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CHALLENGES AND BARRIERS BY TRANSITION TOWARDS 4TH GENERATION DISTRICT HEATING SYSTEM: A STRATEGY TO ESTABLISH A PRICING MECHANISM

U. Osis, N. Talcis, J. Ziemele*
JSC "Rigas Siltums", Cesu Str. 3A, Riga, LV-1012, LATVIA
*e-mail: jelena.ziemele@rs.lv

Transition of the district heating (DH) system to the 4th generation system involves several challenges, which refer not only to the introduction of state-of-art technologies, but also to the development of a sustainable pricing methodology. Introduction of the 4th generation systems will soon force the DH industry to solve issues regarding the possibility of organisation of the market in the same way as it happened in the power industry (Directive 2009/72/EC) by complete separation of producers from the transmission system service providers. The present article discusses various development scenarios of a DH utility within the framework of an organised market and their pricing methodologies, as well as evaluates their sustainability considering the transition to the 4th generation system.

Keywords: *4th generation district heating, heat tariff, pricing mechanism*

1. INTRODUCTION

Gradual transition from the 3rd to the 4th generation systems is taking place in the district heating (DH) systems in Europe and elsewhere in the world where they are developed [1]. This is related to the necessity to modify the conditions of operation of the district heating systems and to shift emphasis to new technological solutions in heat sources [2], networks and at the consumers' side [3] in order to secure their competitiveness and to prevent harm to the environment. At the same time, DH utilities are following the European Union (EU) guidelines and are implementing the requirements stipulated by the EU laws and regulations developed for the purpose of contributing to prevention of the global climate change [4]. In 2008, the EU Commission set the goal to reduce the greenhouse gas (GHG) emissions by 20 % by 2020 in comparison to 1990 [5]. Considering the fact that 64 % of energy consumption in Europe is used for space heating and hot water production [6], district heating has a high potential in the decarbonisation process. In order to attain the set climate goals, the 4th generation district heating (4GDH) systems are based on renewable energy sources, heat transmission takes place by using smart thermal grid and low-temperature networks and the system as a whole is a part of the smart energy system [7]. Introduction of the 4th generation systems will soon force the DH industry to solve issues regarding the possibility of organisation of the market in the same way as it happened in the power industry (Directive 2009/72/EC) [8] by complete separation of producers from the transmission system service providers, which means free access of third parties to the system and competition among producers [9].

The goal of the DH system is to provide the necessary amount of heat to households, commercial and industrial customers by implementing modern and sustainable district heating technologies, to secure their competitiveness, security and high quality service for customers. Nowadays DH systems are integrated in many countries in Europe and North America.

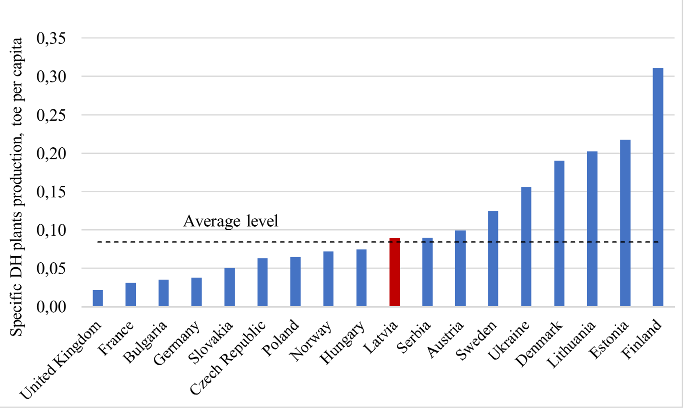

Fig. 1. Specific heat production in 2016 for different European countries [10].

The specific heat production per capita in 18 European countries is presented in Fig. 1, which clearly demonstrates the presence of the DH system in all the Baltic countries. The mean specific heat production amounts to 0.084 toe per capita and this level is exceeded by Latvia, Lithuania and Estonia and a few Scandinavian countries: Sweden, Denmark and Finland.

A modern DH system should be sustainable, competitive and secure. The above-listed criteria both compete among themselves and supplement each other. Coordinated interaction of the above-mentioned criteria secure the advantages of the DH system compared to individual and decentralised heat supply [11]. DH systems possess numerous advantages, which justly allow them to expand in the countries where they are present and develop in the countries where they have not been popular until now, for example, in the UK [12]. The price or tariff of heat, as it is referred to on a regulated market, is among the main parameters describing competitiveness of each DH system. The parameters, which affect the operation of the DH system or the heat tariff, can be grouped in several categories:

- Technological parameters: the volume of consumed heat and the consumption profile, the length of DH networks, the consumption density [13];
- Environment and climate parameters: emissions and use of natural resources, the share of renewable energy resources, use of low potential heat [14];

- Economic parameters: fuel and electricity prices [15], tax payments, specific investments in technologies [16];
- Institutional parameters: standards of building efficiency, heat and power generating plants, policy instruments for implementation of various measures [17];
- Social parameters: sufficiency of heat for households, arrangement of the city environment [18].

Improvement of efficiency at consumers, by implementing energy efficiency measures, installing heat insulation of buildings and implementing innovative projects (passive buildings or buildings as a heat storage) [19], is among the most important factors forcing a DH utility to plan its operations in advance and affecting heat costs [20].

On a regulated DH market, which exists in many post-soviet countries, the heat price is determined by the eligible costs of the DH utility. In this case, the law also defines the profit margin. This method is referred to as the cost-plus method. On a deregulated market, the marginal cost method is used and it is based on the costs of one additional energy unit. None of the pricing methods is perfect and industry experts often propose various improvements and additions thereto [21].

Irrespective of the fact that many studies have been devoted to the heat tariff, various pricing methodologies and their impact upon the DH system sustainability, competitiveness and security have been insufficiently analysed. The study is aimed at defining the tariff changes and their development trends by identifying the factors affecting tariff changes under different DH system development scenarios for transition to the 4th generation system and analysing the possibility of maintaining the competitiveness of the DH system.

