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RIGA TECHNICAL
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Uģis Sarma

METHOD OF DISTRICT HEATING TARIFF BENCHMARKS

Summary of the Doctoral Thesis

RTU Press
Riga 2024

RIGA TECHNICAL UNIVERSITY
Faculty of Natural Sciences and Technology
Institute of Energy Systems and Environment

Uģis Sarma
Doctoral Student of the Study Programme "Environmental Engineering"

METHOD OF DISTRICT HEATING TARIFF BENCHMARKS

Summary of the Doctoral Thesis

Scientific supervisor
Professor Dr. sc. ing.
GATIS BAŽBAUERS

RTU Press
Riga 2024

Sarma, U. Method of District Heating Tariff Benchmarks. Summary of the Doctoral Thesis. Riga: RTU Press, 2024. 55 p.

Published in accordance with the decision of the Promotion Council “RTU P-19” of 1 March 2024, Minutes No. 190.

I would like to express my gratitude to all RTU lecturers at various stages of my studies, especially my deepest appreciation to Professor Dr. habil. sc. ing. Dagnija Blumberga for consistent guidance and encouragement. I also highly appreciate the advice given by my colleagues in the heat supply industry, including those working at the Regulator, and the sharing of practical experience over many years. Lastly, I thank my family for their support and encouragement, but my foremost gratitude goes to my supervisor Professor Dr. sc. ing. Gatis Bažbauers for guiding me through the long doctoral process in a balanced but, at the same time, persistent way.

Cover picture from www.shutterstock.com

https://doi.org/10.7250/9789934371189
ISBN 978-9934-37-118-9 (pdf)

DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science (Ph. D.), the present Doctoral Thesis has been submitted for defence at the open meeting of the RTU Promotion Council on November 14, 2024, at 14:00, at the Faculty of Natural Sciences and Technology of Riga Technical University, 12/1 Āzenes Street, Room 607.

OFFICIAL REVIEWERS

Professor Dr. habil. sc. ing. Dagnija Blumberga
Riga Technical University

Professor Dr. sc. (tech.) Peter D. Lund,
Aalto University, Finland

Professor Dr. sc. ing. Anna Volkova,
Tallinn University of Technology, Estonia

DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for review to Riga Technical University for promotion to the scientific degree of Doctor of Science (Ph. D) is my own. I confirm that this Doctoral Thesis has not been submitted to any other university for promotion to a scientific degree.

Uģis Sarma …………………………… (signature)
Date: ………………………

The Doctoral Thesis has been written in Latvian. It consists of an Introduction, 4 chapters, Conclusions, 23 figures, 5 tables, and 4 appendices; the total number of pages is 195, including appendices. The Bibliography contains 150 titles.

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INTRODUCTION

Topicality of the Doctoral Thesis

In line with the ambitious objective set by the European Commission to ensure that by 2050 Europe has become a climate neutral continent and the interim outcomes set for achieving it, such as the Fit for 55 package, an ambitious process of change has been defined in which the cycle of the entire development cycle of the economy and the society has to transition from development based on cheap resources and continuously growing demand to development that is subordinate to the circulation of resources and sustainability. For effective progress of such an ambitious socioeconomic cycle change, goals that have been set politically and linear programmes developed for attaining such goals might not suffice. Change process management must take into consideration the simultaneity of many processes, which will affect a wide range of stakeholders and cause intense clashes between existing and new technologies, business models, political opinions, and interest groups.

In the proposed ambitious transformation, heat supply will play a major role, as nearly half of the total consumption of energy resources is used in construction and residential heat supply, especially in northeastern Europe; therefore, the potential of replacing fossil energy resources and reducing greenhouse gas emissions is key for heat supply.

However, rather small changes can be seen in the improvement of the regulatory framework governing district heating (DH), unlike the electricity and gas sectors have seen the development of a detailed uniform and rigid legal framework over multiple decades. This might be due to the fact that this type of heat supply, because of the specifics of the climate, is not significant and has not been widely developed in the most influential EU states, except for in a couple of the largest cities. Also, DH is highly fragmented even within a single country, and, apparently, because of this, a relevant EU-level regulatory framework that could apply to DH has not been developed.

The transformation of industries required for the achievement of climate neutrality objectives will also require investment of adequate scope. Although the estimated total amounts of investment required for the transformation vary from study to study, the dimensions of the total funding needs clearly amount to trillions of euros, and it will not be possible to fund this merely by means of grants and subsidies. This means that the industries that are to be transformed, including heat supply, must become commercially active enough to attract the necessary funding based on the principles of the market.

This may turn out to be a critical challenge to DH, which is strictly regulated by traditional methods, because, although the existing methods of regulation seem to guarantee returns to investors, they will fail to provide sufficient risk premiums to ensure the entry of new technologies into such a dynamic environment.

The need for regulation is usually substantiated first by consumer protection when the opportunities to choose another service supplier or find a replacement for the same service are very limited. However, on the other hand, the *inability* of the regulators to prescribe a *moderate* return on capital ratio, to prevent inexpedient investment and to correctly assess the generation costs of DH companies are criticised as the main flaws of regulation, as well as the very common so-called *overregulation*, which manifests itself as inexpedient use of the regulator`s resources in a detailed analysis of minor issues and substantiation of relatively insignificant costs and in prolonged discussions.

An exaggerated regulatory regime with a maximum focus on the reduction of prices and *consumer protection* in the short term will delay DH companies from becoming more flexible or even prevent them from adapting to the new circumstances, sometimes including the circumstances dictated by the very *consumers to be protected*. If all the wealth obtained due to a rise in DH efficiency is immediately redistributed in favour of the consumers by reducing the heat energy tariff, DH company`s ability to invest in future development decreases sharply.

Currently, in the setting of public service fees and tariffs, the overall trend is to move towards a *softening* of the regulatory regime, whereby the end state of the process would be a total deregulation of fees and tariffs and the subjection thereof to the forces of competition. However, there is still no unequivocal answer as to what extent deregulation is economically justified and expedient, even in the Nordic countries, where deregulation processes were carried out several decades ago. At the same time, it must be kept in mind that, at least in northeastern Europe, heat supply is an existential matter for the functioning of the society. Therefore, even when moving towards a highly liberal regulation for the DH industry, the way it will affect the accessibility of the service in the long term must be evaluated. Thus, giving up the supervision of the industry entirely would also be irrational.

