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SMART HEAT TARIFFS IN TRANSITION TO FREE MARKET

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Innovative pricing mechanisms should motivate heat suppliers and consumers to move toward more sustainable energy systems and introduce low-temperature district heating systems and sector coupling in smart energy systems. Therefore, district heating regulation regimes should also be changed to stimulate transformations in the energy sector.

The district heating tariffs depend on many factors, including fuel prices, operational parameters, taxes, investments, and other criteria. Therefore, an analysis of the DH tariffs has been implemented to find solutions to motivate DH enterprises towards energy efficiency and climate neutrality. The analysis results are based on the decision-making assessment approach by selecting various criteria and evaluating them from five significant aspects: engineering, environmental, climate, economic and socioeconomic. The central elements within the developed fuzzy cognitive mapping model are investment costs, heat production costs, and primary energy consumption. Considering the set boundary conditions, the most beneficial method for smart heat tariff definition could be heat tariff benchmarking with integrated energy efficiency standards for DH operators.

Key words: district heating regulation, smart energy systems, demand-side management, energy efficiency.

Introduction

District heating (DH) is defined as a sustainable solution for densely populated areas because of the possibility to integrate renewable energy sources (RES) and the potential reduction of emissions (Boscan & Söderberg, 2021; Pelda et al., 2021). DH benefits society, communities and building owners and tenants through improved environmental quality and reduced emissions, more efficient and cost-effective heat technology, improved energy management, use of local energy resources, reduced heating and running costs and improved consumer comfort (Rezaie & Rosen, 2012). However, high investments are needed to create the infrastructure and knowledge about the technical aspects of energy systems (Rezaie & Rosen, 2012). In addition, DH must be a flexible system, able to manoeuvre between different heating needs and power requirements and operate efficiently, with the thermal energy being available and used efficiently (Selvakkumaran, Eriksson, et al., 2021).

The business and pricing models play an essential role in the DH framework, as they show how the company generates income and customer relationships (Selvakkumaran, Eriksson, et al., 2021). DH is a natural monopoly, as there is little room for competition. DH companies can abuse the monopoly and disproportionately increase prices, complicating invoicing and tariff structure, harming new customers (Gorroño-Albizu & de Godoy, 2021). This abusive method of increasing profits creates disadvantages for DH operators, and end-users can favour individual heat supply.

Creating a resilient DH system can benefit DH system owners, operators, customers, and the end-user financially, improve energy efficiency, reduce peak load expenditure at heat plants, and lower maintenance costs (Selvakkumaran, Eriksson, et al., 2021). Improved DH infrastructure and new technologies can achieve lower system temperatures and move toward 4th generation DH (4GDH)

(Averfalk & Werner, 2020a). The development of 4GDH provides cost-efficient heating in energy-efficient buildings and allows the further integration of district heating into a future smart energy system based on renewable energy sources (Lund et al., 2018). In the case of low-temperature DH systems, the quantified benefits of lower heat losses and more efficient utilisation of RES should exceed the operation and investment costs (Averfalk & Werner, 2020b). Therefore, the heat producers could attract new customers by lowering heat prices and reassuring those customers who previously had not connected to DH.

Lund et al. highlight that the development of 4GDH is essential to implementing smart energy systems that provide the cross-sectoral approach to reach the 100 % renewable energy sector. The concept also identifies the broader integration of the energy supplied by prosumers, but it still lacks innovative business models for a more comprehensive application (Selvakkumaran, Axelsson, et al., 2021).

Thus, the benefits associated with 4GDH and smart energy systems with sector coupling could provide the cost-efficiency of the DH system and long-term energy system improvements. Therefore, the heat tariffs should reflect the system value of heat conservation.

Examples of DH tariff methodologies

DH tariff could be comprehensively regulated or unregulated, and each model has advantages and disadvantages (Li et al., 2015). DH tariffs are often two-part tariffs and consist of fixed and variable fees (Egüez, 2021). Heat tariffs primarily are based on connexion fee, standing cost and unit cost (Li et al., 2015). But there are several DH tariff structure models (Li et al., 2015):

– cost-plus pricing tariff consists of operational cost, annual depreciation and permitted profit;
– marginal-cost pricing tariff components are a cost of one more unit of generation and marginal variable cost as well as the depreciation of fixed cost;
– incremental cost tariff is formed from operational costs of the existing system and discounted costs of future change;
– an integrated model of competitive and regulated methods where heat is integrated from different regions;
– shadow price method tariff is based on willingness to pay for an additional unit of heat production when the market is in equilibrium;
– real-time pricing based on smart metering and is similar to pricing in the electricity sector;
– the equivalent marginal cost method is made of short and long-run marginal costs.

DH tariffs vary for different countries due to diverse tariff structures and regions with one tariff structure. Each area has its energy producer, which affects the tariff. Therefore, existing heat tariffs should be regularly reviewed, and the most optimal tariff calculation should be selected depending on the country's capabilities and resources.

The heat tariff is regulated in all Baltic States. The heating tariff should be approved in Estonia by showing reasonable sales volume and cost-effectiveness. The heat price limit is determined separately for each DH area showing the cost-effectiveness maximum area price. Competition Authority sets it according to technical indicators (Riigikogu, 2017). In Lithuania, heat tariff is based on two variable components and a fixed component. Heat price is determined for three up to five year periods, but tariff components are updated every month or year depending on several conditions (Galindo Fernandez et al., 2021):

– variable component is updated every month based on actual fuel costs from the operator's plants and monthly auctions;
– second variable component – actual energy mix is revised every year by the Regulator to adjust through the year;
– fixed component – includes depreciation and amortisation, staff cost, operation and maintenance, etc. and is revised yearly by the Regulator.

The heat tariff regulation is much more liberal in Nordic countries. The heating prices are not regulated in **Finland** and **Sweden**. The competition in the district heating market keeps the price at a reasonable level (Patronen et al., 2017). In **Norway**, the heating price is regulated for mandatory connections. It depends on electricity prices with grid tariffs and electricity taxes. In Iceland, the heating tariff is regulated by the Ministry of Industry and Innovation. The heat price shows production, distribution, and sales (Patronen et al., 2017).