2. METHODOLOGY

The methodology comprises several steps. Within the first step, for the purpose of evaluating various alternatives of the DH system development, the mathematic model of the district heating systems was developed describing the stages of heat production, transmission and consumption (Fig. 2 Section A) by means of a system of mathematic equations (1).

$$\begin{cases} Q_{con} = Q_{prod} - Q_{los} \\ Q_{con} = Gc\Delta t \\ Q_{los} = T\lambda F \Delta t_{log} = T\sum_{n=1}^{j} q_{losj} L_{i,} \\ Q_{prod} = \eta B Q_{LHV} \\ N_{ee} = Tg\rho G_s H/\eta_p \end{cases} \tag{1}$$

where Q_{con} – heat received by the consumer, MWh/year; Q_{prod} – heat produced by DH company; G – amount of heat carrier, m^3/year; c – volume specific heat capacity, MWh/m^{3}K ; Δt – temperature difference, K; λ – heat conductivity coefficient, MW/(m^{2}K); F – pipe surface, m^2; Δt_{log} – logarithmic temperature difference, K; L – thermal length, m; B – fuel consumption, kg/year; Q_{LHV} – lower calorific value of the fuel, MWh/kg; q_{losj} – linear heat losses (MW/m); L_i – length of heat network segment (m), j – total number of pipe network segments; T – hours per time period (h/year); g – gravitational acceleration (m/s^2); ρ – heat carrier density (kg/m^3); η_p – efficiency of pump (-); H – total pressure drop (m); N_{ee} – electricity consumption, Wh/year; – amount of heat carrier, m^3/s.

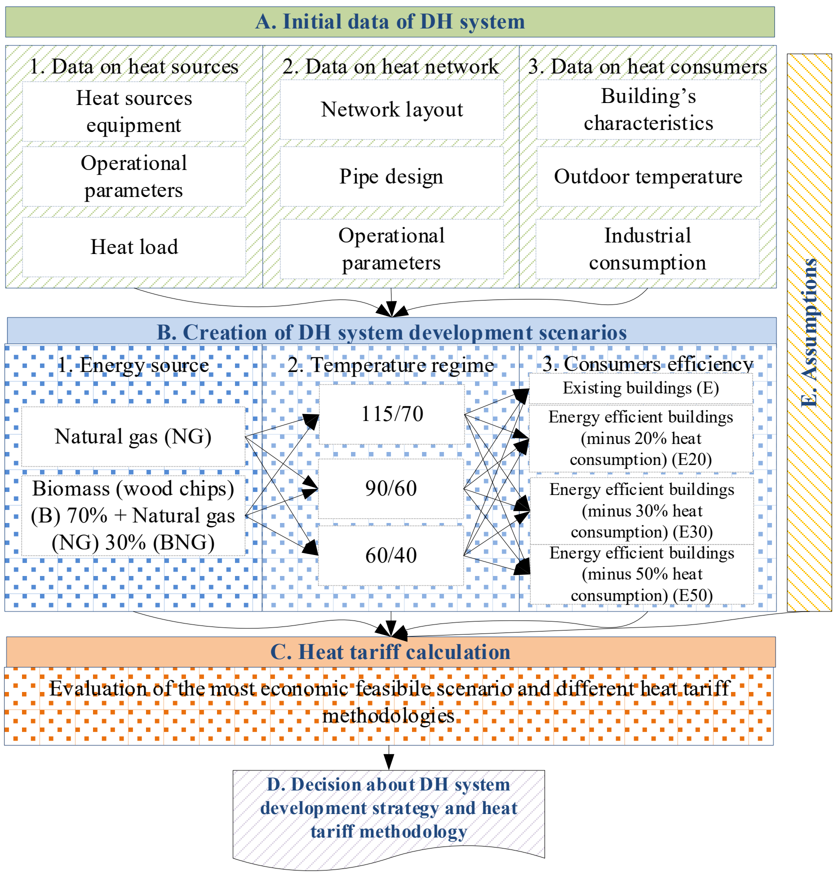

Fig. 2. Conceptual scheme of the study methodology.

In order to optimise the work and costs, each DH utility should have a task of minimising fuel consumption, heat losses and power consumption for pumping the heat carrier.

$$\begin{cases} B \to min \\ Q_{los} \to min. \\ N_{ee} \to min \end{cases} \tag{2}$$

The mathematic model developed within the first step of the methodology allows identifying these values.

Within the next step of the study, 28 estimation scenarios of the DH system were developed (Fig. 2, Section B), potentially describing the development of situations in DH utilities in the cities and villages in Latvia. It was taken into account that many DH systems were producing heat by suing natural gas at the beginning of the 21st century and then it was gradually replaced by renewable energy sources (biomass). Moreover, the process affecting development of the DH system is related to improvement of energy efficiency of buildings. Therefore, development scenarios whereby energy efficiency of buildings improves gradually by 20, 30 and 50 % were studied in the present article.

In the third step of the study, heat tariffs T consisting of one part or two parts (€/MWh) were estimated for all the scenarios in compliance with the methodology approved in the Republic of Latvia [22]. The single component tariff consists of three parts and is expressed by the following equation:

$$T = T_{prod} + T_{tr} + T_{sale}, \quad (3)$$

where: T_{prod} – production tariff, €/MWh; T_{th} – transmission tariff, €/MWh; T_{sale} – sale tariff, €/MWh.

Each of the tariff parts comprises the amounts of fixed and variable costs. For example, the production tariff is determined as follows:

$$T_{prod} = \frac{(VC_R + FC_R)}{Q_{prod}}, \quad (4)$$

where VC_R – variable costs of the production tariff, €/yr; FC_R – fixed costs of the production tariff, €/yr; Q_{prod} – produced heat, MWh/yr.

The variable costs of the production tariff consist of the sum of several components:

$$VC_R = Q_{prod}\left(\frac{C_{fuel}}{\eta} + C_{taxR} + C_{el}Q_{prod}^{el} + C_{othR}\right), \quad (5)$$

where VC_R – variable costs of the production tariff, €/yr; Q_{prod} – produced heat, MWh/yr; C_{fuel} – fuel price, €/MWh; η – efficiency rate of the technology; C_{taxR} – taxes, €/MWh; C_{el} – electricity price, €/MWh; Q_{prod}^{el} – electricity consumption for production needs, MWh_{el}/MWh_{th},; C_{othR} – other production costs, €/MWh.