Accordingly, similarly to the way it is in many areas, in the regulatory practice in the DH industry, a single correct method cannot be defined – to fully deregulate or to regulate strictly and, if regulate DH, then choose a single *ideal* method for the regulation and governance. Thus, the sustainable development of DH would most likely require creating a combination of regulatory methods and approaches.

Meanwhile, solutions of narrower scope have also reached maturity in the DH industry that affects the involved participants of the industry more – consumers of thermal energy and DH companies.

Consumer needs and options have changed significantly because of the development of heat supply and energy efficiency technologies. Consumers request a more flexible service, and the number of consumers who are not only able to produce a fraction of the energy needed but also wish to hand over the surplus to the DH system becoming *prosumers*.

The willingness of new producers of thermal energy to enter the heat supply market both with prospective zero-emission and traditional technologies, including the willingness of various industries to offer low potential residual heat,[1] which in turn will make DH companies direct the adjusting of the infrastructure to lower temperatures of the heat carrier, transitioning to DH of Generation 4. Accordingly, the regulatory regime should not only promote the transformation of DH companies and investing according to the comprehensive challenges of

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[1] Heat that inevitably originates as a by-product in industrial equipment, power plants or in the tertiary sector, which would inevitably be lost in the environment without the use of the DH system.

the Green Deal but also ensure that DH companies are able to do the pricing of energy in a flexible and operative manner.

A more flexible and more dynamic DH pricing system would be a benefit not only to DH companies and consumers of thermal energy. While efficient hydrogen and electricity accumulation technologies have not reached TRL[2] Levels 8 to 9, a flexible DH System in which heat pumps, peak load electric boilers and heat accumulators have been integrated, could theoretically also be, as an accumulator and balancer of a large volume of energy, an effective solution for improving the flexibility of electricity supply systems, which will be the deciding factor in the transforming of electricity supply and an as effective as possible integration of fluctuating and difficult to control renewable energy resources power plants.

Therefore, as fundamental transformations are taking place across the entire European energy sector towards the objective of decarbonization, the regulation of DH must also transform itself, focussing on stimulating DH companies for both effective investment and the needs of the consumers.

The regulatory environment for DH must adapt to the new circumstances and future challenges because the long-term political objectives, technology development, business models, the requirements of heat energy consumers and the needs of DH companies have already surpassed it.

However, despite the increasing importance of DH in the context of decarbonisation goals, the issues of liberalizing DH regulatory regimes and the elaboration and use of benchmarks have not been much explored. A large part of the research found in this area is devoted to the analysis of the full liberalization of DH in Nordic countries. Similarly, the transfer of methods tested in practice in the electricity market (third-party access to infrastructure, day-ahead hourly wholesale market, auctions, etc.) to DH has been modelled. However, most of these studies have used DH systems of large cities (Stockholm, Helsinki, Vilnius) as a modelling field. Therefore, it is relevant to look for solutions and methods for bringing DH regulation and supervision closer to market principles, which would be suitable for use in medium and small DH systems as well.

The Aim and Enabling Objectives of the Doctoral Thesis

The aim of the present Doctoral Thesis is to develop a regulation method for aligning the DH regulatory regime with market principles to improve the DH industry`s ability to contribute to the process of achieving climate neutrality objectives.

To achieve the aim, the following enabling objectives were addressed:

1) to analyse and evaluate general theories of regulation and state interference, methods of regulation, DH governance and deregulation experiences of other countries in which the DH industry is well developed;

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[2] *Technology readiness level* – a widely used system for the assessment of the maturity of technologies.

2) to analyse actual operational and financial data of Latvian DH companies to seek potential regularities and correlations for creating a thermal energy tariff benchmark model;
3) to develop an algorithm for a thermal energy tariff benchmark method that would ensure a significant alignment of the regulation regime with the market principles while maintaining sufficient supervision of the DH industry;
4) to develop proposals for the fundamental principles for the practical use of the thermal energy tariff benchmark method.

Hypothesis

It is possible to develop an optimal DH regulation method based on tariff benchmarks that would replace excessively strict *ex-ante*[3] regulation by *ex-post*[4] supervision promoting investment in zero-emission and efficiency-improving technologies while ensuring sufficient protection of consumers.

Scientific Novelty of the Doctoral Thesis

Several scientific research methods were used and mutually integrated into the Thesis:

1. The evolution of the various schools of thought and approaches to regulation; qualitative content analysis and comparative research methods were used for researching the regulation methods and deregulation results.
2. For the analysis and processing of actual operational and financial data of DH companies, statistical data processing, analysis and hypotheses testing methods were used.
3. The most important scientific novelty is the creation of a thermal energy tariff benchmark method that is based on virtually generating conditions in the thermal energy market by using the Monte Carlo imitation model, which in turn is based on the results of analyses of actual data of DH companies.
4. The algorithm and model developed in the Doctoral Thesis opens further research opportunities, as it can be used not only for practical regulation of DH but also for studying the dynamics of tariffs under the influence of changes in various external factors.
5. For an evaluation of the adequacy of the results and for interpretation, statistical data processing methods were used.

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[3] From Latin – *prior to that.* An analysis, evaluation of the foreseeable impact and results of a document or decision before its adoption.

[4] From Latin – *after that*. An analysis, evaluation of the results of a document or a decision after a defined period of its activity.

Practical Value

In the Doctoral Thesis, a thermal energy tariff benchmark method was developed, as well as fundamental principles for its practical use in DH regulation.

By using the proffered regulation method, the DH industry could be aligned with the market principles, and its regulation could be decoupled from various short-term interests. This would promote a sustainable business for DH companies and the opportunity to receive adequate profits for increasing efficiency and readiness to take the risk of using new technologies. Meanwhile, the use of the method would balance the interests of the companies and the needs of the consumers, as well as the transformation of the industry and its movement towards climate neutrality.

Potential users of the developed algorithm and method could be not only Regulators but also industry policy makers and planners.

The fundamental principles for DH regulation developed within the framework of the Thesis could also be used in other countries where DH plays a key role in energy supply.

