

District Heating Systems Performance Analyses. Heat Energy Tariff

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Abstract – The paper addresses an important element of the European energy sector: the evaluation of district heating (DH) system operations from the standpoint of increasing energy efficiency and increasing the use of renewable energy resources. This has been done by developing a new methodology for the evaluation of the heat tariff. The paper presents an algorithm of this methodology, which includes not only a data base and calculation equation systems, but also an integrated multi-criteria analysis module using MADM/MCDM (Multi-Attribute Decision Making / Multi-Criteria Decision Making) based on TOPSIS (Technique for Order Performance by Similarity to Ideal Solution). The results of the multi-criteria analysis are used to set the tariff benchmarks. The evaluation methodology has been tested for Latvian heat tariffs, and the obtained results show that only half of heating companies reach a benchmark value equal to 0.5 for the efficiency closeness to the ideal solution indicator. This means that the proposed evaluation methodology would not only allow companies to determine how they perform with regard to the proposed benchmark, but also to identify their need to restructure so that they may reach the level of a low-carbon business.

Keywords – District heating, benchmarking, energy efficiency, TOPSIS, multi-criteria analysis, energy policy.

I. INTRODUCTION

A. Current challenges and goals for European district heating companies

Climate change is an urgent global problem that is linked to human actions related to energy resources. The use of low-carbon technologies is particularly important in the energy sector. District heating (DH) systems make up a large part of the energy consumption in the energy sector of European Union (EU) Member States. These systems are developed because they have a number of advantages over decentralized heat supplies. In DH systems it is possible to balance the use of renewable energy resources by replacing fossil fuels. DH systems can operate at higher energy efficiency, and the large chimneys disperse harmful emissions into the upper layers of the atmosphere. We can thereby assert that the combined amount of emissions from large energy sources is smaller and does less harm to people's health [1]. In addition, when burning fossil fuels, district heating systems are not environmentally friendly and contribute to the greenhouse effect because larger amounts of carbon dioxide (CO₂) and other greenhouse gasses are released into the atmosphere.

Growth in urban populations in all of the EU Member States increases the importance and role of DH systems. Firstly, this growth is related to the sovereignty of each EU state [2] because until now DH companies have predominantly

used fossil fuels, stocks of which in several EU nations simply do not exist or are limited. Secondly, the role of DH companies in the reduction of greenhouse gasses is growing [3].

In the energy sector, it is possible to reduce the climate change effect in different ways: by replacing fossil fuels with renewable energy resources by use of low carbon technologies [4], and by increasing energy efficiency for example decreasing the heat losses in heat network [5, 6] or using waste heat from processes in industry [7]. Therefore, the main challenge and goal of DH companies today is the effective use of energy resources and the transition to renewable resources.

Improving energy efficiency is one of the priorities of the EU countries; it contributes to a more competitive economy. To ensure the efficient use of the Energy Directive (2012/27/ES) [8], Member States are required to carry out an analysis of DH potential use effectiveness. State regulatory institutions that regulate the DH company heat tariff pay attention to technological, economic and financial indicators in the production, transmission and realisation of heat energy. All of these components together make up the final tariff by which thermal energy is sold to the public. Usually, the government accepts the methodology by which tariffs are determined and the regulatory institution analyzes the tenders submitted by the heat supply companies with the projected calculated tariffs. The difference variation in tariffs among different DH companies gives reason to study their components and discuss the need to implement energy efficiency measures on-site in energy generation plants [9] as well as the need to replace expensive fossil fuels with relatively cheaper wood fuel [10, 11]. New solutions are to be found to promote the use of renewable sources [12], which can be achieved by creating new DH companies [13] or through the integration of new technological solutions in the existing companies.

A methodology that allows for the full evaluation of technological and economic heat tariff parameters is needed to stimulate heat supply companies to make changes in their operations.

B. Actual situation of DH in Latvia. Factors influencing heat tariffs in Latvia

The Baltic States are located in a climatic zone in which the heating of houses is required approximately 200 calendar days per year. In cities and municipalities this is ensured with the help of a DH system. Heating availability and residents' capacity to pay the bills is a major issue in the Baltic States (namely, Latvia) and other countries with similar climatic conditions [14, 15]. For example, a heating bill in Latvia today

is on average 14 % to 17 % of a household's total income. This figure exceeds even the most pessimistic forecast of 9.1 %

reflected in a study by the European Bank for Reconstruction and Development [14].

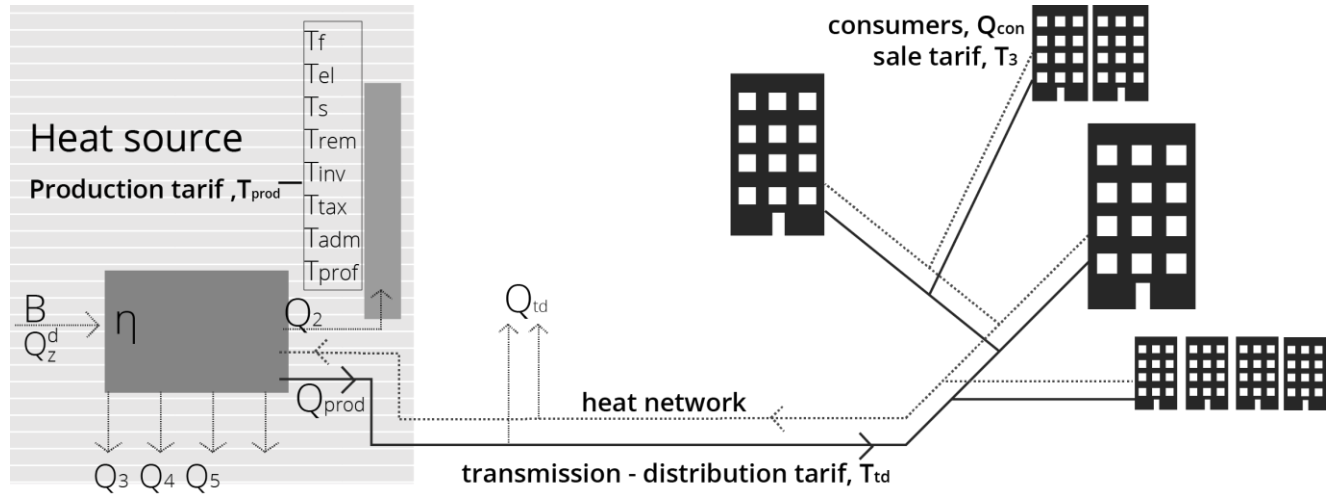


Fig. 1. District heating system structure.