Slightly different regulation mechanisms occur in Denmark, where heat tariff is based on the cost-plus principle and regulated by the energy market authority (Patronen et al., 2017). However, the heat tariff components can differ in various DH systems. The tariff structure is based on variable and fixed parts, which can be attributed either to building heating capacity or building floor area (Galindo Fernandez et al., 2021) (Djørup et al., 2020):

– connection fee (DKK/kW or DKK/m^2) – paid once for connection and as part of an investment;

– annual fixed term (DKK/kW/y or DKK/m^2/y) – depends on capacity;

– variable assignment (DKK/MWh or DKK/m^3) – variable energy consumption costs per consumed MWh or the volume of DH heat carrier every year;

– *bonus/malus* term (DKK/°C) – depends on return temperature. If it differs from the temperature range 30–37 °C by 10 %, a bonus or penalty of 1 % is applied.

A similar heat tariff determination method by applying variable and fixed components has been used in France, Germany and Spain. The tariff structure in **Germany** consists of two parts, and new customers have a connection fee. The fixed component includes capital and operation costs based on maximum capacity (MW), but the variable component is based on consumed MWh. In **France**, the fixed part is affected by installed capacity and consists of energy consumption of auxiliary equipment, cost of operation and maintenance of the network, and yearly capital costs. The variable component is affected by consumed energy, flow in the heat exchanger and season. In **Spain**, there are long term and short-term tariffs introduced in addition to fixed and variable components. The fixed part is higher for the long-term tariff, but the variable component is higher for the short term tariff (Galindo Fernandez et al., 2021). In Spain, heating tariffs are reviewed monthly because of national indexes and changes in gas and electricity prices and for new clients, there are connection fees to connect to the network.

Poland has two options for heating tariffs – a cost-plus method based on planned incomes and costs and benchmarking method based on the Regulator's published heat price level (Changes to the Heat Tariff Scheme in Poland, 2020). Benchmark for heat tariff is usually set for one year, but it is possible to request a change in tariff before the end.

In **Italy**, DH price is not regulated and is updated every year by a published index from the National Institute of Statistics. DH tariff consists of a variable component and two fixed parts. The heat tariff differs for residential and tertiary buildings and depends on the consumed heat and installed capacity (Galindo Fernandez et al., 2021).

Role of DH tariffs toward smart DH systems

The general role of DH tariff from the consumer's and DH operator's perspectives have been shown in Fig. 1. An essential aspect of final consumers is the cost of heat, which depends on the heating area and the building efficiency and different operational conditions. If the tariff structure is not based on the customer's actual consumption, it provides little or no incentive to optimise heat consumption (Songa et al., 2016). Therefore, tariffs that consider customers' actual consumption allow them to influence their energy bills and consumption and motivate them to find more efficient solutions to their energy consumption (Songa et al., 2016). It is also in line with the study results conducted by Djorup et al., which show that a fully variable heat tariff scheme improves the financial incentive for heat savings. On the other hand, the DH tariff should also be affordable not to raise the energy poverty risk.

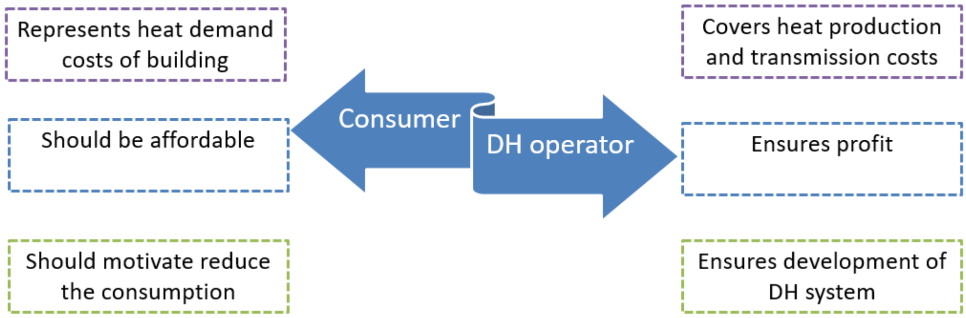


Fig. 1. Role of DH tariff from the consumers and DH operator's perspective

From the DH operator's perspective, DH tariffs should cover the heat production and transmission costs and ensure profit for the future development of the DH system. Tariffs that incentivise heat producers and end-users are excellent for DH systems, but countries where DH pricing is regulate, may face political obstacles (Selvakkumaran, Eriksson, et al., 2021). In addition, improving existing DH tariffs allows the implementation of new business models that are more understandable and encourage the involvement of new stakeholders.

The role of heat tariff and heat cost allocation becomes more complex when desiring to implement smart energy system solutions. The broader digitalisation of the district heating sector is already knocking on the door to provide higher efficiency for heat production, transmission and end-use. Schmidt (Schmidt, 2021) has analysed the potential impact of information and communication technologies from technical and business models' perspectives. The author highlights that future heat supply services could gradually change and provide certain temperature levels within the buildings instead of delivering a certain amount of heat. Such a change of service will also change the heating cost allocation methods.

Reducing heat carrier temperatures is necessary to decrease the transmission heat losses and increase the potential for low-temperature heat source integration. However, the temperature lowering in heating networks significantly depends on the heat consumer's ability to use lower-temperature heat. Hvelplund et al. (Hvelplund et al., 2019) emphasise energy savings as one of the critical aspects of 100 % RES systems because the heat-saving strategies go hand in hand with the heat costs as a driving factor for investments in energy efficiency measures. Therefore, Leoni et al. have investigated different motivation tariffs in Austria, which are used to engage the heat consumers in heating network temperature lowering. Those could include penalties for poorly performing customers that cannot reach the set temperature differences or flow rates or a bonus system for well-performing installations and discounts when using lower temperature heat. However, the authors highlight the necessity for information campaigns and such motivation tariffs to increase consumers' awareness.

Another condition for the sustainable development of DH systems is integrating waste heat into the heating network (Pakere, Gravelsins, et al., 2021). Leoni et al. identify the possible feed-in tariffs to motivate heat recovery. Another research by Dominkovic et al. showed that dynamic pricing fosters feeding the waste heat into the grid and lower marginal heat costs.