Scientific Approbation of the Doctoral Thesis

Scientific conferences

1. Zigurs, A., Sarma, U., Ivanova, P., Implementation of the energy efficiency directive and the impact on district heating regulation: European Energy Market (EEM), 2015 12th International Conference. 19–22 May 2015, Lisbon, Portugal.
2. Bažbauers, G, Sarma, U. District Heating Regulation: Parameters for the Benchmarking Model: International Scientific Conference "Environmental and Climate Technologies" CONECT 2015, 14–16 October 2015, Riga, Latvia.
3. Sarma, U., Zigurs, A., Bazbauers, G. Correlation analysis for district heating tariff benchmarking model.: 13th International Conference on the European Energy Market (EEM), 6–9 June 2016, Porto, Portugal.
4. Sarma, U., Bažbauers, G. District Heating Tariff Component Analysis for Tariff Benchmarking Model: International Scientific Conference "Environmental and Climate Technologies", CONECT 2016, 12–14 October 2016, Riga, Latvia.
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6. Sarma, U. Towards a new regulatory model and market in district heating sector: The 6th WEC EU Baltic Sea Round Table 2019, 12–13 August 2019, Riga, Latvia.
7. Sarma, U., Bažbauers, District heating production tariff benchmark for energy regulation policy: International Scientific Conference "Environmental and Climate Technologies", CONECT 2022, 11–13 May 2022, Riga Latvia.

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Other scientific publications

8. Pūķis, M., Bičevskis, J., Gendelis, S., Karnītis, E., Karnītis, Ģ., Eihmanis, A., Sarma, U. Role of Local Governments in Green Deal Multilevel Governance: The Energy Context. Energies, 2023, 16 (12), art. no. 4759. DOI:10.3390/en16124759 (Indexed in SCOPUS).
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Structure of the Doctoral Thesis

The Thesis has been written as a dissertation, and its structure was made following the common format for structuring scientific research, the so-called *IMRaD* structure: introduction, methods, results, and discussion. The Thesis comprises an introduction and four chapters: literature review, methodology, results and discussion, conclusions and recommendations. The structure of the Doctoral Thesis is schematically illustrated in Fig. 1, also showing the sequence of the steps taken.

The introduction substantiates the topicality of the topic of the Doctoral Thesis and the issues to be researched, defines the goals and enabling objectives of the Thesis, proposes a hypothesis, describes the scientific novelty, practical value and the approbation results of the Doctoral Thesis in scientific conferences and publications.

The literature review examines the general theory of regulation and state interference, focussing in more detail on the various schools and methods of economic regulation, as well as a comparative analysis of the advantages and disadvantages thereof, especially in relation to the DH regulatory environment.

The methodology chapter describes the results of the data analyses that were carried out and the results thereof, which feed into the development of the thermal energy tariff benchmark algorithm to be described below.

The results and discussion chapter evaluates the results obtained via the thermal energy tariff benchmark calculation model that has been created, analyses the compatibility thereof with the set goals, and develops principles for practical use of the benchmark model in the DH industry supervision and policy creation.

The conclusions and recommendations chapter summarises the key conclusions drawn during the writing of the Doctoral Thesis and suggestions made.

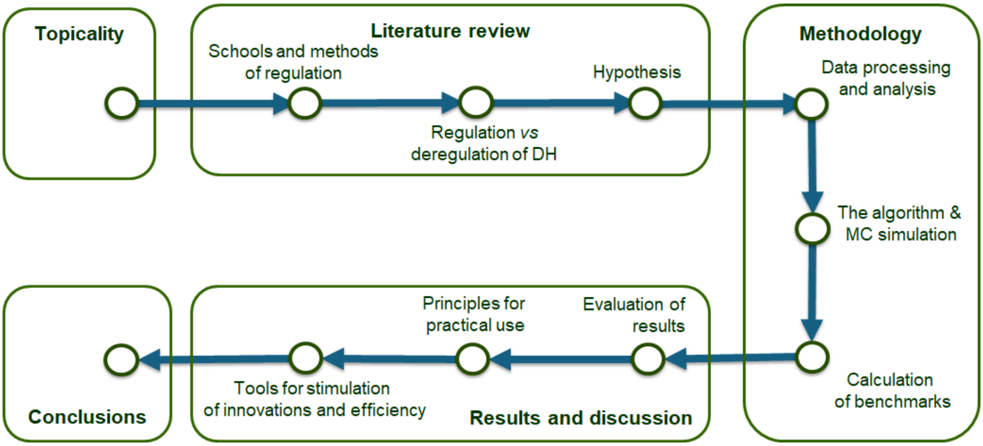

Fig. 1. Structure of the Doctoral Thesis.

1. METHODOLOGY

To test the hypothesis, studies were carried out, and solutions were sought for how to create an algorithm for a benchmark-based DH tariff-setting method that would meet the following requirements:

- the fundamental principles for the formation of the tariffs should be close to those that would occur in a sufficiently liquid competing market if such DH were possible;
- at the same time, the algorithm must also ensure that it is possible for the Regulator to oversee processes within the DH industry and to adjust them if necessary;
- the use of the algorithm must not create more obligations either to the Regulator or to the DH companies in comparison with the strict regulation model that is currently in use – conversely, the burden of the processes should decrease on both sides.

1.1. Data Processing

In the initial phases of the study, data analyses were carried out across various dimensions regarding real regulated DH companies operating in Latvia to find correlations between the final thermal energy supply tariff and parameters characterising the DH system: the amounts of thermal energy supplied, the type of fuel used, thermal energy production technology, and the length of the DH networks. Tariff structures and the features and nature of the elements that the tariffs are comprised of were also analysed, which could then be used when creating the benchmark model for setting DH tariffs.

For the purposes of data analysis, a population dataset (limited, finite and existing in real life) was created comprising data regarding 97 real regulated DH companies operating in Latvia: 57 vertically integrated DH companies and 40 independent heat producers.[5] Information on each DH company`s tariff levels, most significant cost groups and technical and operation indicators were included in the dataset.

The population dataset was created using publicly available sources: Regulator`s decisions on the approval of tariffs, information to the public about the most important components of tariff projects, registers of thermal energy producers, electric power producers, thermal energy supply transmission and distribution operators and thermal energy vendors, information about fuel consumed by energy producers from the air pollution reports database "2-Gaiss" of the Latvian Environment, Geology and Meteorology Centre and other publicly available studies and sources, as well as voluntary surveys of members of Latvian Association of Heat Supply Companies that were carried out directly.

