduce dependence on centralized thermal sources.

The concept of 4th Generation District Heating, as defined in [10], lays the foundation for smart, energy-efficient, and sustainable thermal networks that use multiple energy sources, including low-temperature and locally available renewable resources. Practical implementations of these concepts, such as systems in Helsinki [11], Copenhagen [12], and Salzburg [13], as well as technical recommendations from the International Energy Agency (IEA) for the development of heat storage technologies [14], can serve as models for the future development of Tuzla's district heating system. Recent scientific literature confirms that combining biomass cogeneration, waste-to-energy facilities, solar thermal systems, and thermal energy storage can significantly enhance the technical and environmental performance of urban district heating systems [15–20].

These studies provide a broader scientific framework within which the Tuzla district heating system can be analyzed and optimized. Based on the reviewed international scientific literature and local technical studies, this paper focuses on the assessment of technically and economically feasible options for diversification and decentralization of heat energy sources in the district heating system of Tuzla. Particular attention is given to the integration of biomass, wastederived energy, solar thermal systems, and thermal energy storage as key elements for improving system reliability, flexibility, and environmental performance.

2. DISTRICT HEATING SYSTEM OF TUZLA – DEVELOPMENT AND CHALLENGES

The development of Tuzla's district heating system is closely connected to the construction and operation of TE Tuzla, which began operating in the 1960s. Originally, the system focused on supplying heat to industrial and residential facilities located in the immediate vicinity of the power plant. Over time, as the city expanded, the heating network was extended toward the periphery (Figure 1), today covering most of the city, including distant zones [5].

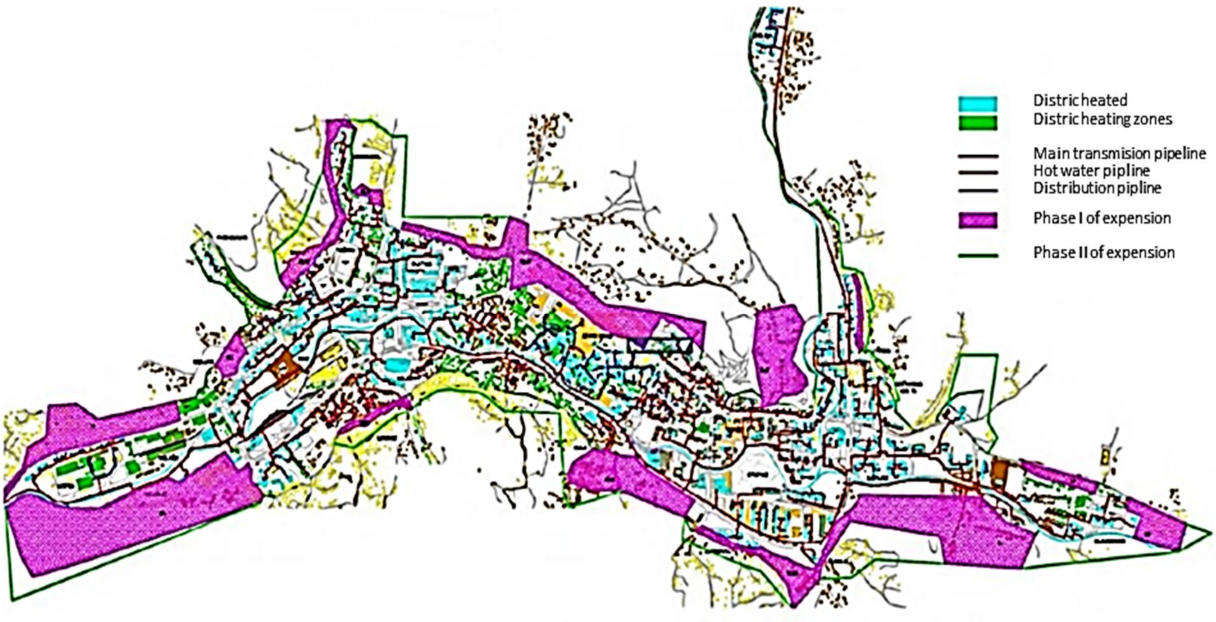


Figure 1 - District heating zones of the city of Tuzla. [5]