According to the literature review and heating tariff regulation mechanisms in different countries, there are various heating market regulation conditions and heat tariff application methods for intelligent energy systems. However, these mechanisms differ for consumers and DH systems. Therefore, different solutions could motivate heat consumers to reduce their heat consumption, adjust internal heating systems and improve the operation of heating substations – for example, discounts for lower return temperature or heat with lower exergy. On the other hand, from the DH operator's perspective, several contrary solutions exist, from unregulated heat tariff, which would allow operating under the freely chosen business model, to heat tariff benchmark, which could set the limitations for reasonable heat price according to different conditions.

Therefore, the research gap regarding the different heat tariff regulation mechanisms in the case of 4GDH and smart energy systems exists. This article compares other heat tariff determination methods and legislative frameworks to promote district heating transition towards sustainable development and carbon neutrality. The research approach includes the energy efficiency increase at both the heat consumer and heat producer sides and considers the impacts from heat carrier temperature modelling. The fuzzy cognitive mapping method has been used to identify the interlinkage of different elements impacting heat costs. The comparison motivates DH operators and heat consumers by implementing an appropriate heat tariff regulation method.

Materials and methods

The Section presents the main steps of the research to identify the most feasible DH tariff regulation method by comparing several alternatives from different aspects. The methodology of the comparison can be seen in Fig. 2.

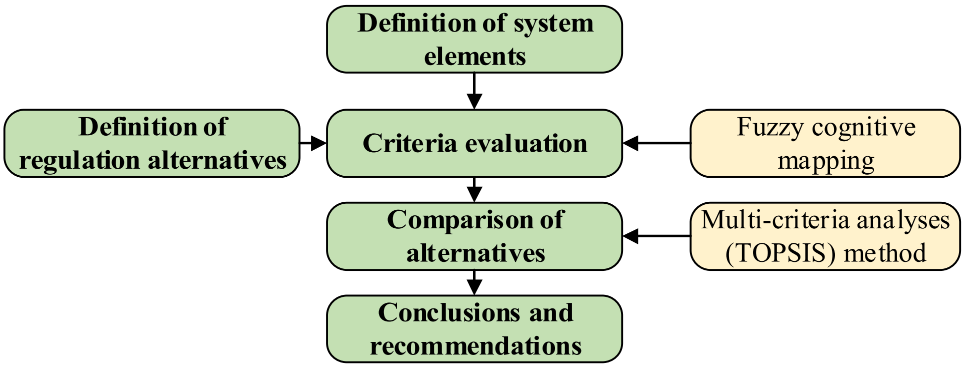


Fig. 2. Main steps of the research

The authors combine two methods to evaluate the most suitable alternative for smart heat tariff introduction: fuzzy cognitive mapping (FCM) and multi-criteria decision-making. First, a simplified DH heat tariff impacting model has been defined using the FCM method in MentalModeler software. Further several alternatives have been compared based on likely changes and impacts on the main system elements. Then, the criteria values of each scenario are further compared by applying the decision-making method – Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Finally, the conclusion and recommendations are drawn according to the obtained results.

Tested methods for heat tariff determination

First, the authors identify the possible solutions for DH system tariff regulation based on literature reviews, policy analyses and experiences of different countries. This study focuses on the instruments that could motivate the DH system operator, but the mechanisms that could boost the heat consumer are included indirectly as FCM elements. However, a more holistic comparison could be introduced in further studies by merging consumer and heat supplier policies.

The analysis includes five different regulation instruments:

1. Unregulated heat tariffs.
2. Unit price regulation.
3. Revenue cap regulation.
4. Tariff benchmarking.
5. Heat tariff according to best available technologies (BAT).

The unregulated heat tariff is based on the Swedish case when the DH system should be businesslike, suggesting that profit generation is an objective. However, the providers may not always use the monopoly prices due to competition with individual or local heat supply. The unit price regulation, in this study, is equal to the Estonian and Latvian regulation mechanisms when the applied heat tariff is approved by the Regulation Authority and should be determined according to a cost-plus method strictly indicating all cost and income flows. The regulated unit price should be applied to all consumers without adjusting the price under certain conditions. The revenue cap regulation is based on the Iceland case study when the utilities can set profits up to a certain level. The tariffs vary, but the price of heat generally reflects the costs of production, distribution, and sales. In addition, the authors suggest two more heat tariff regulation alternatives that are not yet approved in any analysed countries- heat tariff benchmarking and heat tariff according to BAT.

The heat tariff benchmarking approach integrates criteria that have the most significant effect on DH system energy efficiency, sustainable development, and the DH tariffs within this study. In the proposed method, the allowed heat tariff is related to the existing tariff and determined Climate index value which is a complex index consisting of seven different criteria – the specific heat losses, primary energy factor, total CO_2 emissions, specific environmental costs, the share of RES CHP, the percentage of RES, amount of heat purchased from industrial sites. Therefore, the heat tariff could be unregulated for those systems with better energy efficiency and RES share indicators (Pakere, Blumberga, et al., 2021).

The final alternative for heat tariff determination is based on energy efficiency reference levels for different technologies DH operators should reach. The method proposed that if the operation of the heat generation unit is in line with the best practice values, the heat tariff could be unregulated (see Fig. 3). The possible BAT reference documents (BREF) from which the reference values could be obtained are the "BREF for Large Combustion Plants" and "BREF for Energy Efficiency", where the main principles to reach high-efficiency levels are described. However, detailed guidelines are not available, particularly for DH system operation (Lecomte et al., 2017).

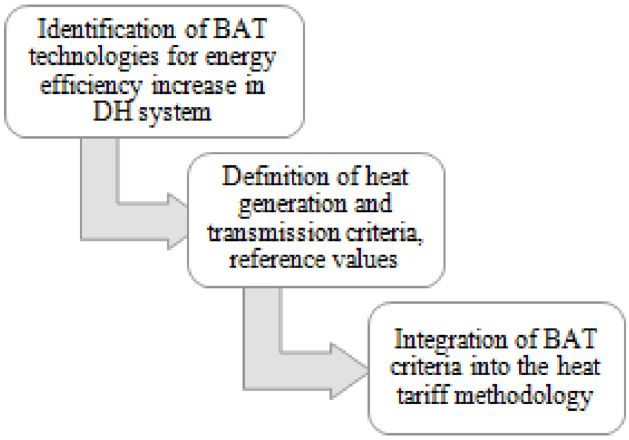


Fig. 3. Proposed methodology for BAT tariff determination

FCM and TOPSIS models

The identified heat tariff determination methodologies are compared by considering different criteria. The set of criteria is defined to analyse various aspects of the heat cost allocation from engineering, economic, environmental, socioeconomic and climate perspectives.