The population dataset to be analysed within the framework of the initial processing of the data was divided into smaller datasets, forming samples based on the most relevant factorial properties of the real DH companies: company size, production technology, and fuel type used. Heat supply end tariff was selected as the resultative property.

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[5] For the purposes of the regulatory framework of the Latvian heat supply industry, independent producers are companies that are only engaged in the production of energy and sell the energy produced to a vertically integrated heat supply company or heat supply system operator.

Data analysis was initiated by using the simplest data processing methods first: correlation and single-factor regression analyses. The results obtained by means of these simple data analysis methods showed that a tendency could not be identified that would indicate distinct connections between the dominant type of fuel used, the technology of production applied, the amount of energy supplied, the intensity of the use of the networks and the level of the tariff in the respective DH system. Certainly, each of the factorial properties characterising a DH system *per se* affects the tariff; however, the effect of shifting the tariff in one direction or the other apparently decreases or erases itself due to other factors.

From the above-mentioned results, it was concluded that the real DH companies and systems are vastly different – even if they can be grouped together into a single dataset based on one parameter, at the same time they differ substantially in terms of other parameters. Therefore, the creation of a benchmark model cannot be based only on regression calculations obtained in an empirical manner, and a simplified approach to setting tariffs cannot be used, for example, trying to find a single tariff ceiling benchmark that is expressed using an absolute value and that all DH companies should aspire towards, or a few different benchmarks for the most typical groups of DH companies or systems.

Therefore, when creating a benchmark algorithm, rather than looking at a total final tariff, the tariff must be split into at least three key components that constitute it: production tariff – T_{pr}; transmission and distribution tariff – T_{td}; and trade tariff – T_s.

The proportion of the thermal energy trade tariff T_s within the final tariff is small – in the population of the analysed DH company data, it ranges from 0.58 % to 2.85 %, and it basically depends only on the organization of invoicing and collection management within a DH company. This means that the effect of T_s on the final tariff is smaller than, for example, a 1 % deviation from the projected fuel price included in the tariff, and it can be acknowledged as insignificant. Therefore, when creating the framework of the algorithm and the structure of the DH tariff benchmark model, T_s can be disregarded.

Whereas thermal energy production tariff T_{pr} makes up approximately 60 – 80 % of the total heat supply costs, the remaining part of the costs is made up of thermal energy transmission and distribution costs. Analysing the formation of thermal energy production costs, as well as transmission and distribution costs and the factors that affect them, it was concluded that the substantial differences of both these technological processes lead to the need to analyse them separately and also to create different algorithms for determining benchmarks.

On the one hand, the technical production and cost indicators of the real DH companies vary in terms of scale and are rather scattered, but on the other hand, in general, the production cost results tend to group themselves around certain values. Moreover, a single qualitative parameter – fuel type – in fact, determines the formation of the entire production costs. The choice of fuel type determines the production technology, whereas the selected technology determines the technical indicators of production to a sufficiently unequivocal degree: efficiency ratio, specific electricity consumption, etc. Therefore, the variable costs within the process of using a specific type of fuel will depend on a single external factor – the price of fuel. Whereas, provided that adequate production capacities have been chosen to meet the demand and that the indicators characteristic of the operation process are optimal, operational costs (OPEX) and capital costs (CAPEX), in fact, depend only on the technology. The formation of the total thermal energy production costs and the determinative role of the choice of fuel type are illustrated in Fig. 1.1.

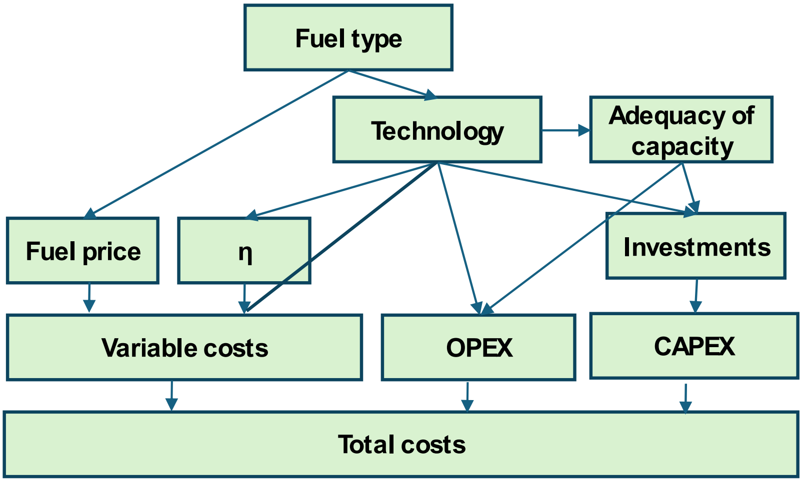

Fig. 1.1. A diagram showing the formation of the total thermal energy production costs.

Thus, the costs of fuel clearly are the element determining the production tariff, but the other components of the costs making up the production tariff, although significantly smaller than the fuel component and to a large extent determined by the choice of the fuel type, still depend on multiple external factors, which in every specific instance affect the size of the component and accordingly affect the production tariff with various degrees of intensity. Therefore, to balance out and consolidate the impacts of the factors while further developing the method, the following solutions were chosen: to introduce a dimensionless indicator for further analyses and simulations – the ratio of the real thermal energy production tariff to a theoretical efficient thermal energy production benchmark, a component of fuel costs that might be obtained at the so-called BAT[6] boiler plant, and that is calculated according to Formula (1.1):

$$R_{tf(i)} = T^{pr}{}_{(i)} / C^{f}{}_{bp} \ , \tag{1.1}$$

where

$R_{tf(i)}$ –the dimensionless indicator characterising the respective (i) DH company`s production tariff;

$T_{pr(i)}$ –the production tariff of the respective (i) DH company, EUR/MWh;

$C^{f}{}_{bp}$ – the fuel cost component as it would be at a BAT heat source, calculated according to Formula (1.15), EUR/MWh.

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[6] Best Available Technology.