The share of variable costs in the sales tariff is low; however, the fixed costs are calculated in the same way for all the tariff parts.

$$FC_i = Q_{prod}C_{M\&R} + \frac{C_{eq}N_N}{\tau_{cr}} + C_{pr} + C_s + C_{ins} + C_{othi}, \quad (6)$$

whereFC_i – fixed costs of the tariff, €/yr; *i* – selected part of the tariff (production, transmission or sale tariff); Q_{prod} – produced heat, MWh/yr; $C_{M\&R}$ – plant repair and maintenance costs, €/MWh; C_{eq} – costs of technologies, €/MW; N_N – installed capacity of the technology, MW; τ_{cr} – loan repayment period, yr; C_{pr} – loan interest repayment, €/yr; Cs – wages including social insurance contributions, €/yr; C_{ins} – insurance costs, €/yr; C_{othR} – other costs, €/yr.

In case of the tariff consisting of two parts, all the costs in each DH system stage (production, transmission and sale) are divided into two components: payment for consumed heat T_1 and fixed payment T_2. The heat transmission and distribution tariff is determined based on the following equation:

$$T_{1i} = \frac{VC_i}{Q_{con}}. \tag{7}$$

On top of that, there is a fixed fee for demanded capacity:

$$T_{2i} = \frac{FC_i}{N_N}. \tag{8}$$

The main simulation assumptions are related to the costs of fuel and electricity, as well as the price of the particular installed technology and operational costs. The estimations were made at the mean natural gas price of 21 €/MWh, the price of wood chips of 17.80 €/MWh and the electricity end price of 110 €/MWh in Latvia (Fig. 2, section E).

In the course of analysis of the transition to the 4GDH, also the possibility of integration of the quality component, which is present in several calculation methodologies in the Scandinavian countries and determine the temperature difference of the heat carrier in the supply and the return, was reviewed. Considering that on a deregulated market the heat tariffs are defined by applying the method of marginal costs, particular variable costs of different scenarios with their marginal costs were compared within the study. Marginal costs (*MC*) represent the increase of the total costs (*VC*) if the production volume changes by one unit:

$$MC = \frac{dVC}{dQ_{prod}} + \frac{dFC}{dQ_{prod}}, \tag{9}$$

where *VC* – variable cost, *FC* – fixed cost, and Q_{prod} – the quantity of production. In addition, it is necessary to take into account that fixed costs do not change short-term and then the component dFC/dQ_{prod} is equal to zero.

Within the study, the tariffs of all the scenarios were analysed considering their sustainability and the maintenance of the competitiveness of the DH system, as well as borders were defined where the system expansion would be desirable (attraction of new customers). In addition, strengths and weaknesses of various heat-pricing methodologies were assessed by testing them under different DH system development scenarios for transition to the 4GDH.

3. CASE STUDY

District heating systems in Latvia and also in the other Baltic countries have been historically well developed (Fig. 1). Natural gas was used as the basic fuel at the end of the last century and at the beginning of this century. As the costs of fossil fuel increased and Latvia also assumed obligations to reduce CO_2 emissions, the use of wood fuel gradually increased. Figure 3 presents the share of fossil and renewable fuel in the DH sector during the last five years.

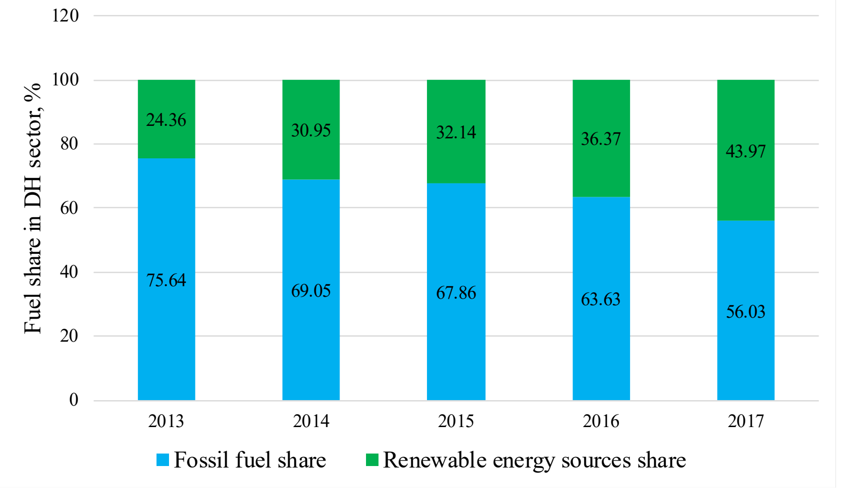

Fig. 3. Fossil and renewable fuel share in the DH sector.

It should be noted that the ratio of renewable energy sources (wood chips) into the total fuel balance has increased over the past years, especially in heat sources that are based only on the boiler technology. In 2017, they used 76.3 % of wood in comparison to cogeneration plants where the share of use of wood was lower and accounted for 37.6 % this year [23].

The goals of development and modernisation of the DH system are defined by the EU legislation, and on the national level the strategy and the means for attaining them are selected. The EU Strategy on Heating and Cooling [9] provides for direction of DH system towards the 4th generation systems based on the use of renewable energy resources, low-temperature heat supply and utilisation of highly efficient technological solutions. The business model of DH systems differs by country. In Latvia, several market participants are interested in development of the DH system: the state, municipalities, the DH utility, new project developers, households and corporate consumers. Municipalities play an important role in development and implementation of the general DH concept. Several 4GDH projects have been implemented in the EU in close cooperation with municipalities [24]. In Latvia, heat supply is provided by using different options: the municipality supplies heat to its residents by performing the functions of the DH utility; this is done by a private DH utility or both options are combined whereby the municipality, a state institution and a private utility form a joint stock company. In this case, the municipality and the state institution perform two functions, in particular – take care of secure and profitable heat supply and provide the legal regulation of the system.