The system operates on the principle of a closed loop of pressurized hot water circulating through main and secondary pipelines from the source to end users and back. Large-diameter main pipelines transfer heat energy to heating substations, from which it is distributed through local networks to individual buildings. With the revitalization of Block 6 in 2023, the installed thermal capacity at the source reached 300 MWth, significantly improving stability and reliability in heat energy delivery [21]. The network currently covers more than 1.7 million m² of heated space. However, challenges in distribution remain, particularly in the eastern parts of the city, where pressure drops and temperature oscillations during peak hours affect user comfort. Aging infrastructure, high heat losses in main and secondary pipelines, and limited network flexibility further complicate reliable energy delivery, especially during cold winter days. The most severe problems are recorded in peripheral zones, where pipelines are the longest and heat losses are the most pronounced, resulting in pressure drops and occasional supply interruptions. The current production regime is characterized by the need for hydraulic balancing, expecially in remote parts of the network during peak loads. Stabilizing pressure and temperature in those areas is becoming an increasingly important operational task. According to available data (Figure 2), the total delivered thermal energy amounted to 386,104 MWh in 2022, 374,771 MWh in 2023, and a decrease to 328,612 MWh in 2024 was recorded [22].

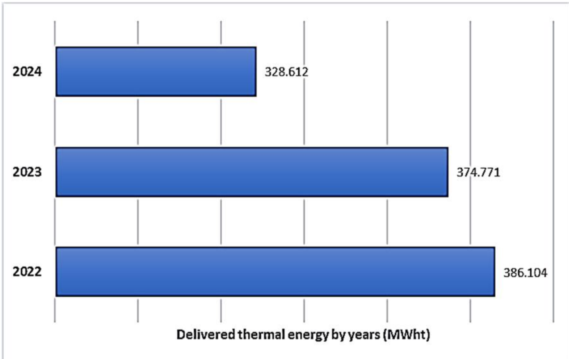


Figure 2 - The delivered amount of thermal energy in the heating system. [16]

This trend partly reflects the impact of weather conditions but also continuous network losses, reduced consumption due to greater energy efficiency of buildings, as well as changes in the structure of end-users. Regarding heat demand at the source (Figure 3), maximum demand reached 145 MWth in 2022, 141 MWth in 2023, and 140 MWth in 2024, while average values remain around 78 MWth [22]. These data indicate a relatively stable peak system demand but also highlight the need for more efficient real-time balancing of production and consumption. The analyzed data form the basis for strategic planning of the district heating energy transition. They enable precise modeling of the amounts of energy that need to be substituted from non-fossil sources primarily solar energy, biomass, and waste-to-energy.

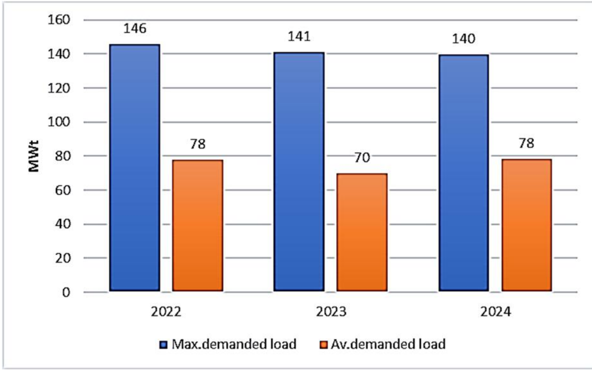


Figure 3 - Maximum and average load of the heat source during the heating season. [22]

Quantification of seasonal and annual needs, as well as peak loads, allows proper sizing of new sources and storage systems, contributing to improved supply security, reduced CO_2 emissions, and greater energy independence of the city.

3. POSSIBILITIES OF APPLYING ALTERNATIVE ENERGY SOURCES AND HEAT STORAGE

Combining renewable energy sources (RES) with thermal energy storage (TES) is a key modernization pathway for Tuzla's district heating system. This approach increases system resilience and provides more flexible management of heat loads, which is expecially important given pronounced seasonal and daily consumption variations.

Local resources such as solar thermal collectors, energy from waste (RDF) and biomass enable heat generation close to consumers, reducing stress on the central source and enhancing network stability.

Integration of these sources with storage allows surplus heat to be accumulated and used during peak demand, improving delivery dynamics and reducing the risk of supply interruptions. Substitution of part of fossil-fuel-based heat production with renewables directly reduces CO_2 emissions, aligning with European climate objectives and improving energy security by reducing import dependence.