As a result, by introducing, instead of the absolute value of the thermal energy production tariff, a dimensionless value that characterises the deviation of a specific producer`s total production costs from a simple efficient production benchmark, the following is achieved:

- it is simple and clear to compare any of the production tariffs to the most significant thermal energy production benchmark – BAT boiler plant production efficiency indicator;
- it is also easy and convenient to compare the production tariffs of various DH companies among themselves;
- the introduced thermal energy production benchmark could be a highly convenient and effective tool for the Regulator to guide the motivation of DH companies to improve efficiency.

Continuing to process the data of the real DH companies and the calculated R_{tf} values by using the methods of descriptive statistics, a significant effect of the structure of the fuel used in the production of thermal energy was observed on the indicators characterising the tariffs (in Latvia, two fuel types dominate in the heat supply: biomass and natural gas). It was concluded that the parameters forming the tariffs show a distinct trend of grouping themselves within specific ranges depending on the structure of the fuel. Whereas when analysing the data samples pertaining to borderline cases (DH companies using only natural gas or only biomass), it was observed that R_{tf} frequency distribution might display properties of normal distribution. By using the most significant indicators of descriptive statistics – means, standard deviations, etc., R_{tf} frequency graphs were created. In the first approximation, to estimate whether R_{tf} frequency distribution might possess properties of normal distribution, frequency graphs were created for both samples under the circumstances of identical standard deviations, for the case if R_{tf} frequencies precisely complied with the normal distribution. The graphs that were obtained are shown in Fig. 1.2.

a) b)

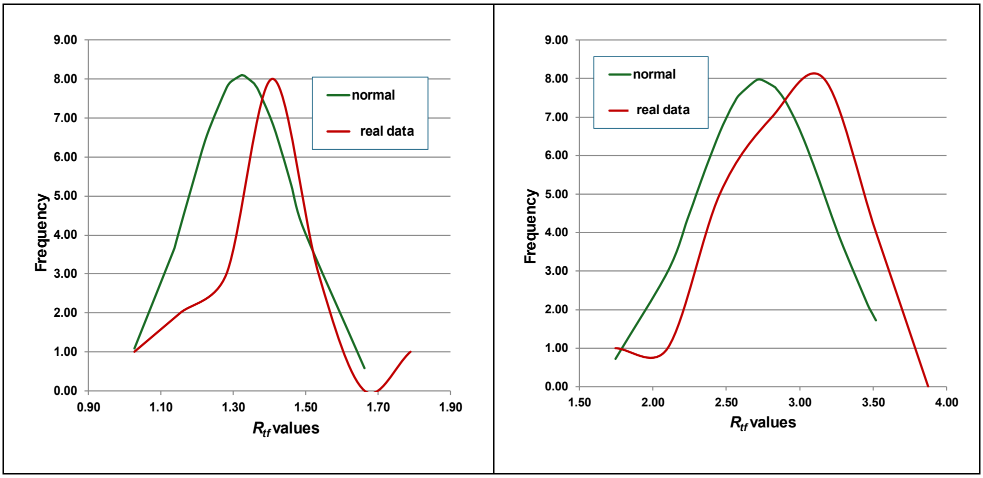

Fig. 1.2. R_{tf} frequency distribution for two groups of DH companies that differ in terms of the type of fuel used: a) DH companies using only natural gas, b) DH companies using only biomass.

Using this simple approach, it was possible to arrive merely at a general hypothesis regarding the potential correspondence of R_{tf} of both samples to normal distribution. Therefore, in-depth data analysis was carried out afterwards using the statistics package *"IBM SPSS Statistics for Windows version 23" (IBM Corp., Armonk, N.Y., USA*).

First, using Kolmogorov–Smirnov and Shapiro–Wilk and Levene tests, it was checked whether the differences in the R_{tf} values of both samples are statistically significant, as well as whether the output data values for both samples that were calculated based on the data of real Latvian SCA companies and that were input are statistically significant. The tests that were carried out proved that the differences in both the R_{tf} and the output data of both samples are statistically significant. This means that it is justifiable to create separate benchmark algorithms for thermal energy production from biomass and natural gas.

Proceeding with further data analysis, the results of statistical analyses showed that the null hypothesis that the empirical distribution of the R_{tf} values of both samples corresponds to normal distribution cannot be rejected. The distribution of R_{tf} values for producers using natural gas and producers using biomass, which have been calculated using the data of the real DH companies, are presented in Figs. 1.3. and 1.4., respectively.

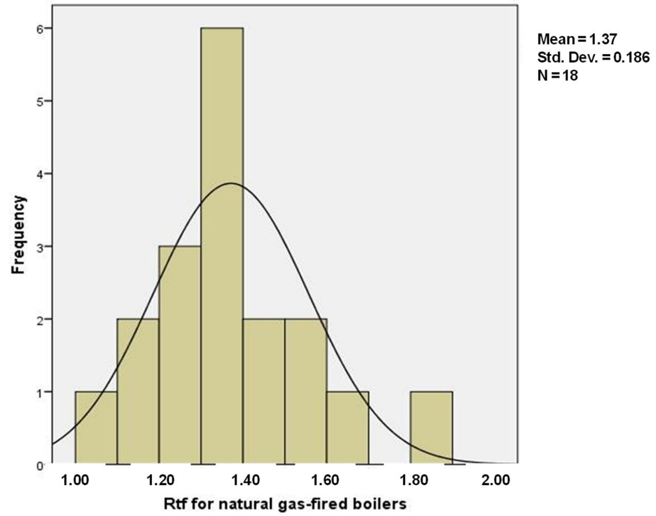

Fig. 1.3. A histogram showing R_{tf} value frequency distribution for Latvian DH companies using natural gas. BAT heat source efficiency quotient was established at $\eta_{bp} = 0.92$ (printout from SPSS).

Also, an analysis of the most significant technical parameters in the production of thermal energy – efficiency quotients and real data pertaining to the capacity usage indicator – and the tests of statistical analyses that were carried out showed that with a 0.95 probability, it cannot be rejected that these parameters are normally distributed. An efficiency quotient value distribution for real boiler plants using natural gas is shown in Fig. 1.5.