TABLE I
NOMENCLATURE

T	heat tariff, EUR/MWh	Q_{prod}	heat produced by DH company, MWh/year
T_{prod}	production cost, EUR/MWh	Q_{th}	Heat losses in pipes, MWh/year
T_{td}	transmission-distribution tariff, EUR/MWh	Q_{con}	heat received by the consumer, MWh/year
T_3	sale tariff, EUR/MWh	Q_z^d	lower calorific value of the fuel, MWh/kg; MWh/m ³
T_f	Fuel part of cost in the tariff, EUR/MWh	Q_2 or q_2	losses in flue gas, MWh/kg; MWh/m ³ or %
T_{el}	electricity part of cost in the tariff, EUR/MWh	Q_3 or q_3	chemically incomplete combustion losses, MWh/kg; MWh/m ³ or %
T_s	wage part of cost in the tariff, EUR/MWh	Q_4 or q_4	mechanical incomplete; MWh/kg; MWh/m ³ or %
T_{rem}	manufacturing and auxiliary equipment repair part of cost in the tariff, EUR/MWh	Q_5 or q_5	losses in the environment; MWh/kg; MWh/m ³ or %
T_{inv}	investment pay part in the tariff, EUR/MWh	B	fuel consumption, kg/year; m ³ /year
T_{tax}	tax component in the tariff, EUR/MWh	η	efficiency coefficient
T_{adm}	administrative part of expenditure in the tariff, EUR/MWh	L	thermal length, m
T_{prof}	part of corporate profits in the tariff, EUR/MWh	q_{th}	specific heat losses in pipes, W/m
C_f	fuel price, EUR/kg	G	amount of heat carrier, m ³ /year
t_{el}	electricity price, EUR/MWh	c	volume specific heat capacity, MWh/m ³ K
E	electricity consumption, MWh/year	Δt	temperature difference, K
M_s	wage expenditure, EUR/year	λ	heat conductivity coefficient, W/(m ² K)
M_{rem}	repair costs, EUR/year	F	pipe surface, m ²
M_{inv}	investment pay, EUR/year	Δt_{log}	logarithmic temperature difference, K
M_{tax}	tax payment, EUR/year	M_{prof}	company's profit, EUR/year
M_{adm}	administration maintenance costs, EUR/year	N_N	power requirement during heating season, MW
N_{uz}	installed capacity of the company, MW	VC_F	fuel cost, EUR/year
IE_Q	proceeds from the sale, EUR/year		

A DH system is composed of three elements: a heat source, a heating network and the consumer (Fig. 1). Consumer heat tariffs T consist of three components: production T_{prod} , transmission-distribution T_{td} and sales T_3 rates [16]. Of these,

the largest role belongs to the production component. The transmission and distribution tariff component is the second in size, with the realization component being the smallest. The

most essential costs included in T_{prod} are fuel cost, investment return conditions, loan interest and corporate profits [9,17].

Each town in Latvia has a different heating system. The main differences are the heat source (boiler or cogeneration heat and power (CHP)), the installed capacity and energy resources. Each of the above factors plays its part in creating the overall production tariffs. Most of the Latvian DH companies have a monopoly in their city or town and therefore there is no increase in production efficiency at the expense of competition. The only option for achieving positive change is the introduction of manufacturing process efficiency indicators as a part of a state regulation mechanism.

The classic energy efficiency indicator of heat production technologies is the efficiency coefficient (η), which is determined by the direct or indirect method. Its size directly affects production costs. In many Latvian heat sources, where reconstruction projects have recently been implemented, such an indicator has received considerable attention. In a number of heat sources, condensing economizers [18] and a cooling flue gas condensation unit [19] been installed in order to increase efficiency.

Distribution costs are determined by the heat loss in DH pipes [20], which depend on pipe diameters, insulation quality and thickness. A decisive role is played by heating consumer density and location in the area.

Energy efficiency is a very important element in tariff reduction [9,17, 21]. Promoting energy efficiency in all three stages of heat supply (heat source, heating networks and consumer) should lead to lower tariffs.

C. Case Study

The existing methodology for determining heat energy does not guide DH companies towards the reduction of greenhouse gasses. Therefore, the authors have evaluated heat tariffs with the goal of helping to reduce global climate change. The authors thus put forward the following goals:

- find technological and economic indicators that describe the efficiency of a DH system's operations and contribute to a reduction of greenhouse gasses;
- use the indicators to create a model that can help to analyze a DH system's operations;
- use the selected indicators and expert opinions to create a multi-criteria model of analysis for the energy efficiency of heating companies, which will allow a rating of the company to be determined;
- develop a methodology for the evaluation of DH company tariffs that include the created multi-criteria analysis model and supplement it with the setting of benchmarks.

This paper summarizes the operating data of the 26 largest DH companies (installed capacity of 14 MW to 560 MW) for three years (2010–2012). These 26 companies supply the heat

for the largest Latvian cities (except the capital city Riga); hence, the authors consider that these companies accurately describe the situation of DH systems in Latvia and Baltic countries.

II. METHODOLOGY OF HEAT ENERGY TARIFF ANALYSES

A. Heat tariff evaluation methodology

Considering that heat tariff determination requires the pooling of a number of indicative values, an algorithm was created based on both the heat source operating indicators and the tariff calculation methodology (Fig. 2). The modelling algorithm combines 15 modules.

To start up tariff evaluation, it is necessary to define the output data. Module 1 collects initial data on tariffs implemented within a specified time period (the last three or five years). In Module 2 data about the amount of fuel consumption and heat produced during this period is inserted. Module 3 indicates the installed capacity of DH plants. In this calculation model a number of assumptions have to be made, which are summarized in Module 4. The assumption module includes technological parameters such as equipment efficiency coefficients and energy resource parameters (net calorific value). Before starting the statistical processing of data, it is necessary to define the independent variables (equipment and production process characteristics); this definition is carried out in Module 5. Using all the initial data (Modules 1, 2, 3) and defined assumptions, together with the independent variables (Modules 4 and 5), indicators are calculated in Module 6.

Table 2 shows the indicators that have been used within this study to analyse the efficiency of DH operations.