Based on maximum observed source load, a plan for gradual substitution of approximately 140 MW of coal-derived heat with alternative sources has been developed. Figure 4 in the original document outlines three key sources planned for coal substitution: a biomass-fired cogeneration plant of 69 MWth, a municipal waste thermal treatment plant contributing 31

MWth, and solar thermal systems up to 40 MWth. Integration of thermal storage is foreseen to enhance flexibility and efficiency. Details on each source are provided in the following subsections.

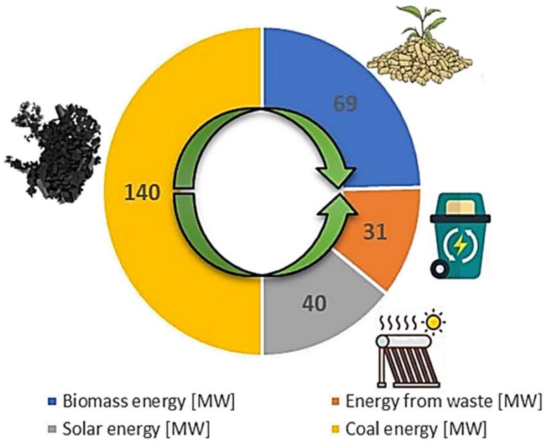


Figure 4 - Substitution of coal energy with alternative energy sources – biomass – energy from waste – solar energy.

3.1. Integration of biomass energy into Tuzla's heating system

To address the identified challenges, EP BiH plans [23] to construct a new biomass-fired cogeneration unit with a maximum heat output of 69 MWth, to be located on the site of the former Units 1 and 2. This investment will further improve system flexibility and resilience. Heat storage tanks will be installed to accumulate surplus production for use during peak periods, thus increasing supply security.

The proposed solution is based on a grate-fired boiler, which is well-suited to variable-quality local biomass (e.g. wood chips, forest residues and short-rotation plantation residues) without strict fuel granulometry requirements. The steam parameters of 40 bar and 400 °C are selected to minimize corrosion induced by chlorine and sulfur contained in biomass [23].

The cogeneration unit will be equipped with a steam turbine capable of extracting steam for district heating. In maximum heat-only mode the boiler can supply up to 69 MWth without concurrent electricity generation, while in summer operation up to 25 MWe of electricity may be produced. Operational flexibility is further supported by bypass systems enabling direct steam supply to the network without passing through the turbine (Table 1).

A daily heat storage tank with a capacity of 360 MWhth is planned, enabling storage of surplus heat for approximately six hours at full load. Biomass will be stored in two silos with a total volume of 11,520 m³, corresponding to roughly seven days of reserves at maximum operation.

Table 1. Overview of CHP plant operating modes [23]

Operating Mode	MWel	MWth (DH)
Electricity only	24.8	0
Regular cogeneration	14.3	46.3
Max. heat – cogeneration	8.3	52.4
Heat only (DH)	0	68.9

Estimated annual biomass demand ranges from 90.000 to 120.000 tonnes, with basic supplies expected from local forest resources and gradual establishment of short-rotation plantations by 2030. Additional quantities (approximately 30,000 t/year) could be sourced from the surrounding region if needed to extend operational duration or expand capacity [23].

3.2. Integration of waste-to-energy into Tuzla's heating system

Although the biomass cogeneration plant would significantly contribute to decarbonization and system stability, it cannot fully cover peak system demand. Therefore, integrating additional heat sources is necessary, with a particular focus on energy recovery from municipal waste through RDF (Refuse Derived Fuel) production. Thermal treatment of municipal waste can provide stable and environmentally acceptable heat while reducing landfill pressure and aligning with European emission standards.

A major implementation challenge is underdeveloped source segregation in the Tuzla Canton. Most household waste is still not separated at source, and systemic deficits in infrastructure and public awareness complicate high-quality RDF production. RDF quality depends on the presence of plastics, paper and textiles, while organic and inert fractions reduce calorific value and increase processing costs. Reliable RDF production therefore requires improvements in waste management, collection, and mechanical-biological treatment capacities.