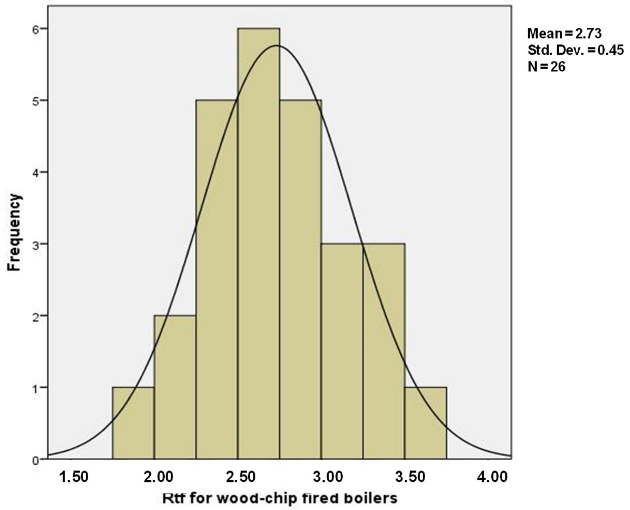

Fig. 1.4. A histogram showing the frequency of R_{tf} values for Latvian DH companies using biomass. BAT heat source efficiency quotient was established at $\eta_{bp} = 0.85$ (printout from SPSS).

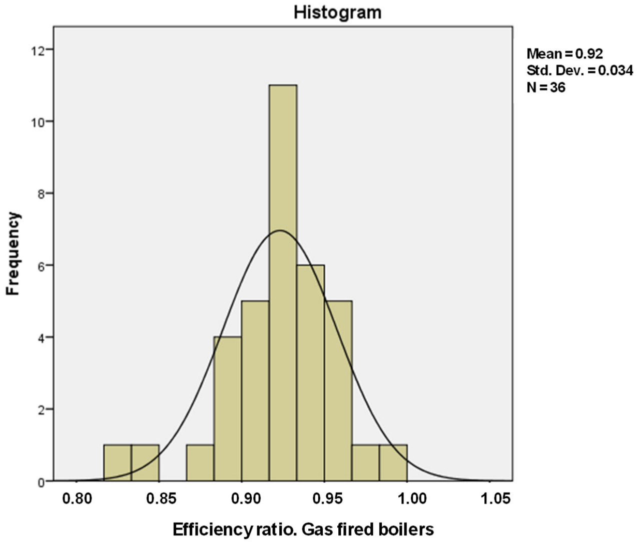

Fig. 1.5. A histogram showing efficiency ratio frequencies for Latvian DH companies using natural gas (printout from SPSS).

However, for some of the parameters required for calculating thermal energy tariffs, it is not possible to obtain enough unmediated and precise data either from the Regulator or from information released by DH companies to carry out descriptive statistics calculations at a sufficient confidence level and tests for testing data distribution hypotheses. This pertains to parameters characterising the prices of goods, services and technologies that DH companies purchase in an open market from various suppliers. Therefore, information on these parameters was obtained in the form of generalized and collated data from several publicly available sources:

- Data on energy resource prices and the situation in the Latvian market and globally – from reviews on the gas, electricity and woodchips from wood markets published by the Regulator, timber industry market reports, *European Energy Exchange (EEX)* data and market reviews, *International Biomass Exchange Baltpool*, Nordic and Baltic power exchange wholesale platform *Nord Pool* data, and the freely accessible economic and financial data platform *Trading economics.*
- Data on technical parameters characteristic of thermal energy production, specific OPEX and CAPEX were obtained from the technology data catalogue maintained by the Danish Energy Agency. The above-mentioned source can be considered one of the most authoritative data sources in this field, as it contains a wide range of sufficiently detailed data and has been developed over a long period of time while also being regularly updated, keeping up with the development of technologies.

Data on specific transactions of specific DH companies cannot be obtained from the publicly available sources listed above: prices of fuel purchased, the actual operational and maintenance cost items of a specific company, and actual investment amounts for creating production assets. Therefore, it is also not possible to analytically draw conclusions regarding the nature of the distribution of these data. However, from the above-mentioned sources, it is possible to obtain means and the most characteristic ranges for a number of parameters. The values of the parameters that are identical for all the commercial operators, for example, wholesale prices of natural gas and electric power, were also obtained from the above-mentioned public sources.

Lacking an opportunity to analytically estimate the data distribution of the above-mentioned parameters, it was presumed with a high confidence level that these data are also normally distributed, based on the following judgments:

- In a general case, if nothing were known about the nature of the value distribution of the parameter being studied, a hypothesis could be assumed regarding an even distribution of the parameter. In this case, there is an identical probability that the parameter being studied could take any value from the range.
- However, taking into consideration the fact that most of the unknown data are determined by a number of prices (labour, materials, technological equipment), real experience regarding the formation of prices under the conditions of competition shows that the market prices of a product or goods have a tendency towards a most common mean value and the variance of its deviated values is not large – the further from the mean, the rarer the occurrence, i.e., most often, price value distribution in the market is close to the normal distribution.
- Most natural processes and processes created by human activity that result in a sufficiently large number of empirical values of a specific parameter most often are normally distributed, and, therefore, normal distribution is of very wide use. Thus, it is implausible that the parameters affecting the thermal energy tariff, which can

take various values due to market forces, would not be subjected to the principles of normal distribution.

Even if the actual values of one of the parameters were not normally distributed, they would most likely be distributed in a way that is close to log-normal distribution, which can be substantiated by the fact that a number of parameters of economic nature under real circumstances usually tend not to take negative values.

Neither would the functional form of individual parameter values change the fundamental principle of the method discussed below because all the actual data pertaining to the parameters affecting the tariff clearly are at the Regulators` disposal, and, applying the methodological approach proffered below in practice, Regulators can determine and use the actual distribution of the values of the specific parameter.

1.2. The Algorithm

The number of real Latvian DH companies is finite, which means that all the analyses of the real data were carried out using finite populations in which the number of variations does not exceed a few dozen. The results of processing such rather small datasets usually show rather significant uncertainties; therefore, it was necessary to find a solution for how, when forming the tariff benchmark model, to reduce uncertainties in the results of the calculations. A method suitable for processing uncertainties is the Monte Carlo simulation (MCs), which is commonly used to analyse the features of large sets of results for which it is difficult or impossible to use deterministic analyses. The method is based on a simulation of the values to be calculated in accordance with a set probability distribution using a large number of randomly generated values.