The methodology developed within the present article was tested in a DH district located in Riga. Heat supply there is provided to 32 buildings with the total floor area of 53,000 m^2. Heat is produced by natural gas fired boilers with the installed capacity of 2 x 2.5 MW equipped with condensation economisers. The temperature schedule 115/70 was maintained in DH networks. The average heat consumption during the last 5 years was 8820 MWh per year (70 % is consumed by households and 30 % is consumed by industrial consumers). The total length of the DH networks in the system is approximately 3,300 m (supply). Supplied heat is consumed for space heating and hot water production.

4. RESULTS AND DISCUSSION

4.1. Transition towards 4GDH: Possibilities, Bottlenecks, and Challenges

Transition to the 4GDH system is related to the necessity to provide heat supply to buildings with high efficiency by transiting to a low-temperature schedule in DH networks allowing for reduction of heat losses in the networks and integration of low potential heat sources [1]. The transition involves not only technological innovations, but also the necessity to perform institutional and organisational structural changes in the DH sector in order to provide suitable cost and motivation structure. The heat tariff is among the most important indices describing the efficiency of the DH system.

Fig. 4 (in Section 1) summarises the factors that affect the technological solutions of the DH system and therefore influence the total costs. It is a historically accepted practice that the DH system should be based on a high security back-up. As a result, higher capacity generating plants are installed, the temperature regime in the networks is higher than needed and this contributes to the increase of heat production costs (Figure 4, Section 1, Maintenance & repair costs, Depreciation costs, and DH system efficiency).

Transition to the 4GDH system makes one assess the system reserve in order to reduce heat losses and investment costs. When new buildings are constructed, projects comprise modern solutions of heating elements (floor or wall heating). Heat substations should be equipped with appropriate low-temperature schedule heat exchange surfaces (Fig. 4, Section 1 – Consumers).

Fuel costs are among the most important parameters, which have substantial impact upon the heat costs. As it was emphasised before, the 4GDH is based on diversification of used fuel and transition to domestic renewable energy resources (Fig. 4, Section 2 – Production). Use of renewable energy resources contributes to a positive impact upon:

- development possibilities on the regional and local scale;
- employment opportunities;
- energy independence and secure energy supply;
- use of modernised energy technologies;
- reduction of GHG emissions.

	Production	Networks	Consumers
1.Factors that influence price of DH production	Fuel price Electricity price Depreciation (technologies cost) Labour costs Taxes (property, emissions) Maintenance & repair costs Insurance costs	Heat losses (fuel price) Electricity price Depreciation (technologies costs) Labour costs Taxes Maintenance & repair costs Insurance costs	Energy performance of buildings Behaviour of the residents Heat consumption Presence of a heat substation (heat exchanger) on the consumers side Depreciation (technologies costs) Labour costs; Taxes Maintenance & repair costs Insurance costs
2. 3GDH towards 4GDH	Fuel diversification (waste, solar, wind, hydro, geothermal, and other) Heat storage Emissions reduction District cooling Efficiency improvment measures Utilisation of surplus heat	Low temperature DH New technologies Smart grid Efficiency improvement measures	Low energy buildings (synergy with low temperature DH) Increase implementation of the smart measuring systems Prosumers Demand response
3. Challenges	Implementation of new technologies in the market Coupling of the new technologies implementation with appropriate taxes	Integration of the new technologies	Decreased consumption Involvement of the consumers to stimulate efficiency measures To mantain temperature difference at the same level as in 3GDH or increase it
	Investment payback time Competitiveness of DH Conservative attitude to the new technologies Lack of a regulatory support Flexibility		

Fig. 4. Transition towards 4GDH: possibilities, bottlenecks, and challenges.

Many studies focus on the introduction of the low-temperature schedule in DH networks [25], [26], where various positive aspects of their implementation are evaluated [27]:

- Higher efficiency in distribution networks since heat losses are lower;
- The possibility of using plastic pipes in distribution networks with low operation pressure;
- The reduced supply temperatures also reduce the risk of water boiling in the network, i.e., resulting in a lower risk of two-phase flow in pumps.

In the International Energy Agency report, transition processes to a low temperature in the DH are divided into two stages [28]. At the first stage, the temperature potential in the current DH system is reduced by using the current system potential and compensating the efficiency measures at the consumer's side. Consequently, if consumers replace windows, the energy consumption is reduced. Within the second stage, by making capital investment, longer thermal lengths should be used in substation heat exchangers or some devices of heat substations should be replaced (regulators, heat exchangers). All measures for reduction the current temperature levels used in DH systems need to be developed by a coherent modernisation process and must be coordinated by DH company.

Consumers who produce part of heat or electricity and who are referred to as prosumers also play their role within the 4GDH (Fig. 4, Section 2, Consumers). Small-scale production of heat is generally less efficient in comparison to the

DH system [19]. New challenges to consumers are caused by the demand side management when consumers modify their consumption profile by transferring consumption from peak hours to another time, thus the consumers' heat demand can be satisfied by a lower installed capacity and savings of capital investments can be obtained [29]. Integration of renewable energy resources is related to the necessity to develop heat storage because energy generation and consumption profiles do not coincide on the time scale, which generally improves the system flexibility.

The lack of know-how and experience of introduction of new technologies consisting of hybrid systems when several technologies are used at the same time (CHP, HP, solar systems and other) creates a barrier for their implementation in Latvia (Fig. 4, Section 3, Production, Networks).

Development of new technologies requires considerable investment and often, within a regulated market, the available resources are limited in DH utilities. Therefore, it would be desirable that the state and the municipal taxation policy is favourable for innovation.

Maintenance of competitiveness of the DH system is an important factor from the point of view of economy and environment. The economic profitability of the DH system presents an opportunity to attain lower costs and to provide lower tariffs to consumers [30]. There are several factors serving as reasons for the above: the possibility to produce heat and generate electricity at the same time [31]; to use modern technologies and the most profitable fuel at all DH stages [32]; to integrate surplus heat [33]; to use the advantages presented by economies of scale.