Existing mechanical processing at the Desetine landfill provides a basis for further development [6]. The integration of an RDF thermal treatment plant would create prerequisites for stable heat supply, CO_2 emission reductions, landfill relief and increased energy self-sufficiency. Linking the incineration plant with heat storage would allow surplus heat to be stored for later delivery during peak loads, further improving flexibility. Such models are successfully applied in European cities like Vienna and Copenhagen.

In terms of thermal energy production (Table 2), the required amount of RDF was estimated using a simplified steady-state energy balance. The average thermal power output of the waste-to-energy plant can be expressed as:

$$\dot{Q} = \frac{m \cdot LHW \cdot \eta}{t} \tag{1}$$

where $\dot{Q}$ is the thermal power output, m the annual mass flow of RDF, LHV the lower heating value of the fuel, η the overall plant efficiency, and t the annual operating time. For a target thermal output of 31 MW, an annual operating time of 5,000 h, an assumed RDF lower heating value of 15 MJ/kg, and an overall plant efficiency of 85%, the required RDF quantity amounts to approximately 43,700 tons per year. Sensitivity analysis for lower and higher heating values of RDF is presented in Table 2, reflecting realistic variations in waste composition.

Table 2. Required RDF quantity for the target heat output of 31 MW(th).

Target heat output	Annual operating hours (h)	Lower heating value (LHV) of RDF (MJ/kg)	Required RDF quantity (t)
31	5,000	15	43,730
31	5,000	12	54,660
31	5,000	18	36,440

3.3. Integration of solar energy into Tuzla's heating system

Solar thermal systems can play a significant role in the decarbonization strategy of the district heating system. The required solar thermal capacity was estimated using a simplified steady-state energy approach, in which the average thermal power output of a solar collector field is expressed as:

$$\dot{Q} = \frac{A \cdot G \cdot \eta}{t} \quad (2)$$

where $\dot{Q}$ is the thermal power output, A the total collector area, G the annual global solar irradiation, η the overall system efficiency, and t the equivalent full-load operating hours. To achieve approximately 40 MWth of installed solar thermal capacity, the required collector area can be determined as:

$$A = \frac{\dot{Q} \cdot t}{G \cdot \eta} \quad (3)$$

Assuming the solar potential of Tuzla Canton in the range of 1.200–1.400 kWh/m²·year [24], an overall efficiency of modern flat-plate or vacuum tube collectors of 0.45–0.55, and 1,200–1,400 h/year of equivalent full-load operation, the resulting total collector area amounts to approximately 55,000–65,000 m². This area could be realized through a combination of centralized solar fields and distributed rooftop collectors on public and residential buildings, enabling phased and spatially flexible implementation.

Since demand for space heating in the summer months is minimal, solar heat produced during that period can be used for domestic hot water preparation or accumulated in large-capacity storage tanks. Such storage enables solar heat captured during sunny days to be utilized in the evenings or in autumn and winter, reducing peak loads and supporting hydraulic balancing of the network (Figure 5). Therefore, deployment of TES in parallel with solar collectors is essential to achieve meaningful utilization of solar thermal energy in district heating.

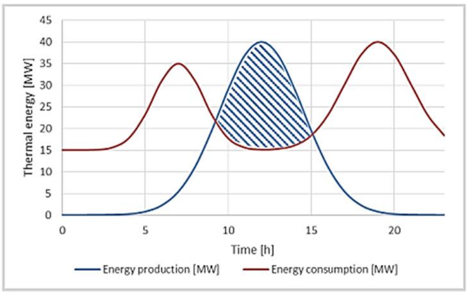


Figure 5 - Comparison of daily energy production from solar systems and energy consumption for the heating system with thermal storage charging time.

4. ASSESSMENT OF ENVIRONMENTAL AND ENERGY BENEFITS OF THE TRANSITION

To quantify the potential substitution of coal-derived heat with renewable energy sources in Tuzla's district heating system, a screening-level techno-energetic assessment was performed. The presented scenarios represent peak-load substitution pathways and are not the result of a formal optimization procedure.