Fuzzy Logic Cognitive Mapping (FCM) has been used to determine the impact of different smart heat tariff determination methods. This method allows for identifying the key concepts and causal relationships, among other elements in the case of complex systems such as DH.

The analytical mechanics of FCM are based on examining the structure and function of DH heat tariff, using graph theory-based analyses of pairwise structural relationships between the elements included in a model. The FCM model has been developed by implementing three main steps:

1. The main elements impacting the DH tariff have been identified through systematic literature analyses and case study analyses by investigating the heat tariffs of several DH systems.

2. Several DH experts have determined the quantitative relations among the system elements to present the system's operation from different perspectives adequately. The opinions of experts are collected using a designed questionnaire by the researchers. The level of importance has been evaluated by assigning language variables ("without any importance", "not important", "moderate, important", "significant"). The linguistic variables are further converted to fuzzy numbers according to the methodology described by Nozari et al. (Nozari et al., 2021) All analysed relationships take values in the range of 0 to 1 (Özesmi & Özesmi, 2004).

3. Further, a knowledge graph consisting of nodes (concepts) and links has been drawn to represent the main DH system elements and DH heat tariff-impacting factors. The direct links between elements have been introduced as either positive or negative. The cause-effect relationships are presented within the FCM model. The structure of the model can be seen in Fig. 4.

The main elements influencing the final heat tariff are heat production costs and heat transmission costs (heat losses). The heat production costs are directly affected by several heat generation parameters – heat production efficiency, CO_2 emissions, primary energy consumption, RES technologies and investment costs. The investment costs are related to DH operator profit if a higher profit could also result in higher investment levels. The investments increase when there are higher energy efficiency standards and RES technologies. In addition, the reverse impact is assumed, as higher investment levels could decrease the heat losses and increase the heat generation efficiency and integration of RES technologies.

Two essential DH heat tariff evaluation criteria have been introduced – transparency and predictability. The heat production costs impact the predictability and transparency of heat tariffs, integration of RES technologies, and increased energy efficiency standards by assuming that sustainable DH systems would be motivated to apply more cost-based heat tariffs. On the other hand, these criteria could influence the energy poverty risk associated with high heating costs. Due to this reason, social payments are usually used by municipalities to support the purest society (Barrella et al., 2021; Desvallées, 2022).

An essential part of DH systems is consumers, determining the necessary final energy consumption. Therefore, the final energy consumption is impacted by the two influencing factors – building energy efficiency and new consumers. The model also includes the discount for buildings to determine the potential impact of different heat tariff regulation methods on the final energy consumption. This discount factor consists of the reduced payments for energy-efficient heating subsystems and reduced return flow temperatures as a single element within the study. Therefore, the discounts could lower heat carrier temperatures in heating networks and decrease heat losses. A reverse link is identified for these discounts impacting the social payments and DH profit. Increased building energy efficiency would reduce the total heating costs and lower necessary social gains. Still, on the other hand, social payments do not motivate consumers to increase building energy efficiency.

Further, several scenarios determine how the system might react under different heat tariff regulation methods. The plan indicates the relative change in the components included in the model based on the edge relationships defined in the FCM model. A value between H+ (significant negative change in an element) and H- (significant positive change in component) is set for several variables in each scenario. In case of unregulated heat tariff, the DH operator could apply the discounts for energy-efficient internal heat supply systems of buildings and increase the profit. Values for certain facilities are not allowed in the unit price regulation scenario. However, the transparency and the predictability of heat tariff increases due to regulatory conditions. In the case of revenue cap regulation, the profit of the DH operator is limited, but it is assumed that the predictability of heat tariffs could increase. In tariff benchmark and BAT heat tariff scenarios, discounts for consumers are allowed, and the DH efficiency increase is required. In BAT tariff, the energy efficiency increase is obtained directly through reference value introduction for heat losses and heat production efficiency increase. Still, in the benchmarking method, the efficiency standards are increased. The values of vital harmful and robust positive components changes are modelled from 0.1 to 0.5.