TABLE II
ENERGY EFFICIENCY INDICATORS OF A DH SYSTEM

Parameters	Symbol	Unit
Efficiency coefficient	η	–
Capacity utilization factor	A_N	–
Fuel component in tariff	A_F	–
Heat losses in pipes	Q_{th}	MWh/year or %

The greenhouse gas emissions indicator E (t CO₂ per year) was not included as an independent indicator in order to avoid a repetition of the dependent variable. The greenhouse gas emissions indicator is dependent on the fuel consumed, the efficiency of the production and transmission of heat energy and the type of fuel used. All of these components have already been included as independent indicators.

To calculate the specific indicators for a specific DH company, a system of equations was established by which the initial data output is determined in Module 6:

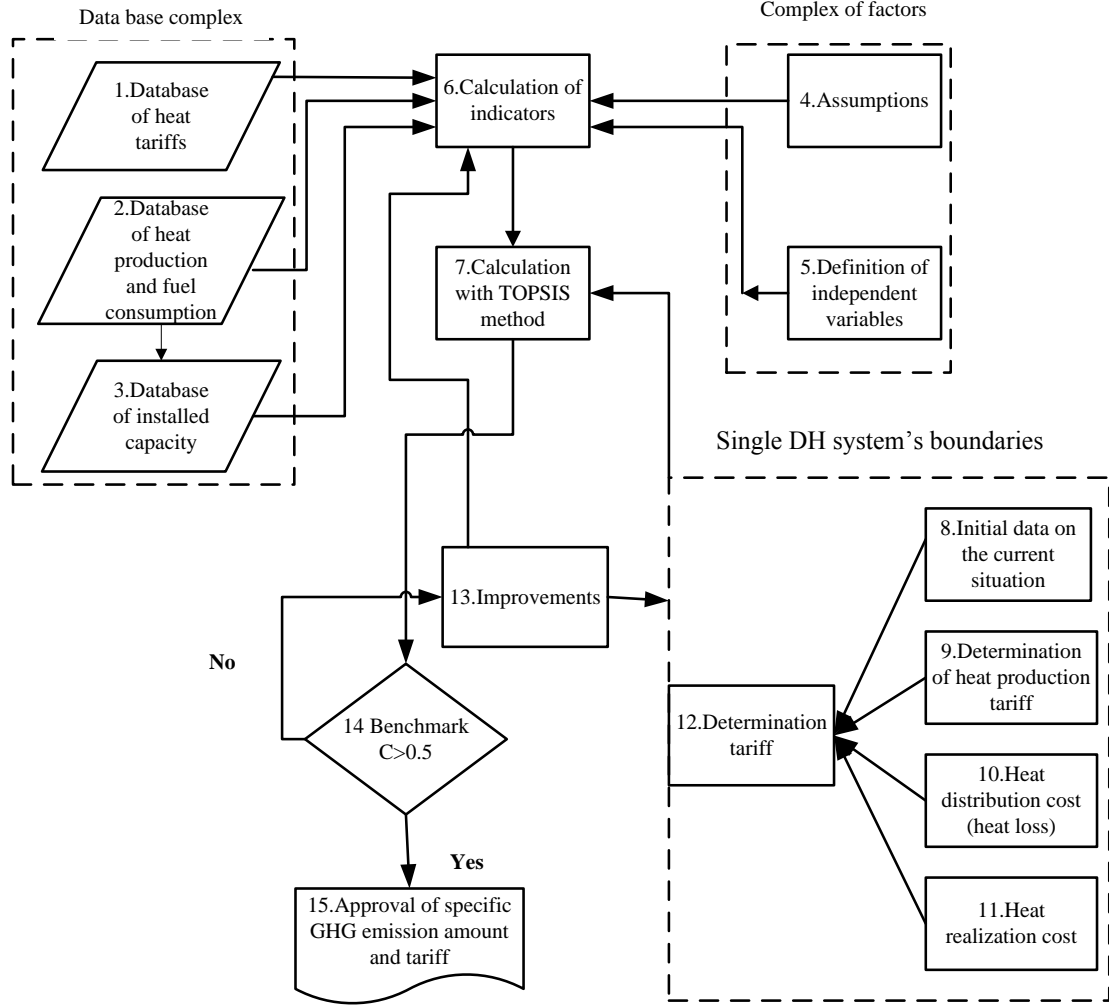


Fig. 2. Tariff evaluation algorithm.

$$\left\{ \begin{array}{l}
 Q_{con} = Q_{prod} - Q_{td} \\
 Q_{con} = Gc\Delta c \\
 Q_{td} = \lambda F \Delta t_{log} = q_{td} L \\
 Q_{prod} = \eta B Q_z^d \\
 \eta = 100 - q_2 - q_3 - q_4 - q_5 \\
 q_2 = Q_2 / Q_z^d \\
 q_3 = Q_3 / Q_z^d \\
 q_4 = Q_4 / Q_z^d \\
 q_5 = Q_5 / Q_z^d
 \end{array} \right. \quad (1)$$

The equation system includes the determination of production parameters for DH companies. When the production parameters have been determined, it is possible to calculate the selected indicators.

The capacity utilization factor is used for cross-referencing of the heating company's operation:

$$A_N = N_N / N_{uz} \quad (2)$$

Another DH energy parameter is the fuel part in the tariff A_F , which includes heat production costs:

$$A_F = VC_F / IE_Q \quad (3)$$

The next most important parameter is the amount of produced heat energy. The costs of production M_{prod} (EUR/year) according to equation (4) are divided into two parts: fixed costs FC_{prod} (EUR/year) and variable costs VC_{prod} (EUR/year).

$$M_{prod} = FC_{prod} + VC_{prod} \quad (4)$$

According to the concept of “economies of scale”, the greater the production of Q_{prod} , the lower per unit costs T_{prod} (5).

$$T_{prod} = (FC_{prod} + VC_{prod}) / Q_{prod} \quad (5)$$

The installed capacity N_{uz} affects FC_{prod} when entering in as part of the payment for investments. VC_{prod} also affects N_{uz} as a properly chosen N_{uz} reduces fuel and electricity consumption per unit of produced heat and the costs associated with it. This, of course, is reflected in the tariff [22].