4.2. Heat Tariff Development Methodology

As several authors have pointed out, the heat pricing methodologies are obsolete and do not correspond to the actual market situation [34]. Irrespective of that DH utilities operate under the same conditions within a single national regulated market, often there are considerable differences of tariffs. Therefore, researchers and industry experts propose different methods of defining heat tariffs. For example, there is a proposal to introduce benchmarking in order to restrict the possibility for DH utilities to increase their costs [35], or to use the incremental cost method, which considers not only the marginal costs of the existing system, but also its replacement costs (the incremental cost method) [36].

4.2.1. Development of Low-Temperature Network. The Cost of Heat Energy Distribution

Transition of the current DH system to a low-temperature schedule depends on several factors that describe this system, in particular, the network length, the heat load density, the possibility of consumers to switch to a low-temperature schedule.

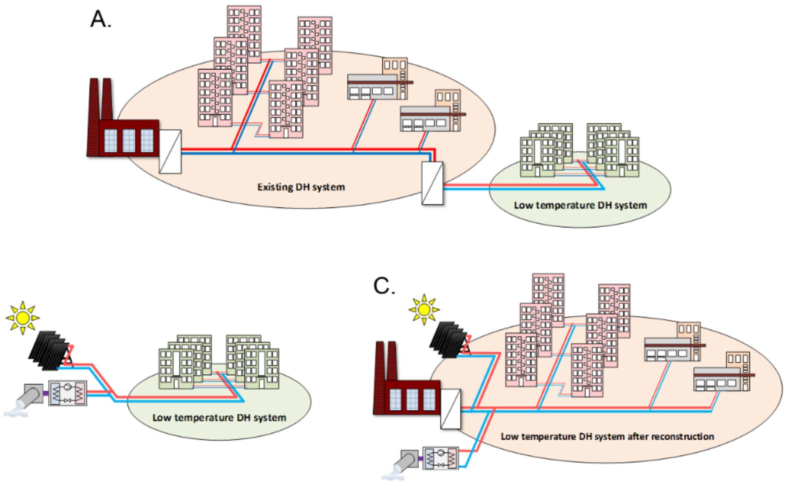

Fig. 5. Options of connection of a low-temperature DH district.

Thanks to the advantages of the low-temperature heat supply system, several EU DHs have got involved in the introduction of low-temperature heat supply. Transition to low-temperature heat supply can be done both within an existing heat supply system and by constructing a new system. The following three scenarios are possible for implementing low-temperature heat supply:

- Connection of low-temperature districts to an existing system through sectioning it by using a heat exchanger and creating two hydraulic circuits (Fig. 5, Version A). In this case, new consumers or reconstructed houses may be connected.
- Another option is to create low-temperature DH systems by constructing new districts when the heating systems of buildings are originally designed as low-temperature systems with floor heating or low-temperature heating elements (Fig. 5, Version B).
- Coherent modernisation of the current system and transition to a low-temperature system (Fig. 5, Version C).

The technical performance of the connection point to the existing DH networks can be different [37], for example, mixing of return water with supply water, increase of the return water temperature potential by means of economizers, condensers, heat pumps and other solutions.

The present article focuses on the study of the DH system, which is modernised in a coherent manner (Version C) and at the same time, by transition to the low temperature, the efficiency in buildings is improved and 70 % of natural gas is replaced by wood fuel.

Operational parameters of different development scenarios of DH systems are presented in Table 1.

Losses of the transmission system for scenarios where natural gas is used as fuel are presented in Fig. 6, which shows that transition to lower temperature schedules reduces losses in the networks allowing for reduction of operational expenditure.

Table 1

Heat Distribution Parameters for Different Development Scenarios

Scenarios	Produced heat, MWh/yr	Consumed heat, MWh/yr	Heat losses, MWh/yr	Electricity consumption, MWh/yr	Heat load, MW
E-115/70-NG E-115/70-BNG	8828	7977	851	103	3.99
E20-115/70-NG E20-115/70-BNG	7233	6381	851	88	3.19
E30-115/70-NG E30-115/70-BNG	6435	5584	851	80	2.79
E50-115/70-NG E50-115/70-BNG	4840	3988	851	65	1.99
E-90/60-NG E-90/60-BNG	8700	7977	723	107	3.99
E20-90/60-NG E20-90/60-BNG	7105	6381	723	90	3.19
E30-90/60-NG; E30-90/60-BNG	6307	5584	723	83	2.79
E50-90/60-NG E50-90/60-BNG	4712	3988	723	68	1.99
E-60/40-NG E-60/40-BNG	8540	7977	563	115	3.99
E20-60/40-NG E20-60/40-BNG	6945	6381	563	98	3.19
E30-60/40-NG E30-60/40-BNG	6147	5584	563	90	2.79
E50-60/40-NG E50-60/40-BNG	4552	3988	563	73	1.99

For example, expenditure for transmission (heat losses and electricity consumption of pumping of the heat carrier) will be reduced by 22 % by transition from the temperature schedule 115/70 to 60/40 in existing buildings.

However, it is necessary to take into account that transition to lower temperature schedules is compatible with improvement of building efficiency at the consumer's side. Reduction of heat consumption by 20 % and transition to the temperature schedule 60/40 (E20-60/40-NG) allows reducing transmission expenses only by 2 % (A compared to B). As the heat reduction at the consumer's side increases, transmission costs get relatively higher compared to the initial situation (A compared to C, D, E)). Furthermore, in all the cases transmission costs are relatively lower at the temperature schedule 60/40.