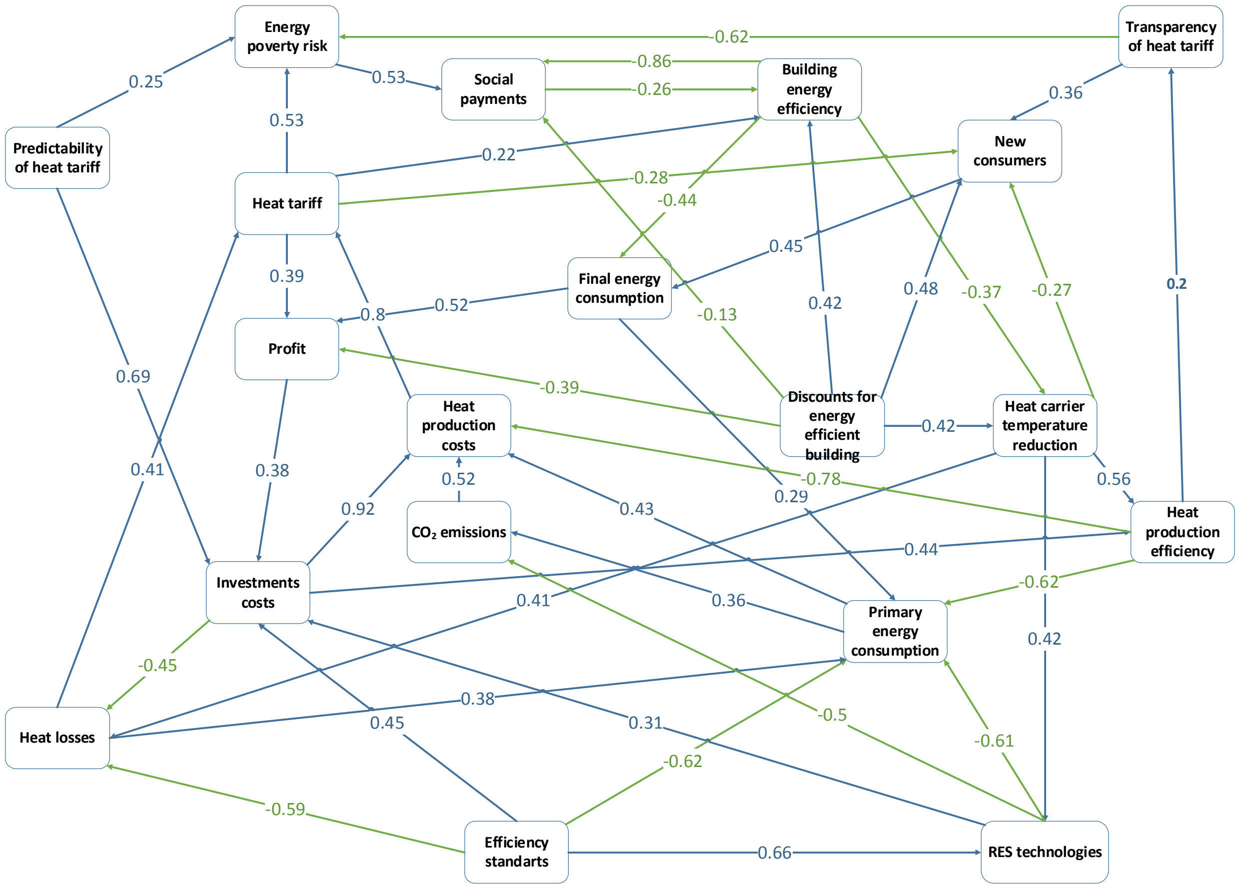


Fig. 4. Modelling of DH tariff influencing vectors by FCM

Further, according to the TOPSIS decision-making method, the multi-criteria assessment compares the analysed scenarios (Balioti et al., 2018). TOPSIS chooses the heat tariff regulation alternative of the shortest distance from the ideal solution and the most significant distance from the perfect negative solution. All the elements of the FCM model presented in Fig. 4 have been used as a comparison criterion with the determined values from the model. Further, the criteria values are normalised to transform the assigned values into non-dimensional attributes, allowing comparisons across measures. The positive ideal alternative and the damaging ideal alternative have been calculated from the normalised decision-making matrix. The last step within the TOPSIS method is the determination of the closeness to the perfect solution, which allows the rank identified alternatives for heat tariff regulation.

Table 1

Overview of changes of components in each scenario

	Discounts for buildings	Profit	Transparency	Predictability	Efficiency standards	Heat production efficiency	Heat losses
Unregulated heat tariffs	0.1...0.5	0.1...0.5					
Unit price regulation	-0.1...-0.5		0.1...0.5	0.1…0.5			
Revenue cap regulation		-0.1...-0.5		0.1...0.5			
Tariff benchmarking	0.1...0.5			0.1...0.5	0.1...0.5		
BAT heat tariff	0.1...0.5					0.1...0.5	-0.1...-0.5

Results and discussions

The section presents the comparison results from the FCM model and multi-criteria analyses to identify the main barriers and drivers in each heat tariff regulation alternative and determine which proposed heat tariff regulation methods could promote the transformation toward smart energy systems.

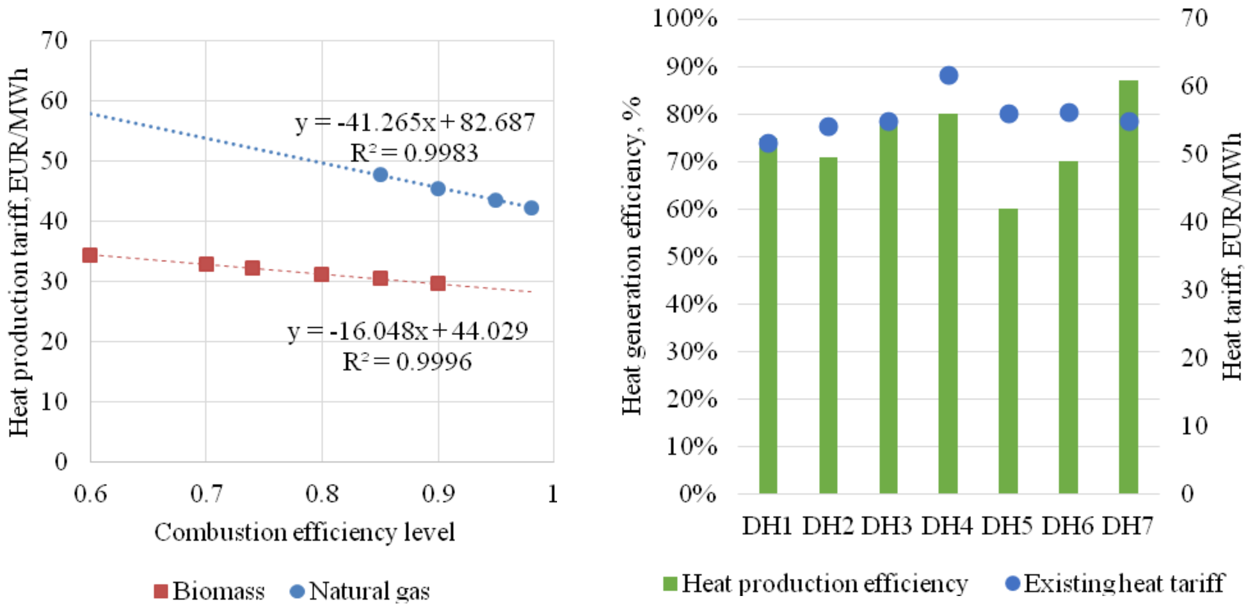
Relating energy efficiency levels with smart heat tariffs. Existing situation analyses

The legislation framework in Latvia states that licenced DH systems should ensure that energy efficiency levels of different technologies should be higher than the reference levels summarised in Table 2 (Cabinet of Ministers, 2016). For example, natural gas-only boiler houses' overall heat production efficiency should be less than 92 %. There are also defined efficiency levels for solar fields, stated efficiency class for heat pumps and maximal allowed specific heat losses in the DH network.