The statistical analysis method was used in this work in order to analyze heat source operating parameters [23, 24]. Its aim is to obtain graphical or analytical relationships between

variables. Data statistical processing is carried out using STATGRAPHICS Centurion software. The dependent variable is the tariff, while the independent variables are the capacity utilization factor, the fuel component of the tariff and the production of heat release.

Selected and calculated indicators are included as criteria in the determination of efficiency levels of DH companies in the multi-criteria analysis (Module 7).

Within a single heat supply system's boundaries, with the help of the methodology, the tariff is determined by the system of equations (6).

$$\left\{ \begin{array}{l} T_{prod} = T_f + T_{el} + T_s + T_{rem} + T_{inv} + T_{tax} + T_{adm} + T_{prof} \\ T_{td} = Q_{td} T_{prod} / Q_{prod} \\ T_f = C_f B / Q_{prod} \\ T_{el} = t_{el} E / Q_{prod} \\ T_s = M_s / Q_{prod} \\ T_{rem} = M_{rem} / Q_{prod} \\ T_{inv} = M_{inv} / Q_{prod} \\ T_{tax} = M_{tax} / Q_{prod} \\ T_{adm} = M_{adm} / Q_{prod} \\ T_{prof} = M_{prof} / Q_{prod} \end{array} \right. \quad (6)$$

Within a single heating system's limits, the tariff is calculated (Module 12) based on the components. To start the calculations it is necessary to clarify the situation (Module 8). Module 8 verifies all payments made by the current object: investments, bank loans and other payments. These, together with other production costs (salaries, expenses for repairs, electricity, taxes, etc.), make up the total cost of production and approved amount of specific GHG emission (tonne CO₂ per MWh) (Module 9). Transportation of the produced heat energy to the consumer costs money; these expanses are summarized in Module 10. Another part of the tariff is the realization expenses: thermal unit maintenance, billing, invoicings and other expenses; these are calculated in Module 11. The calculated tariff from Module 12 is included as one of the criteria in the multi-criteria analysis (Module 7).

B. Efficiency rating of DH companies using multi-criteria analysis

In conducting an analysis of the energy efficiency ratings for heating companies, it is necessary to compare the technological indicators, financial indicators and expert opinions relating to the three stages in heat supply: the heat source, heating networks and the consumer. In order to perform this task, a multi-attribute or multi-criteria decision making (MADM/MCDM) method based on TOPSIS – are used [25, 26]. With the help of TOPSIS, all of the companies are ranked according to how close they are to the ideal company. TOPSIS is based on the distance of the analyzed object from the best and the worst variant as well as its position in relation to other objects being analyzed.

The analysis process begins with the selection of seven criteria (X_n) according to which the companies are compared

(Table 3). Four of these criteria are: the fuel component in the tariff A_F , the heat energy tariff T , the capacity utilization coefficient A_N and heat source efficiency η . The remaining three criteria are expert opinions regarding the development of heating companies: whether a reconstruction of the heat source has taken place within the last five years, whether the heating networks have been reconstructed in the last five years and what technological solution is being used to produce heat energy. When analyzing the technological solutions, four aspects were taken into account: whether it was a boiler house or a CHP, and whether fossil or renewable fuel was used, which in turn affects greenhouse gas emissions.

TABLE III
OVERVIEW OF EVALUATION CRITERIA

Criteria	Criteria symbol	Criteria type
Fuel part in tariff, A_F	X_1	Indicator
Heat tariff October 2013, EUR/MWh	X_2	Indicator
Heat source efficiency, η	X_3	Indicator
Capacity utilization factor, A_N	X_4	Indicator
Reconstruction in boiler house in the last 5 years	X_5	Expert opinions
Reconstruction in heating network in the last 5 years	X_6	Expert opinions
Heat production technological solutions	X_7	Expert opinions

There are several methods to determine expert opinions. The authors have used the Analytic Hierarchy Process (AHP) as offered by Saaty [27] (Table 4).

TABLE IV
THE SAATY RATING SCALE

Intensity of importance	Definition
1	Equal importance
3	Somewhat more important
5	Much more important
7	Very much more important
9	Absolutely more important
2, 4, 6, 8	Intermediate values

A calculations matrix is created using the raw data of the above mentioned seven criteria is shown with raw data [28]:

$$A_i \begin{bmatrix} X_1 & X_2 & X_3 & X_4 & X_5 & X_6 & X_7 \\ x_{11} & x_{12} & x_{13} & x_{14} & x_{15} & x_{16} & x_{17} \\ x_{21} & x_{22} & x_{23} & x_{24} & x_{25} & x_{26} & x_{27} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ x_{111} & x_{112} & x_{113} & x_{114} & x_{115} & x_{116} & x_{117} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ x_{261} & x_{262} & x_{263} & x_{264} & x_{265} & x_{266} & x_{267} \end{bmatrix} \quad (7)$$

where A_i are the analyzed objects, $i = 1, \dots, 26$; X_j is the qualitative or quantitative analysis criterion, $j = 1, \dots, 7$; x_{ij}^k indicates the evaluation of the object A_i for the decision maker k . One matrix is created when analyzing the efficiency of heating companies. We have used Weitendorf's linear normalization method because the calculated values are dependent on the

size of the interval $|\max x_{ij}^k; \min x_{ij}^k|$. Other methods cannot be applied as the used values are out of defined range [29].

In selecting weight values, the authors used the following criteria priorities to emphasize importance of energy efficiency and heat tariff determined:

$$X_2 > X_3 > X_1 = X_4 = X_5 = X_6 = X_7 \quad (8)$$

The Expected Value method [30] was used to determine the criteria weights. Subsequent calculation steps are shown in Figure 3.

The largest – C_i^* values correspond to the most efficient heat energy producers. The obtained results are then ranked, and the most efficient producer is ranked number 1; the least efficient producer is ranked last.