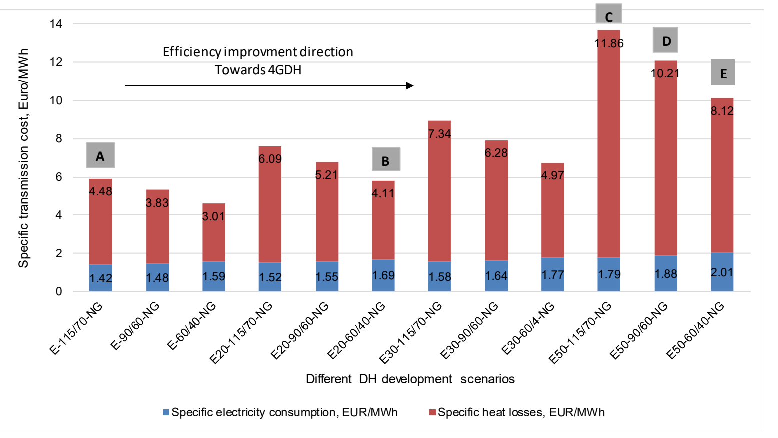

Fig. 6. Specific distribution costs for different scenarios (the natural gas price 21 €/MWh; the electricity price 110 €/MWh), where 115/70, 90/60 and 60/40 – the temperature regime in the DH network, NG – natural gas, E – existing building, E20, E30, E50 – buildings with improved efficiency to a specific level.

4.2.2. One- and Two-Part Tariff Evaluation for the Developed Scenarios

By using the equations defined in the Methodology Section (from (3) to (6)), the one-part tariff was estimated for 28 created scenarios described in Section 3.

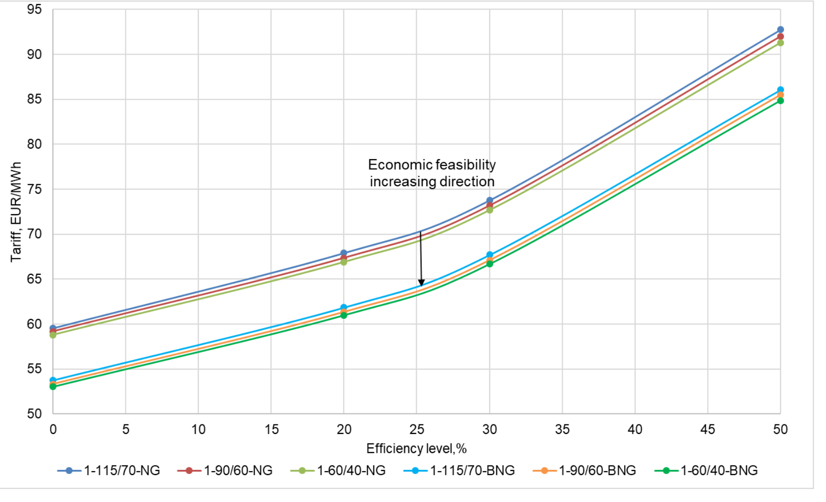

Fig. 7. The one-part tariff development for all the scenarios reviewed by the study (115/70, 90/60 and 60/40 – the temperature regime in the DH network, NG – natural gas, 1 – one-part heat tariff).

As the consumption decreases by more than 20 %, it is necessary to take into account that the heat tariff will increase sharply (Fig. 7). If it was 59.53 €/MWh under the initial scenario, as the heat consumption decreased by 50 %, the tariff would increase to 92.75 €/MWh, which would be 55.8 % above the initial tariff. Transition to the renewable energy resource (biomass) allows the DH utility to partially compensate an increase in the tariff, and by a decrease in consumption to 50 % and transition to a lower temperature schedule (60/40) the heat tariff will be 84.86 €/MWh, which will be 42.6 % above the initial tariff. Lower losses in the network and lower transmission costs contribute to an additional decrease of 13.2% in the total tariff. Each heat supply utility is interested in installation of innovative technologies allowing for reduction of costs. In case when the DH utility uses boilers for heat production, the fuel price has the largest impact upon the tariff. Thus, if a competitive fuel is selected, there is a possibility to partially compensate for an increase in the tariff.

Sven Werner [4] emphasises that municipal DH utilities traditionally prefer the cost-oriented methodology for setting tariffs and obtaining the profit guaranteed by the law. Upon transition to the 4GDH system, the pricing methodology should be changed to ensure that it encourages not only introduction of innovations in DH utilities, but also technological modifications at the consumer's side. As heat consumption in the current DH system decreases, the specific fixed costs of the utility will increase (FC/Q_{con}, €/MWh). Therefore, the DH company is interested in changing to a two-part tariff. Considering the fact that improvement of energy efficiency at the consumer's side is taking place in Latvia, though at a slow pace, several heat supply utilities are considering this opportunity. This possibility is envisaged by the current heat pricing methodology [22]. Payments for consumed heat T_1 and the fixed payment or the fee for installed capacity T_2 were estimated for all the 28 scenarios by applying equations (7) and (8) (Fig. 8).

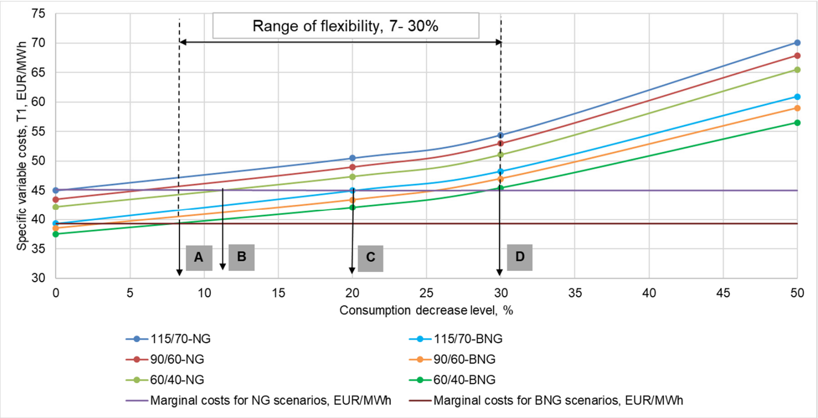

Fig. 8. Variable heat price by a two-part heat tariff.