Taking into consideration the fact that, with a high confidence level, the value probabilities of both the dimensionless value R_{tf}, characterising the actual levels of the real thermal energy production tariffs, and the factors relevant for forming the tariff can be deemed normally distributed, it can be presumed that, obtaining a sufficiently large number of values of these factors by means of the MCs method and using them in the calculations of the production tariff T_{pr}, uncertainties could be reduced and a more objective picture could be obtained of the possible variations of both T_{pr} and R_{tf} and the probability distributions of the frequencies thereof.

Thus, for calculations of the parameters forming the tariff, the values of the production tariff T_{pr} itself and, accordingly, the dimensionless indicator R_{tf}, an algorithm for calculating thermal energy production benchmarks was created in MS Excel, incorporating MCs modules into the algorithm. In cases of similar conditions (high uncertainty, finite amount of real data but with determinable parameters of distribution rules), the MCs method is being used successfully in the simulating of various processes, including in the energy sector for cost and price analysis and for forecasting under uncertainty.

Taking into consideration the conclusions drawn from the real data analysis that it is justifiable to carry out separate calculations for the thermal energy production tariffs if natural gas or biomass are being used, the calculation algorithm was adapted for carrying out two separate calculations while keeping the fundamental principles of the calculation algorithm constant.

Simulations of the parameters forming the tariff and a block diagram of the calculation algorithm are shown in Fig. 1.6.

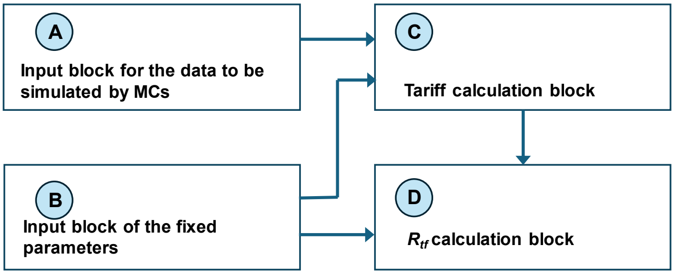

Fig. 1.6. A block diagram of the thermal energy production tariff benchmark calculation algorithm.

Input block for the data to be simulated by MCs

This block includes those parameters forming the tariff that can take a unique value for each specific DH company, thus forming a population dataset. A mean value and standard deviation are input for each of the parameters included in this block, and the mean and the standard deviation are then used by MCs, obtaining a set of simulated variations for each of the parameters. Data to be input was obtained from analyses carried out based on data of the real DH companies, if such data were available, or based on data from the public data sources mentioned previously.

The input block for the data to be simulated is illustrated in Fig. 1.7, and a characterization and data sources of each parameter are provided in the description of the algorithm principles, and the significance of each parameter within the benchmark calculation model has been interpreted. Carrying out calculations for each of the parameters, 1,000 simulations were run, obtaining 1,000 values, i.e., $i = [1;1000]$. Thus, the results represent the data of 1000 simulated DH companies.

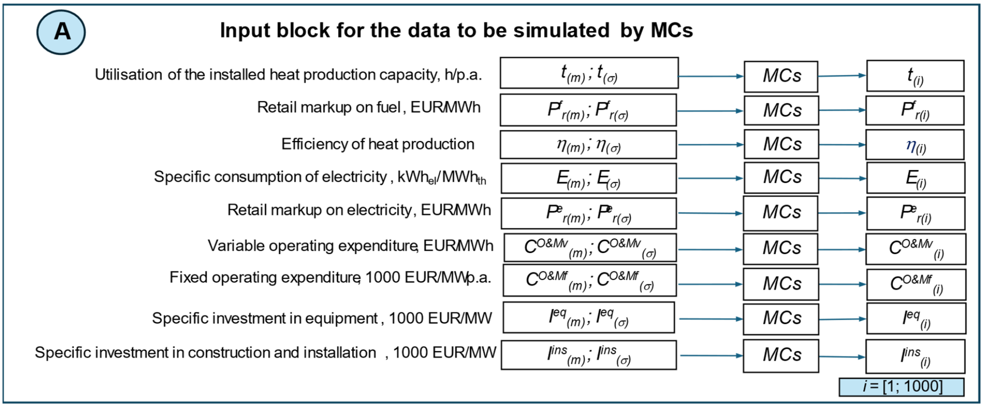

Fig. 1.7. The input block for the data to be simulated by MCs.

Input block of the fixed parameters

This block comprises those benchmark calculation model parameters (see Fig. 1.8), the values of which for all the DH companies vary to an insignificant degree under real conditions, and, therefore, in the model, it can be assumed that they are identical for all the DH companies in a specific period of time. Thus, when using the model, the values of these parameters would be fixed for a specific period of time, for example, a year, if the macroeconomic situation is rather balanced, or for an indefinite time, i.e., the values would be changed when drastic changes take place in the external economic and financial environment, as it was seen in 2022.

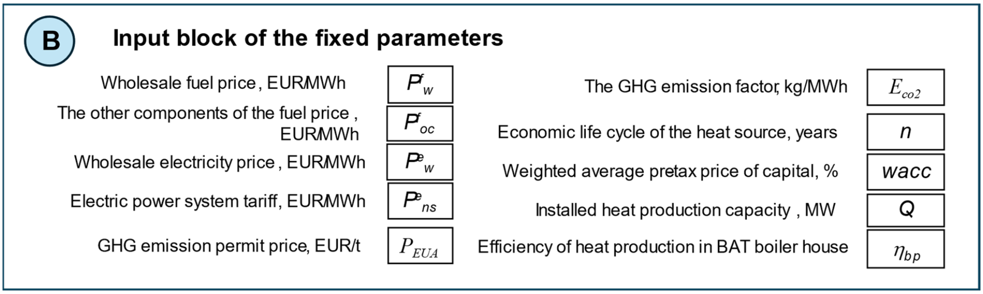

Fig. 1.8. Input block of the fixed parameters.

Tariff calculation block and R_{tf} calculation block

The structure of the tariff calculation block is illustrated in Fig. 1.9.