Table 2

Example of BAT reference levels set in Latvia (Cabinet of Ministers, 2016)

Criteria/technology	Reference value
Energy efficiency levels for heat only boilers	
Gaseous fuel	92 %
Liquid fuel	85 %
Solid fuel	75 %
Energy efficiency levels for CHP plants	
Gaseous fuel	80 %
Solid fuel	75 %
Solar collectors	
Vacuum solar collectors	70 %
Flat plate solar collectors	75 %
Heat pump efficiency class	C
Specific heat losses in the heating network	17 %



a *b*

Fig. 5. Example of heat combustion impact on heat production tariff:
a – analyses of the existing situation in different biomass boiler houses;
b – modelled heat production tariff in biomass and natural gas heat-only boiler houses

An example of combustion efficiency's impact on heat production efficiency can be seen in Fig. 5, *a*. The analyses have been conducted for two different DH systems with heat-only boilers-natural gas-based systems and wood chip boiler houses. The modelled results show that heat tariff increases due to efficiency in natural gas boiler houses because of higher energy source costs. However, the actual heat tariffs compared from seven different wood chip-based systems showed in Fig. 5, *b* does not indicate a relation to heat production efficiency. The actual efficiency levels vary from 60 % to 87 %. The lowest heat tariff is not stated in the systems with higher efficiency where additional heat recovery systems are installed. On the contrary, the lowest efficiency plants do not have the highest heat tariffs. It also shows that systems operate with an efficiency below the indicated reference levels (75 % for solid fuels). Therefore, the BAT heat tariff determination method would relate the energy efficiency levels with the allowed heat tariffs to motivate the integration of innovative heating systems.

Results on comparison of heat tariff regulation methods

The developed simplified FCM model consists of 19 components and 46 connections. The results show three main driving features with a centrality ratio above 3 – investment costs, heat production costs and primary energy consumption. Centrality shows the ratio of receiver variables to transmitter variables and measures the degree to which driving force outcomes are considered.

The obtained normalised results for analysed DH regulation mechanisms are summarised in Table 3. In the case of unregulated tariffs, the investment costs increase due to higher profit and causing a decrease in primary energy consumption. In this scenario, discounts for buildings are allowed. Therefore, new consumers are reached.

Table 3

Normalised decision-making matrix

Parameters	Unregulated tariffs	Unit price regulation	Revenue cap regulation	Tariff benchmarking	BAT tariff
Investments costs	1.11	1.22	1.09	1.31	0.99
Primary energy consumption	0.95	0.91	0.96	0.64	0.86
Final energy consumption	0.99	1.04	1.00	1.03	1.03
Transparency of heat tariff	1.01	1.30	1.01	1.03	1.03
Energy poverty risk	1.00	0.91	1.08	0.98	0.88
CO_2 emissions	0.99	0.97	0.98	0.81	0.95
RES technologies	0.99	1.00	1.00	1.13	1.00
Heat tariff	1.01	1.03	1.01	0.86	0.80
New consumers	1.15	0.95	1.00	1.19	1.21
Heat carrier temperature reduction	0.99	1.00	1.00	1.00	1.00
Heat losses	0.95	0.90	0.96	0.75	0.85
Efficiency standards	1.00	1.00	1.00	1.20	1.00
Heat production costs	1.05	1.09	1.04	0.95	0.82
Profit	1.30	1.05	0.70	0.95	0.93
Building energy efficiency	1.18	0.85	0.99	1.14	1.14
Heat production efficiency	1.04	1.10	1.04	1.13	1.15
Discounts for energy-efficient building	1.30	0.70	1.00	1.30	1.30
Predictability of heat tariff	0.99	1.30	1.30	1.30	1.03
Social payments	0.81	1.12	1.05	0.84	0.78
Investments costs	1.11	1.22	1.09	1.31	0.99

In the case of unit price regulation, the transparency and predictability of heat tariffs are increased. Still, discounts for heat consumers are reduced. Therefore, the new consumers and building energy efficiency decrease in this case. However, the investment costs increase, resulting in higher heat production efficiency. The DH operator's profit decreases in the case of revenue cap regulation which also lowers the potential investments. The other parameters are not changing significantly in this scenario. In the tariff benchmarking scenario, the energy efficiency standards are increased. Therefore, the heat losses are reduced, but the share of RES technologies and heat production efficiency increase. It results in lower heat production costs and heat tariff values. Finally, in the BAT tariff scenario, the energy efficiency parameters are increased directly. Therefore, the heat production costs and heat tariff is also reduced.

As can be seen from Table 3, the criteria results do not clearly show the most sustainable heat tariff regulation mechanism. Therefore, the multi-criteria analyses method is applied. The requirements which should be minimised in the preferred solution from the DH operator's perspective are primary energy consumption, energy poverty risk, CO_2 emissions, heat tariff, heat losses, heat production costs and social payments, but the rest of the criteria should be minimised.

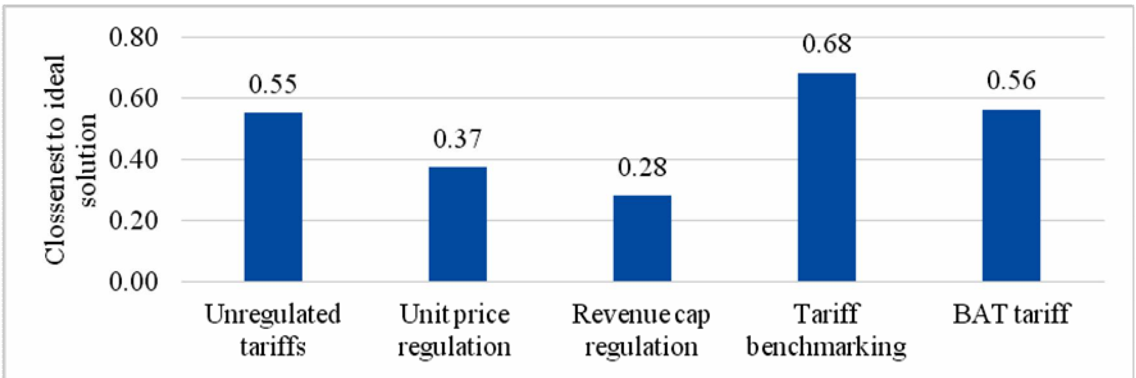


Fig. 6. Results of multi-criteria assessment

Fig. 6 shows the obtained multi-criteria assessment results, which indicate that tariff benchmarking with integrated energy efficiency standards is the most sustainable solution. It increases both the energy efficiency of the DH system and the consumer. However, the applied discounts to motivate heat consumers to improve the operation of heating substations are crucial.