In addition, the marginal costs per additional unit were calculated (9) (short-term marginal costs) for the DH system with the initial parameters (E-115/70-NG and E-115/70-BNG). The DH system is operated by natural gas in the initial situation and a high potential temperature schedule is maintained in the networks (115/70), the heat consumption reduction (improvement of energy efficiency at the customer's side) by 12 % will mean that even by transition to the lowest temperature schedule the utility will not be able to maintain the tariff at the preceding level (Fig. 8, point B). The DH systems where the aggregate fuel costs and variable costs are lower will be more sensitive to reduction of the heat consumption (Fig. 8, point A). Relatively more freedom in terms of reduction of heat consumption is provided to DH utilities by the possibility of transition not only to the cheapest fuel (the consumption decrease of up to 20 % may not change the heat rate, see Fig. 8, point C), but also to a lower potential heat carrier (the consumption decrease of up to 30 % may not change the heat tariff, see Fig. 8, point D). Implementation of both conditions (low-temperature heat networks and renewable energy sources) corresponds to the definition of the 4th generation system and it is a sustainable solution.

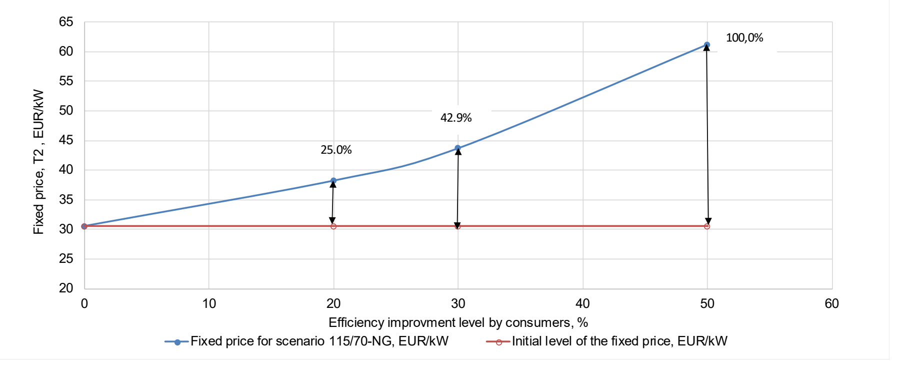

Fig. 9. Fixed price component for 115/70-NG scenario by changing the efficiency level at the consumer's side.

The second element of a two-part tariff is a fixed fee (it is also referred to as the capacity fee), which provides for maintenance of the installed generating capacity in the operational order for the DH utility. The fixed fee is the fee for capacity needed for ensuring heating of a property. Consequently, these are fixed payments to be paid by consumers irrespective of whether heat is or is not consumed. In order to make this fee comprehensible to customers, it is usually recalculated from EUR per installed capacity in kW or MW to EUR per square metre of heated floor area. In this way, the index clearly defines fixed fees payable by households. As the efficiency at the consumer's side increases by more than 20 %, the fixed fee increases rapidly according to a non-linear pattern (Fig. 9). Zvingilaite & Jacobsen [38] in their study concluded that improvement of efficiency at the consumer's side by 18.3 to 23.8 % is economically justified. The heat supply utility should find ways for compensating reduction of consumption. The DH system expansion is usually among the development scenarios implemented most often. However, transition to the 4th generation system forces DH utilities to look for other potential innovative solutions that comply with the circular economy principles and are sustainable accordingly. For example, JSC "Fortum" integrated production of biooil in the CHP plant operation in Joensuu (JSC Fortum, Joensuu CHP plant).

4.2.3. Introduction of the Consumption Quality Component in the Heat Pricing Methodology

Costs of heat production depend on numerous parameters. The volume of consumed heat is determined by using the system of equations presented in the methodology section (10) where the consumption of heat carrier *G* [m3/h] may be reduced by increasing the temperature difference between supply and return upon the condition that remains unchanged:

$$Q_{con} = G \downarrow c\Delta t \uparrow. \tag{10}$$

Thus, in order for the DH to be operated as efficiently as possible, it is important that there is a large temperature difference between the DH water that the property receives and the one sent back. The temperature difference is called cooling. DH companies in the deregulated market introduce the cooling requirement (for example, Δt=30 °C). If the cooling in the property is up to 5 °C higher or lower than the cooling requirement, no extra payment or bonus is charged. If the cooling over the year averages over 36 °C, a bonus is paid out.

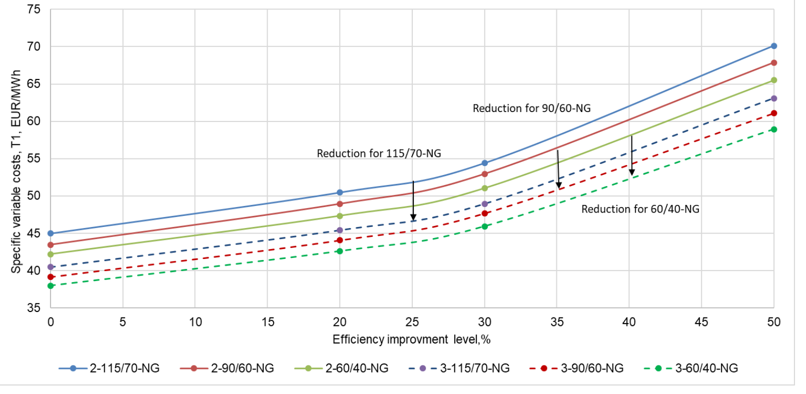

Fig. 10. Reduction in energy price T1 by qualitative heat carrier cooling at the consumer's side (115/70, 90/60 and 60/40 – the temperature regime in the DH network, NG – natural gas, 2 – a two-part heat tariff, 3 – a two-part heat tariff with additional quality component).

For instance, Fig.10 presents an adjusted energy component for the scenarios with a two-part tariff where natural gas is used as fuel. The adjustment level on the deregulated market is set by each DH utility independently according to the principle of economic profitability because generally reduction of the return temperature allows increasing the heat and electricity production efficiency. Efficiency of the 10MW condensation economiser is illustrated in Fig. 11.