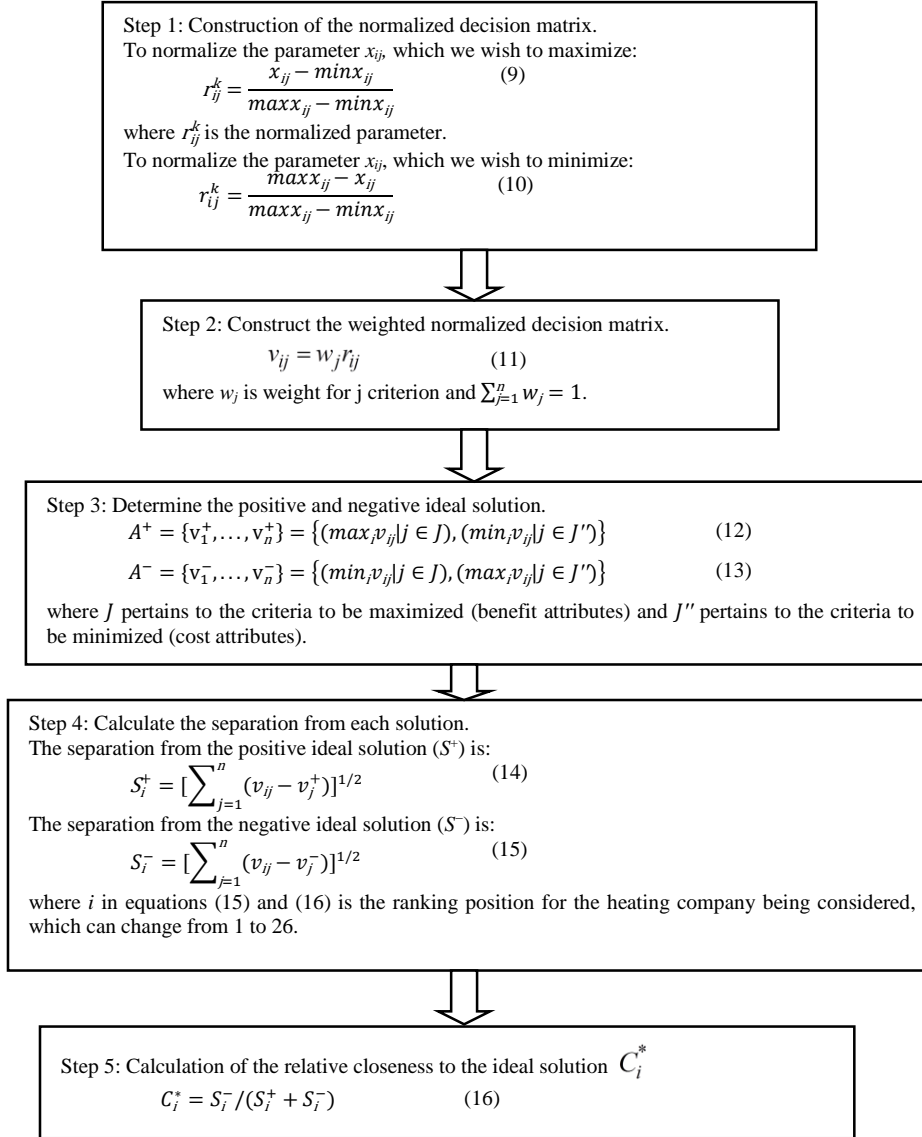


Fig. 3 Stepwise procedure for performing TOPSIS methodology [31].

C. Use of the benchmarking method in the heat tariff evaluation method

The benchmarking method is a mathematical method used for data analysis based on data comparison. A variety of data characterizing the company's operation and coefficients, obtained by calculations, are used to form DH benchmarks [32, 33]. Benchmark introduction stimulates the company's energy efficiency by achieving an understanding of the particular company's current situation and its position compared to other companies. The company can assess this

situation and set new goals for energy efficiency and incorporate them into its operational plan. Benchmarks are based on threshold values. For example, the benchmark for heat loss in networks corresponds to the maximal possible losses [20]. This means that if losses exceed the benchmark value, the owner of the heating network needs to address energy efficiency issues.

In Module 14, each company's established rating is compared with the benchmark 0.5. If the established rating is below 0.5, the company's operations require improvements

(Module 13). But if the rating is above 0.5, the company is sufficiently energy efficient and environmentally friendly. The tariff for such a company can be approved (Module 15). If the company does not reach the established benchmark, the tariff and indicator calculation is repeated and improvements in the company's operations are made (Module 16). If the company cannot reach the established benchmarks, a transition period is defined and, after that period, procurement for the heat production and supply in the district is officially announced. A new heating company is selected in a competition.

III. RESULTS

In accordance with this paper's goals and developed methodology, the authors performed studies to determine which indicators are needed to characterize a DH company's energy efficiency and how they can be included in the tariff evaluation methodology. The DH company efficiency level was also important.

A. Results of the analysis of the heat tariff

Prior to the analysis, the authors specified several energy efficiency indicators, from which they then selected those that best characterized a DH company's level of efficiency. The proposed methodology was tested using performance data of the Latvian DH companies. Regression equations were created with the selected indicators that then allow to determine the tariff based on these indicators. The relevant factors affecting the formation of the tariff were identified during the statistical data processing: the capacity utilization factor A_N ; the fuel component of the tariff A_F ; the heat losses in the pipes, %; the equipment efficiency η ; the production of heat release Q_{prod} .

The dependent variable is the tariff, while the independent variables are the capacity utilization factor, the fuel component of the tariff and the production of heat release.

The capacity utilization factor expresses the relationship between real demand and the heat that can potentially be produced. Under Latvian conditions, this ratio is in the range of 0.326 to 0.983 (Fig. 4). A low capacity utilisation

coefficient (0.326) means that the DH company has an installed system capacity that exceeds the necessary one by three times. The installed systems need to be maintained according to technological requirements, which in turn demand additional financial resources. This fact is negatively reflected on the tariff, which comprises 66.21 EUR/MWh and is one of the highest. The study shows that there is no correlation between the heat tariff and the capacity utilisation coefficient. The capacity utilisation factor of Latvian DH companies is shown in Figure 4.

If the capacity utilization factor is close to 1.0, then it means that the installed capacity is used better and decreases the production costs per amount of energy produced. So there is no need to maintain excess, unused capacity. Just seven of the 26 large heating companies have a capacity utilization factor of more than 0.8, and another three have a factor of over 0.6. A low capacity utilization factor means higher tariffs. The capacity utilisation coefficient A_N was included as one of the energy efficiency criteria in the multi-criteria analysis (Table 2).

Another important indicator that reflects the heat source operation is the amount of energy produced. Normally, as heat production increases, the fixed costs FC_{prod} and the units of energy produced decrease (5). This means that an increase in heat production should decrease the tariff. But, unfortunately, this regularity (scale economies) does not work under Latvian conditions.