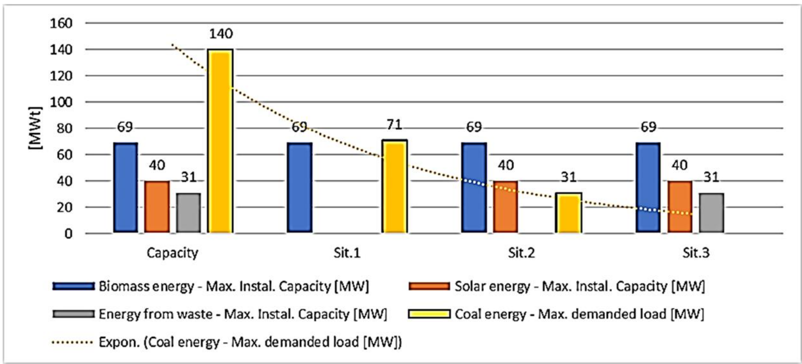


Figure 6 - Peak energy substitution scenarios

Instead, installed thermal capacities are translated into representative annual heat production in order to estimate avoided coal-based heat generation and associated CO_2 emissions. This approach enables a consistent comparison between alternative system configurations. Analysis of operational data from the past three heating seasons indicates that the reference peak heat load of the Tuzla district heating system is approximately 140 MWth. Based on this value, three transition scenarios were formulated (Figure 6), representing successive stages of coal substitution.

Scenario 1 considers the contribution of the planned biomass cogeneration plant alone, with an installed thermal capacity of 69 MWth, corresponding to approximately 49% of the observed peak demand.

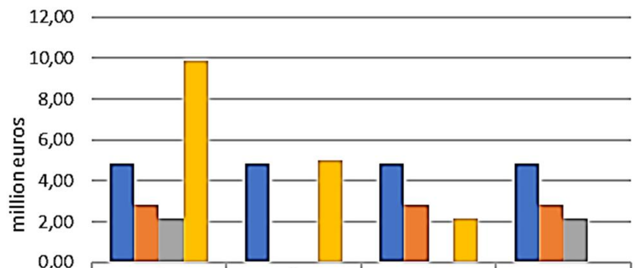
Scenario 2 combines the biomass plant with 40 MWth of solar thermal capacity, increasing the total renewable-based peak capacity to 109 MWth, or approximately 78% of peak demand.

Scenario 3 integrates biomass, solar thermal energy and an additional 31 MWth RDF-based waste-to-energy plant, reaching a combined capacity of 140 MWth and enabling full substitution of coal-based peak heat production. Figure 6 illustrates the reduction of required coal-based peak capacity as renewable heat sources are progressively introduced. To link installed thermal capacity with environmental impact, the annual useful heat production of each scenario was estimated using representative equivalent full-load operating hours:

$$E_{annual} = Q_{instaled} \cdot h_{FL} \quad (4)$$

where E_{annual} is the annual heat production (MWh/year), $Q_{instaled}$ is the installed thermal capacity (MWth), and h_{FL} represents equivalent full-load hours characteristic for each technology (biomass, solar thermal and RDF).

The avoided coal-based heat production was then assumed to be directly proportional to avoided CO_2 emissions, based on the reference operating characteristics of TE Tuzla. It was assumed that producing 1 MWh of heat from coal corresponds to approximately 0.2 MWh of electricity, reflecting a typical heat-to-electricity ratio of 5:1 for the reference coal-fired CHP system. Furthermore, 1 MWh of electricity generation was associated with approximately 1 tonne of CO_2 emissions in the reference scenario. Based on these assumptions and an adopted CO_2 price of 75 €/t, the annual cost of emissions for the coal-only reference system was estimated at 9.87 million euros (Figure 7). Partial or full substitution of coal-based heat with renewable sources proportionally reduces these costs.



	1	2	3	4
Biomass CO_2 savings in [m.eur]	4,86	4,86	4,86	4,86
Solar CO_2 savings in [m.eur]	2,82		2,82	2,82
Waste-to-energy CO_2 savings in [m.eur]	2,19			2,19
Coal energy CO2 emissions in [m.eur]	9,87	5,01	2,19	0,00

Figure 7 - Savings of millions of euros in CO_2 emissions

Introduction of renewable heat sources leads to a stepwise reduction of coal-based heat generation and corresponding CO_2 emission costs. In Scenario 1, the introduction of biomass reduces the annual CO_2 emission cost by 4.86 million euros, resulting in a remaining coal-related CO_2 cost of 5.01 million euros per year.

In Scenario 2, the additional contribution of solar thermal energy further reduces coal-based operation, decreasing the remaining annual CO_2 emission cost to 2.19 million euros. Finally, Scenario 3 enables full substitution of coal-derived heat production, resulting in zero annual CO_2 emission costs.