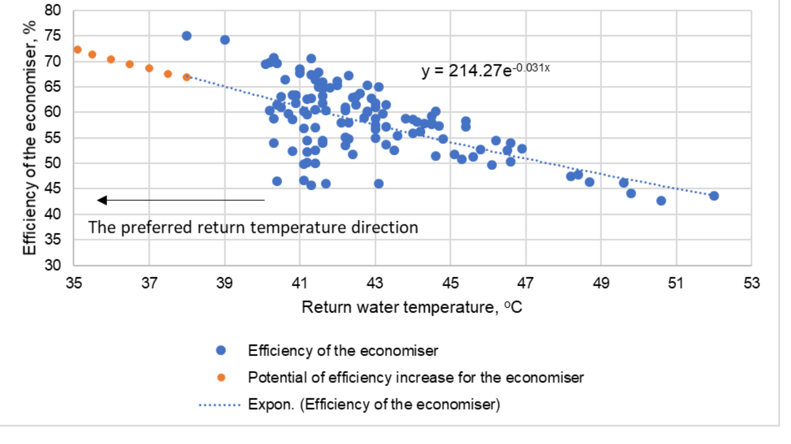

Fig. 11. Modelling of efficiency of the condensing unit versus network return temperature.

Modelling of efficiency of the condensation economiser (orange dots) clearly shows that the productivity of the economiser increases as the return temperature decreases. However, reduction of the return temperature may be provided only by the consumer by means of intensifying the heat exchange processes or by increasing the heat exchange surfaces through installing heat exchangers and heating elements. Reduction of the return temperature, which will also allow increasing the temperature difference, also secures other advantages related to the overall efficiency of the DH systems (Fig. 12).

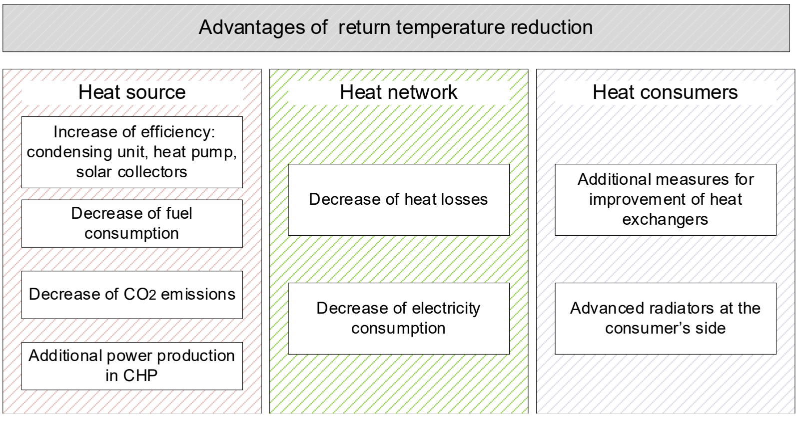

Fig. 12. Advantages of the reduction of return temperature in the DH network.

Efficiency is improving not only in condensing economisers, but also the operation of solar collectors and heat pumps is getting more efficient, the CHP productivity increases. The total DH system efficiency improvement allows reducing expenses and offering the lowest heat tariff, which is emphasised by A. Dalla Rosa et. al in their study [39]. Considering the fact that high-level professionals, who carefully follow up innovations in the heat supply area and perform energy efficiency measures, manage the DH utility, this generally allows reducing energy production costs and providing more optimum heat tariffs to customers.

5. CONCLUSIONS

Transition to the 4GDH systems causes new challenges for DH utilities regarding implementation of innovative technologies characterised by low-temperature heat sources, low-temperature transmission networks and low consumption buildings within a common smart energy system. Heat pricing is an essential issue to be taken into account by trying to achieve sustainable development of DH systems setting new tasks for all the parties involved in the DH system (DH utilities, consumers, property developers, policy makers and other stakeholders). The study reveals that the current procedure when consumers pay to DH utilities on a regulated market based on the one-part tariff has to be changed because transition to the 4th generation systems is related to the improvement of energy efficiency at the customer's side, reduction in the temperature schedule and implementation of an open network (provision of the third party access).

The study has demonstrated that DH utilities have to follow up carefully changes in heat consumption. Transition to a lower temperature schedule and use of cheaper fuel allows implementing energy efficiency measures within the framework of 20–30 % without changing the tariff.

The study has confirmed that implementation of the two-part tariff will allow DH utilities to compensate fixed costs incurred by maintaining the heat generating plant in the good operational condition. Consumers, however, will need to assess the demanded capacity carefully. In order to encourage consumers to improve efficiency of heat exchangers and heating elements by implementing modernisation measures, it is necessary to introduce the energy quality component (temperature difference between supply and return temperature). The energy quality component will allow reducing payments for the consumers who have improved their heat supply systems, and consumers who have low efficiency systems will have to pay more.

The methodology proposed in the present article allows evaluating the tariff changes and their development trends within the transition from the current DH system to the 4GDH system by maintaining its competitiveness. The optimum solution for the DH system development in order to follow the direction towards the 4GDH system prescribes that the best design should reduce the utility costs and, more importantly, provide an optimum heat price for end customers. Therefore, A DH company policy should base on the three pillars of sustainability - economic feasibility, high-level environmental performance and social responsibility strategy.

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IZAICINĀJUMI UN BARJERAS PĀREJAI UZ 4. PAAUDZES CENTRALIZĒTĀS SILTUMAAPGĀDES SISTĒMU. CENU MEHĀNISMA VEIDOŠANAS STRATĒĢIJA

U. Osis, N. Talcis, J. Ziemele

K o p s a v i l k u m s

Centralizētās siltumapgādes pāreja uz 4.paaudzes sistēmu saistīta ar vairākiem izaicinājumiem, kas paredz ne tikai inovatīvo tehnoloģiju ieviešanu, bet saistīti arī ar ilgtspējīga tarifa aprēķina metodoloģijas izstrādāšanu. 4.paaudzes sistēmu ieviešana jau tuvākajā laikā liks siltumapgādes nozarei rast atbildes par iespēju organizēt siltumapgādi līdzīgi kā tas notika elektroenerģijas nozarē (Directive 2009/72/EC), pilnīgi nodalot ražotājus no pārvades sistēmas pakalpojumu sniedzējiem. Rakstā pētīti dažādi siltumapgādes uzņēmuma attīstības scenāriji regulētā pakalpojuma ietvaros un to tarifu noteikšanas metodikas, ka arī vērtēta to ilgtspējība, ņemot vērā pāreju uz 4.paaudzes sistēmām.

17.07.2019.