The third of the influencing factors is the fuel component of the tariff (Fig. 5). Only wood fuel and natural gas is used as fuel in the Latvian DH system. The type of fuel used for the production of heat determines a company's expenses. If wood is used as a fuel to produce heat, the cost is around 20 EUR/MWh (Fig. 5). Wood is 1.9 times cheaper than natural gas. But, if a company uses wood, its expenses for systems and maintenance are higher, and these together with the cost of the fuel make up the tariff. Figure 5 shows the dependence of the heat tariff on the fuel share in it. The data were grouped according to the type of fuel: wood or natural gas. A regression equation was created and its statistical evaluation was made for each group.

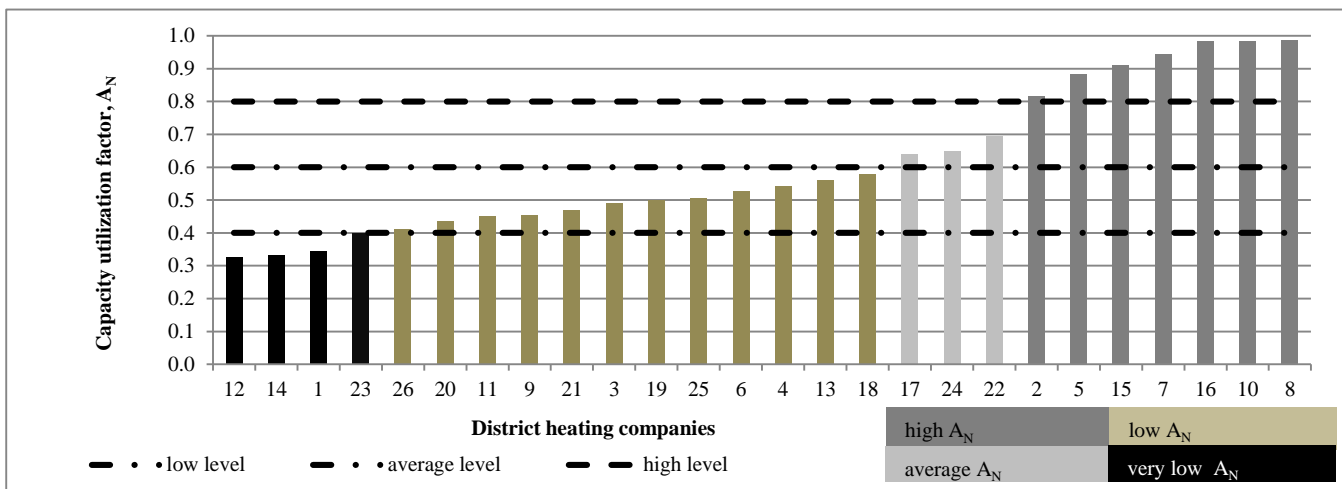


Fig. 4. The capacity utilization factor of large Latvian DH companies.

The regression equation for natural gas fuels boiler houses is:

$$T = 105.80 - 72.85 A_F \quad (17)$$

The value of the correlation coefficient shows a close correlation between the heat tariff and the fuel component in the tariff. The created model explains 96.2 % of the analyzed cases.

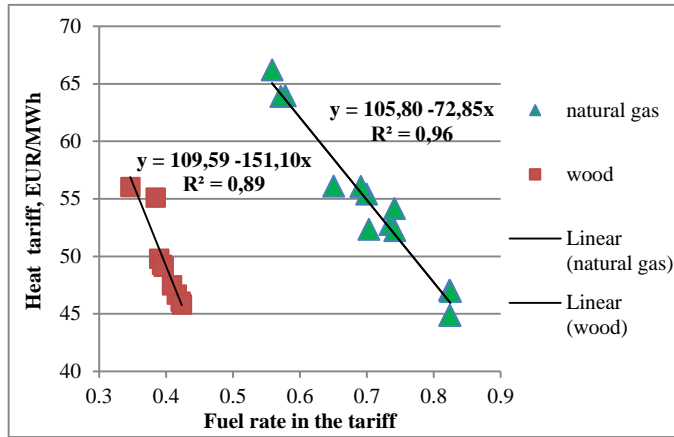


Fig. 5. Heat tariff depending on fuel rate in tariff.

Only a factors regression equation is obtained for wood fuel boiler houses:

$$T = 109.59 - 151.10 A_F \quad (18)$$

The results of the statistical evaluation are summarized in Table 5.

TABLE V
RESULTS OF THE STATISTICAL EVALUATION

Parameters	Value	<i>t</i> criterion	<i>P</i> value
Constant b_0 (17)	105.80	35.37	0.0000
Constant b_1 (17)	-72.85	-17.43	0.0000
Constant b_0 (18)	109.59	13.70	0.0000
Constant b_1 (18)	-151.10	-7.52	0.0001
Constant b_0 (19)	109.26	42.15	0.0000
Constant b_1 (19)	-76.32	-22.17	0.0000
Constant b_2 (19)	-0.0000075	-2.99	0.0123

The created model explains 88.98 % of the analyzed cases.

Our results show (Fig. 5) that the fuel part of the tariff is average 0.4 in wood fuel DH companies, but in natural gas fuel DH companies it is average 0.7. The other trend, clearly seen in Fig. 5 is that the tariff is lower in wood fuel boiler houses. This is logical, because cheaper fuels lead to lower tariffs. This makes it possible to set up innovative technologies and to invest in energy efficiency measures, which results in consumer confidence. Wood-fuelled equipment has become cheaper due to the development of technological solutions. Using local fuel makes consumers feel safer, and less money is spent on buying expensive fossil fuels. Local fuels also support the use of domestic labour and support the national economy.

The study has created a multifactor regression equation for natural gas fuel boiler houses, The set tariff is the dependent variable; the independent variables are the capacity utilization factor (A_N), the fuel part of the tariff (A_F) and the production of

heat release (Q_{prod}). With the gradual selection method (forward selection) in STATGRAPHICS Centurion, the multifactor equation is obtained:

$$T = 109.26 - 76.32 A_F - 0.0000075 Q_{\text{prod}} \quad (19)$$

The regression equation coefficients and their statistical evaluation are given in Table 4. The P-value of the selected significance level is 0.05, corresponding to the confidence probability 0.95. R^2 value obtained by the calculations is 97.905 %. But the P-value of the independent variable (capacity utilization factor) significance level is 0.3219, and it is greater than the selected 0.05. This means that the capacity utilization factor cannot be used to create the corresponding 95 % confidence level multifactor regression equation. It is removed from the equation with the gradual selection method.