Conclusions

Different heat tariff regulation mechanisms exist. For example, there are countries with strictly regulated unit price regulations where the heat tariff is unregulated, and DH operates businesslike. Therefore, the authors seek to understand which regulatory mechanisms would promote the transformation of existing DH systems toward smart energy systems with higher efficiency and integrated RES shares.

The research investigates the role of the heat tariff as a motivator toward more efficient energy systems. The smart heat tariffs should, on the one hand, promote innovative solutions in DH systems and, on the other hand, motivate heat consumers to adjust their internal heating systems. Therefore, the role of the heat tariff should be evaluated from different perspectives.

With increasing energy prices, the socioeconomic role of heat tariffs increases. The methodologies for heat cost allocation should ensure the transparency of heat tariffs to promote the services of DH systems. In addition, the heat costs should be cost-effective to reduce the energy poverty risk. The research includes the analyses of impacts obtained from social payment introduction, which sometimes do not motivate the end-users to reduce their heat consumption. Therefore, the dilemma exists between ensuring a low level of heat costs while still encouraging heat consumers to increase their energy efficiency.

The introduction of smart energy systems will require new business models due to the increasing role of digitalisation and the introduction of new value chains for services in heat supply. In addition, the participation of heat consumers is crucial for the introduction of a low-temperature heat supply system. Therefore, countries with strictly regulated heat tariff methods will need to reframe the legislation to allow the DH providers to engage with the consumers. Therefore, further investigation and in-depth modelling of payment methods should be continued under various conditions.

Multicriteria decision analysis methodology with the integrated FCM model results allows comparing and prioritising five regulation methods of heat energy tariffs. The central elements within the developed FCM model are investment costs, heat production costs, and primary energy consumption. The applied methods include several aspects that have not been considered in previous research, such as the impact of consumers' motivation to implement energy efficiency measures and the relation to heat tariffs. Therefore, the most appropriate heat tariff regulation method should promote sufficient investment levels and motivate to reduce of production costs and immediate energy consumption. This research's most effective heat tariff regulation method is the heat tariff benchmarking method with integrated energy efficiency standards for DH operators.

The developed FCM model is a simplified method for comparing different impacting factors of heat tariff. However, the identified elements could be further used in more complex models for system optimisation and applied to DH systems to investigate circumstances under different technological solutions and configurations. Further research should analyse and compare the broader economic effects of the proposed DH tariff regulation methods and interlink the heating tariff with power prices.

References

Averfalk, H., & Werner, S. (2020a). Economic benefits of fourth generation district heating. *Energy*, 193, 116727. URL: https://doi.org/10.1016/j.energy.2019.116727.

Averfalk, H., & Werner, S. (2020b). Economic benefits of fourth generation district heating. *Energy*, 193. URL: https://doi.org/10.1016/J.ENERGY.2019.116727.

Balioti, V., Tzimopoulos, C., & Evangelides, C. (2018). Multi-Criteria Decision Making Using TOPSIS Method Under Fuzzy Environment. Application in Spillway Selection. In *Proceedings* (Vol. 2, Issue 11). URL: https://doi.org/10.3390/proceedings2110637.

Barrella, R., Linares, J. I., Romero, J. C., Arenas, E., & Centeno, E. (2021). Does cash money solve energy poverty? Assessing the impact of household heating allowances in Spain. *Energy Research & Social Science*, 80, 102216. URL: https://doi.org/https://doi.org/10.1016/j.erss.2021.102216.

Boscan, L., & Söderberg, M. (2021). A theoretical and empirical analysis of district heating cost in Denmark. *Energy Economics*, 99 (April). URL: https://doi.org/10.1016/j.eneco.2021.105304.

Cabinet of Ministers. (2016). *Regulations Regarding the Energy Efficiency Requirements for Centralised Heating Supply Systems in the Possession of a Licensed or Registered Energy Supply Merchant, and the Procedures for Conformity Examination Thereof*. URL: https://likumi.lv/ta/en/en/id/281914.

Changes to the heat tariff scheme in Poland. (2020). December.

Desvallées, L. (2022). Low-carbon retrofits in social housing: Energy efficiency, multidimensional energy poverty, and domestic comfort strategies in southern Europe. *Energy Research & Social Science*, 85, 102413. URL: https://doi.org/https://doi.org/10.1016/j.erss.2021.102413.

Djørup, S., Sperling, K., Nielsen, S., Østergaard, P. A., Thellufsen, J. Z., Sorknæs, P., Lund, H., & Drysdale, D. (2020). District Heating Tariffs, Economic Optimisation and Local Strategies during Radical Technological Change, *Energies*, Vol. 13, Page 1172, 13(5), 1172. URL: https://doi.org/10.3390/EN13051172.

Egüez, A. (2021). District heating network ownership and prices: The case of an unregulated natural monopoly. *Utilities Policy*, 72(July), 101252. URL: https://doi.org/10.1016/j.jup.2021.101252.

Galindo Fernandez, M., Bacquet, A., Bensadi, S., Morisot, P., & Oger, A. (2021). Integrating renewable and waste heat and cold sources into district heating and cooling systems – Case studies analysis, replicable key success factors and potential policy implications. In *Publications Office of the European Union*. URL: https://doi.org/10.2760/111509.

Gorroño-Albizu, L., & de Godoy, J. (2021). Getting fair institutional conditions for district heating consumers: Insights from Denmark and Sweden. *Energy*, 237. URL: https://doi.org/10.1016/j.energy.2021.121–615.