For an illustrative long-term economic comparison, a discount rate of 5% and an analysis period of 25 years were assumed, consistent with standard district heating planning practice. The annual avoided CO_2 emission costs were converted into present value using the present worth factor (PWF):

$$PWF = \frac{1-(1+r)^{-n}}{r} \quad (5)$$

where r is the discount rate and n is the analysis period.

The present value of avoided CO_2 costs was then estimated as (PV_{CO2}):

$$PV_{CO2} = C_{annual} \cdot PWF \qquad (6)$$

The resulting values are summarized in Table 3. The results indicate that, even under conservative assumptions and simplified modelling, the discounted value of avoided CO_2 emission costs is comparable to or exceeds the expected investment magnitude of renewable heat technologies.

Table 3. Estimated annual and discounted CO_2 emission costs for coal substitution scenarios.

Scenario	Annual CO_2 cost (€ mil/year)	Avoided cost (€ mil/year)	PV of avoided CO_2 cost (€ mil)
Reference	9.87	–	–
Scenario 1	4.86	5.01	70.6
Scenario 2	5.01	4.86	68.5
Scenario 3	~0	9.87	139.1

Although the analysis does not represent a full techno-economic optimization, it clearly demonstrates the order of magnitude of environmental and economic benefits associated with progressive coal substitution. The results therefore justify further detailed studies focusing on optimized sizing of renewable sources, thermal energy storage capacities, and operational strategies within the Tuzla district heating system.

5. CONCLUDING REMARKS

Modernizing Tuzla's district heating system is a strategic priority for energy transition, environmental protection, and service quality. Revitalization of existing capacities (e.g., Unit 6) and the planned construction of a biomass cogeneration plant are key steps towards increasing flexibility and supply security. However, technical challenges, especially in peripheral network zones, require complementary systemic measures. The deployment of thermal energy storage and the decentralization of the network help stabilize distribution, reduce hydraulic losses, and improve consumption control, thereby extending equipment service life and increasing energy efficiency. Parallel integration of solar collectors, energy from waste, and biomass reduces CO_2 emissions and enhances resilience to energy market shocks. Utilizing waste-to-energy (RDF) provides Tuzla with a means to address waste management while producing stable heat in an environmentally acceptable manner. Scenario analysis demonstrates the technical feasibility of fully substituting coal-fired heat by combining biomass, solar, and waste-derived energy, which would significantly reduce emission costs and enhance system sustainability. Successful implementation requires improvements in waste segregation infrastructure, public education, and the exploration of financing instruments such as EU decarbonization funds. Further research should focus on detailed techno-economic modelling for sizing local substations, optimizing seasonal storage, and integrating real-time control systems to further increase efficiency and reliability.

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REZIME

DIVERZIFIKACIJA I DECENTRALIZACIJA IZVORA TOPLOTNE ENERGIJE U SISTEMU DALJINSKOG GREJANJA GRADA TUZLE

Ovaj rad istražuje mogućnosti diverzifikacije i decentralizacije izvora toplotne energije u sistemu daljinskog grijanja Tuzle, s ciljem jačanja energetske sigurnosti, smanjenja emisija CO_2 i unapređenja ukupne efikasnosti sistema. Postojeći model, koji se gotovo u potpunosti oslanja na Termoelektranu Tuzla (TE Tuzla), odlikuje se visokom zavisnošću od fosilnih goriva, ograničenom operativnom fleksibilnošću te hidrauličkim problemima u perifernim dijelovima mreže.Studija analizira potencijale integracije alternativnih izvora toplote, kogeneracije na biomasu, postrojenja za energiju iz otpada (RDF) i solarnih toplotnih sistema, te razmatra ulogu skladištenja toplotne energije u optimizaciji rada i ublažavanju sezonskih varijacija. Komparativna analiza scenarija pokazuje izvodive tranzicione pravce ka održivom modelu grijanja koji smanjuje emisije i povećava lokalnu kontrolu nad snabdijevanjem energijom, uz uvažavanje specifičnog tehničkog i institucionalnog konteksta Tuzle.

Ključne riječi*:* *sistem daljinskog grijanja, alternativni izvori toplote, skladištenje toplote*