The study shows that not all DH company energy efficiency indicators can be used to create regression equations. But these technological and economic indicators definitely provide an indication for a company's level of efficiency. Therefore, the selected indicators were included as criteria in the multi-criteria analysis.

B. Analyses using TOPSIS of the energy efficiency of DH companies

By using the TOPSIS method, a matrix for the determination of energy efficiency has been developed. Table 5 shows the weighted criteria determined by the Expected Value method.

The greatest weight (0.37) was given to the tariff because, according to the authors, in the end this is what determines the efficiency of a DH company's operations. Heat source efficiency (η), which creates the efficiency of a DH company's operations, was given a weight of 0.23. The weights of the other criteria are all equal.

After the compilation of the raw matrix, it is then normalized according to equations (9) and (10). As a result, the normalized and weighted matrix is obtained (Appendix 1), for which the ideal positive S_i^{k+} and ideal negative S_i^{k-} solutions according to equations (14) and (15) are determined.

Further, equation (16) is used to obtain the indicator C_i^* relatively nearest to the ideal solution. In Fig. 6 all of the heating companies are ranked according to their C_i^* value. The largest - C_i^* value corresponds to the most efficient producer of heat energy.

The heating company efficiency indicator determined by the TOPSIS method can fall between 0 and 1. The determined mean efficiency value is 0.557, and half of the companies fall above this mean level, while the other half fall below this level. Four efficiency zones have been developed in Fig. 6. Six heating companies are located in the highest zone (above 0.7). The performed analysis indicates that these companies have modernized their systems in recent years and have managed to preserve their relatively low heat energy tariff. In studying these companies in more detail, it has been established that they use wood fuel, which allows them to lower their production costs.

TABLE VI

MATRIX FOR THE DETERMINATION OF THE ENERGY EFFICIENCY OF HEATING COMPANIES

Criteria	X_1	X_2	X_3	X_4	X_5	X_6	X_7
Criteria weight	0.08	0.37	0.23	0.08	0.08	0.08	0.08
Optimal values	max	min	max	max	max	max	max
DH company							
1	8	62.52	0.92	0.35	1	6	4
2	9	45.92	0.90	0.82	8	4	2
3	9	48.59	0.85	0.49	8	6	9
4	9	53.09	0.85	0.54	6	4	5
5	9	51.48	0.87	0.88	3	7	4
6	9	57.09	0.85	0.53	5	5	2
7	2	55.89	0.94	0.94	6	7	2
8	8	49.80	0.89	0.99	9	7	9
9	9	60.46	0.89	0.45	3	3	4
10	8	50.68	0.82	0.98	5	6	7
11	1	69.02	0.92	0.45	3	5	2
12	1	63.57	0.90	0.33	8	6	7
13	1	62.28	0.89	0.56	7	4	4
14	1	51.48	0.92	0.88	3	7	4
15	9	57.19	0.92	0.91	4	3	4
16	9	61.51	0.92	0.98	3	5	4
17	7	57.75	0.85	0.64	3	6	2
18	6	56.02	0.66	0.58	5	2	2
19	8	56.63	0.76	0.50	2	3	7
20	8	59.79	0.94	0.44	2	3	4
21	7	66.89	0.73	0.47	8	7	8
22	7	55.35	0.92	0.69	7	7	8
23	9	61.13	0.87	0.40	8	6	8
24	5	59.93	0.87	0.65	3	4	7
25	4	62.62	0.87	0.50	7	4	8
26	8	63.20	0.86	0.41	6	5	2

Another nine heating companies fall within the next efficiency zone. Their energy efficiency is above the mean. This means that these companies have performed partial modernization and the directors of the heat sources are working at improving their energy efficiency.

The largest number (10) of heating companies falls between the 0.5 and 0.3 efficiency levels and two of those companies are under the 0.4 level. The directors of these two companies, as well as those of the lowest ranking company (whose efficiency level of 0.3 is critical), will need to focus on solving the issue of efficiency in the nearest future. The companies with the lowest values should study and learn from those six companies with the highest values.

IV. CONCLUSION

A methodology for the evaluation of the DH company heat tariff has been developed that will allow DH companies to evaluate their abilities and move towards low-carbon systems. The tariff evaluation methodology includes data base and calculation equation systems as well as an integrated multi-criteria analysis module using MADM/MCDM (Multi-Attribute Decision Making / Multi-Criteria Decision Making) and its tool, TOPSIS (Technique for Order Performance by Similarity to Ideal Solution). The results of the multi-criteria analysis are used to set tariff benchmarks. This means that the evaluation methodology allows us to signal DH companies that are below the benchmark value regarding the need to restructure so that they may reach the level of a low-carbon business.