Hvelplund, F., Krog, L., Nielsen, S., Terkelsen, E., & Madsen, K. B. (2019). Policy paradigms for optimal residential heat savings in a transition to 100 % renewable energy systems. *Energy Policy*, 134, 110–944. URL: https://doi.org/ 10.1016/J.ENPOL.2019.110944.

Lecomte, T., Ferrería de la Fuente, J. F., Neuwahl, F., Canova, M., Pinasseau, A., Jankov, I., Brinkmann Serge Roudier, T., & Delgado Sancho, L. (2017). *Best Available Techniques (BAT) Reference Document for Large Combustion Plants.*

Li, H., Sun, Q., Zhang, Q., & Wallin, F. (2015). A review of the pricing mechanisms for district heating systems. *Renewable and Sustainable Energy Reviews*, 42, 56–65. URL: https://doi.org/10.1016/j.rser.2014.10.003.

Lund, H., Østergaard, P. A., Chang, M., Werner, S., Svendsen, S., Sorknæs, P., Thorsen, J. E., Hvelplund, F., Mortensen, B. O. G., Mathiesen, B. V., Bojesen, C., Duic, N., Zhang, X., & Möller, B. (2018). The status of 4th generation district heating: Research and results. *Energy*, 164, 147–159. URL: https://doi.org/10.1016/J.ENERGY. 2018.08.206.

Nozari, M. A., Ghadikolaei, A. S., Govindan, K., & Akbari, V. (2021). Analysis of the sharing economy effect on sustainability in the transportation sector using fuzzy cognitive mapping. *Journal of Cleaner Production*, 311, 127–331. URL: https://doi.org/10.1016/J.JCLEPRO.2021.127331.

Özesmi, U., & Özesmi, S. L. (2004). Ecological models based on people’s knowledge: a multi-step fuzzy cognitive mapping approach. *Ecological Modelling*, 176(1), 43–64. URL: https://doi.org/https://doi.org/10.1016/ j.ecolmodel.2003.10.027.

Pakere, I., Blumberga, D., Kamenders, A., & Vıtoliņš, V. (2021). Does district heating tariff motivate energy efficiency improvement? *Energy Reports*, 7, 410–418. URL: https://doi.org/https://doi.org/10.1016/j.egyr.2021.08.087.

Pakere, I., Gravelsins, A., Lauka, D., & Blumberga, D. (2021). Will there be the waste heat and boiler house competition in Latvia? Assessment of industrial waste heat. *Smart Energy*, 3. URL: https://doi.org/10.1016/J.SEGY. 2021.100023.

Patronen, J., Kaura, E., & Torvestad, C. (2017). Nordic heating and cooling: Nordic approach to EU’s Heating and Cooling Strategy. In *TemaNord NV – 2017:532*. Nordisk Ministerråd. URL: https://doi.org/10.6027/TN2017-532.

Pelda, J., Holler, S., & Persson, U. (2021). District heating atlas – Analysis of the German district heating sector. *Energy*, 233, 121018. URL: https://doi.org/10.1016/j.energy.2021.121018.

Rezaie, B., & Rosen, M. A. (2012). District heating and cooling: Review of technology and potential enhancements. *Applied Energy*, 93, 2–10. URL: https://doi.org/10.1016/j.apenergy.2011.04.020.

Riigikogu. (2017). *District Heating Act*. URL: https://www.riigiteataja.ee/en/eli/ee/520062017016/consolide/ current.

Schmidt, D. (2021). Digitalization of district heating and cooling systems. *Energy Reports*, 7, 458–464. URL: https://doi.org/10.1016/J.EGYR.2021.08.082.

Selvakkumaran, S., Axelsson, L., & Svensson, I.-L. (2021). Drivers and barriers for prosumer integration in the Swedish district heating sector. *Energy Reports*, 7, 193–202. URL: https://doi.org/10.1016/J.EGYR.2021.08.155.

Selvakkumaran, S., Eriksson, L., Ottosson, J., Lygnerud, K., & Svensson, I.-L. (2021). How are business models capturing flexibility in the District Energy (DE) grid? *Energy Reports*, 7(September), 263–272. URL: https://doi.org/ 10.1016/j.egyr.2021.08.146.

Songa, J., Wallina, F., Lia, H., & Karlssona, B. (2016). Price models of district heating in Sweden. *Energy Procedia*, 88, 100–105. URL: https://doi.org/10.1016/j.egypro.2016.06.031.

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РОЗУМНІ ТАРИФИ НА ТЕПЛОВУ ЕНЕРГІЮ В УМОВАХ ПЕРЕХОДУ ДО ВІЛЬНОГО РИНКУ

Інноваційні механізми ціноутворення мають мотивувати постачальників і споживачів теплової енергії переходити до більш стійких енергетичних систем, впроваджувати низькотемпературні системи централізованого теплопостачання та об’єднувати сектори у розумних енергетичних системах. Для стимулювання вказаних трансформацій в енергетиці необхідно змінити систему нормативного регулювання у системах централізованого теплопостачання.

Тарифи на послуги з централізованого теплопостачання залежать від багатьох факторів, зокрема: цін на паливо, робочих параметрів, податків, інвестицій та інших критерії. Тому було здійснено аналіз тарифів на теплову енергію, щоб знайти рішення для мотивації підприємств централізованого теплопостачання до енергоефективності та кліматичної нейтральності. Результати аналізу базуються на підході до оцінки прийняття рішень шляхом вибору різних критеріїв та їх оцінювання за п'ятьма важливими аспектами: інженерним, екологічним, кліматичним, економічним та соціально-економічним. Центральними елементами розробленої моделі нечіткого когнітивного відображення є інвестиційні витрати, витрати на виробництво тепла та споживання первинної енергії. Враховуючи встановлені граничні умови, найвигіднішим методом для визначення розумного тарифу на тепло може бути порівняльний аналіз тарифів на тепло з інтегрованими стандартами енергоефективності для операторів централізованого теплопостачання.

Ключові слова: нормативне регулювання централізованого теплопостачання, розумні енергетичні системи, керування попитом, енергоефективність.