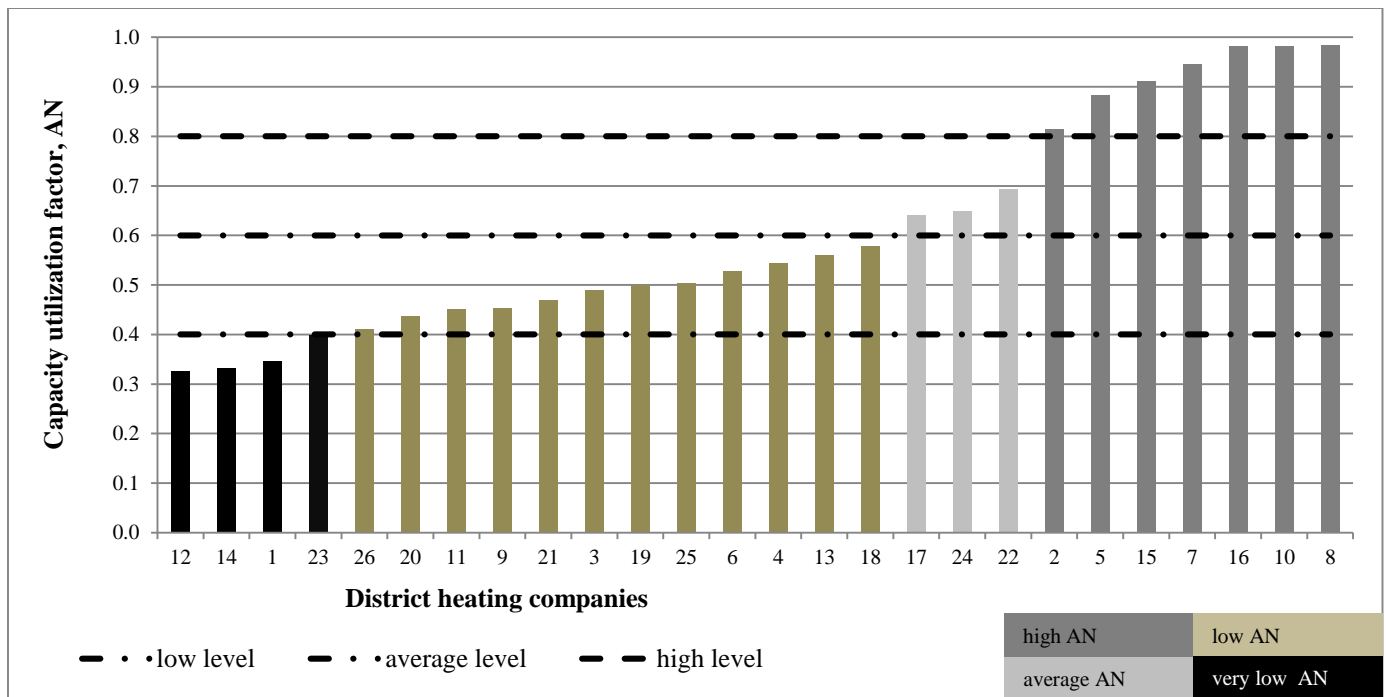


Fig. 6. DH company efficiency relative to their closeness to the ideal.

Heat tariff evaluation methodology is particularly important when DH companies implement innovative technologies, replace fossil fuel with renewable energy sources, introduce energy efficiency measures on the consumers' side and introduce smart systems. Each of the above mentioned measures can potentially create changes in the heat tariff. The proposed heat tariff evaluation methodology allows benchmark values to be set for the heat tariff, which guarantees the sustainable development of the DH system.

The main indicator is efficiency closeness to the ideal. This depends on the following criteria: fuel part in tariff, heat tariff, heat source efficiency, capacity utilization factor, reconstruction in the boiler house in the last five years, reconstruction in the heating network in the last five years and heat production technological solutions/ The benchmark value for the efficiency closeness to the ideal solution is set at equal to 0.5.

The methodology was approbated for Latvian heat supply systems. The evaluation methodology was tested for Latvia's heat tariffs, and the obtained results show that only half of the heat supply companies achieve a benchmark value of 0,5 for the efficiency closeness to the ideal solution indicator. The performed energy efficiency analysis shows that, on the whole, half of Latvia's heat supply companies have begun to address the issue of increasing their energy efficiency, but the remaining companies must adopt best practice experience from heat supply companies in Latvia and the European Union. In the long term, the implementation of the model proposed in this paper will allow DH companies to achieve energy efficient operations and, as a result, decrease emissions of greenhouse gases.

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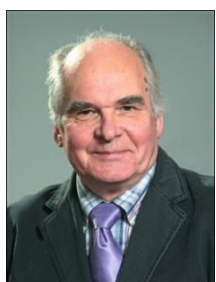
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APPENDIX
NORMALIZED AND WEIGHTED VALUES MATRIX WITH SEPARATION MEASURE FOR EACH COMPANY

DH company	Normalized and weighted values							S_i^{k+}	S_i^{k-}	C_i^*	Rank
Criteria	X_1	X_2	X_3	X_4	X_5	X_6	X_7				
1	0.070	0.104	0.214	0.002	0.000	0.064	0.023	0.295	0.257	0.466	19
2	0.080	0.370	0.196	0.060	0.070	0.032	0.000	0.102	0.438	0.812	2
3	0.080	0.328	0.155	0.020	0.070	0.064	0.080	0.105	0.392	0.788	3
4	0.080	0.255	0.155	0.026	0.050	0.032	0.034	0.163	0.318	0.661	8
5	0.080	0.281	0.171	0.068	0.020	0.080	0.023	0.135	0.356	0.725	5
6	0.080	0.191	0.155	0.025	0.040	0.048	0.000	0.223	0.268	0.546	11
7	0.010	0.211	0.226	0.076	0.050	0.080	0.000	0.195	0.332	0.631	9
8	0.070	0.308	0.189	0.080	0.080	0.080	0.080	0.074	0.402	0.844	1
9	0.080	0.137	0.186	0.016	0.020	0.016	0.023	0.267	0.248	0.481	17
10	0.070	0.294	0.131	0.080	0.040	0.064	0.057	0.133	0.352	0.726	4
11	0.000	0.000	0.210	0.015	0.020	0.048	0.000	0.399	0.217	0.352	25
12	0.000	0.087	0.197	0.000	0.070	0.064	0.057	0.308	0.243	0.441	21
13	0.000	0.108	0.192	0.029	0.060	0.032	0.023	0.292	0.234	0.445	20
14	0.000	0.281	0.214	0.068	0.020	0.080	0.023	0.147	0.370	0.715	6
15	0.080	0.190	0.214	0.071	0.030	0.016	0.023	0.207	0.309	0.598	10
16	0.080	0.120	0.214	0.080	0.020	0.048	0.023	0.266	0.277	0.510	14
17	0.060	0.181	0.155	0.038	0.020	0.064	0.000	0.232	0.258	0.526	12
18	0.050	0.208	0.000	0.031	0.040	0.000	0.000	0.310	0.220	0.416	23
19	0.070	0.199	0.077	0.021	0.010	0.016	0.057	0.256	0.233	0.477	18
20	0.070	0.148	0.228	0.013	0.010	0.016	0.023	0.258	0.282	0.523	13
21	0.060	0.034	0.053	0.017	0.070	0.080	0.069	0.385	0.155	0.287	26
22	0.060	0.219	0.214	0.045	0.060	0.080	0.069	0.159	0.338	0.680	7
23	0.080	0.127	0.172	0.009	0.070	0.064	0.069	0.261	0.257	0.496	17
24	0.040	0.146	0.172	0.039	0.020	0.032	0.057	0.252	0.242	0.491	16
25	0.030	0.103	0.172	0.022	0.060	0.032	0.069	0.289	0.226	0.438	22
26	0.070	0.093	0.164	0.010	0.050	0.048	0.000	0.307	0.213	0.410	24