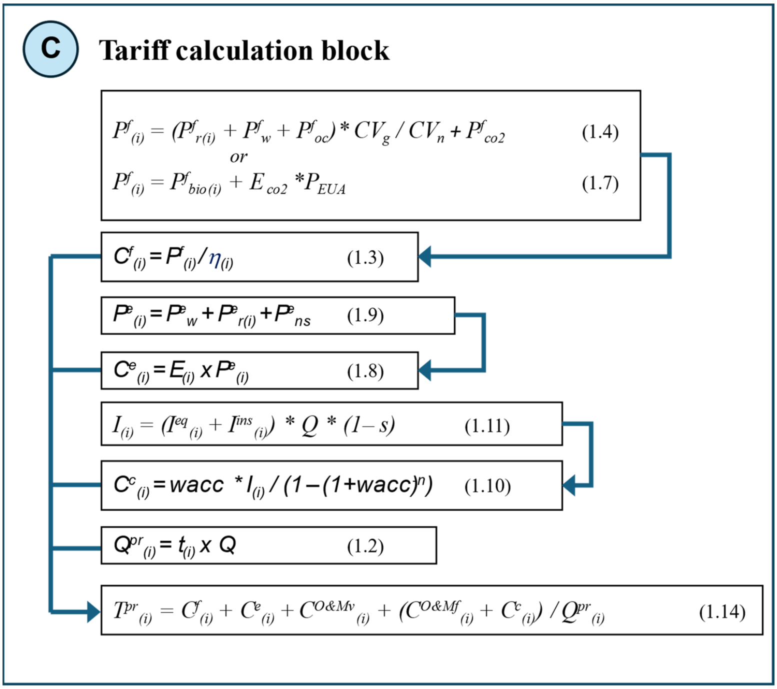

Fig. 1.9. Tariff calculation block.

The tariff calculation formulae block includes traditional formulae for the calculation of thermal energy production tariff that are necessary to calculate several interim results and components of the thermal energy production tariff.

The calculation ends in the R_{tf} calculation block, where fuel cost component in a BAT boiler plant C^f_{bp}, R_{tf} values and the distribution of frequency of these values are calculated (see Fig. 1.10).

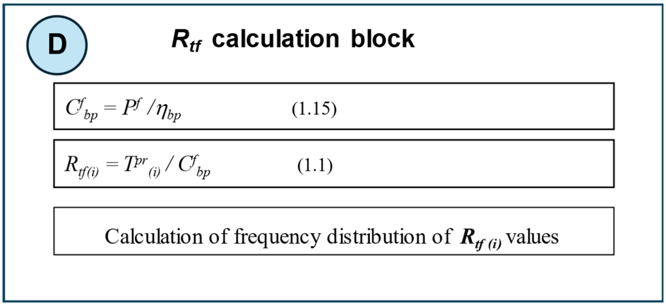

Fig. 1.10. R_{tf} calculation block.

For all of these parameters (except for the fuel component in a BAT boiler house), the sizes of the calculated result datasets correspond to the size of the input datasets obtained by means of MCs, i.e., $i = [1;1000]$.

1.3. Parameters and Data for Calculating Benchmarks

Volume of thermal energy, installed capacity, load of the installed capacity

Thermal energy production volume is a critically important parameter for determining the thermal energy production tariff because the proportion of the fixed components within the tariff depends on it. The proportion of the fixed costs in the thermal energy production process varies from 15 % to 20 % (if using natural gas) to 40–60 % if using biomass.

To create a thermal energy production benchmark simulation model, the absolute indicators of the real systems had to be abandoned and the possibility of generalizing the defining of the demand for thermal energy. Taking into consideration the fact that plausible heat load indicators that would allow to define the volumes of thermal energy from the side of the demand are not available, but information regarding installed thermal energy production capacities could be obtained from the register of thermal energy producers, installed production capacity utilisation indicator t was calculated for every DH system that was included in the dataset to be analysed. The data analysis that was carried out showed that its mean value within the dataset to be analysed is 1492 hours, and with a probability of 0.95, this indicator is normally distributed. Carrying out MCs of the values of this indicator, a dataset is obtained that is sufficiently representative and characterises at an adequate confidence level the demand for thermal energy in various DH systems because, in fact, it is a resultant indicator for all the factors (climatic, energy efficiency, the condition of DH networks, consumer structure and behaviour, etc.), which both increases and reduces the demand for thermal energy in real DH systems. This indicator mainly depends on processes on the side of the thermal energy consumption. It can be forecast that in the real DH systems, this indicator will predominantly tend to gradually decrease due to energy efficiency measures, development of *active consumer* and energy communities, improvement of DH network efficiency, depopulation and other factors. Whereas looking from the perspective of the thermal energy producer, the higher this indicator, the more efficiently the production assets are being utilised. However, the producer cannot control and independently influence this indicator, being only able to influence it in a stepped manner, reviewing and reducing the composition of the production assets after rather long active operation periods.

A DH system, the indicator of the load of the installed production capacity of which would be pronouncedly low and only reach a few hundred hours per year, is unthinkable. Meanwhile, the Regulator, with the current tariff regulation methodology, stimulates DH companies to not maintain surplus production capacities, prescribing that the profitability permitted within the tariff may reach the maximum value if the installed capacity usage indicator t is at least 1200 hours per year.

From the goal set for the creation of the benchmark model – to create a model simulating efficient heat supply market conditions in which convenient tools for the Regulator for purposefully directing the market processes would also be incorporated – it can be concluded that on the one hand production asset load indicator values must reflect the reality of the market, but on the other hand, this indicator must be used as a critically important tool for the Regulator for stimulating an efficient use of assets. Therefore, when carrying out the testing of the model, the following approach was used in the selection of indicators to be input into MCs:

- The mean obtained via an analysis of the real companies` data was used as the mean value of the usage of the installed capacity indicator $t_{(m)}$. Thus, a link between the simulated value dataset and the real conditions is ensured.
- Whereas the standard deviation of the installed capacity usage indicator $t_{(\sigma)}$ was used to represent the difference between $t_{(m)}$ and the current efficient usage of capacity criterion that has already been set by the Regulator. This choice ensures a link between the model and reality, given that the criterion set by the Regulator is already in operation (it is known to DH companies, and they are interested in exceeding it), and also ensures that the Regulator can continue to use this indicator as a tool for stimulating efficiency.

Using the i values of the installed production capacity usage indicator obtained by means of MCs, the values of the volumes of thermal energy produced are calculated in the model according to Formula (1.2):

$$Q^{pr}{}_{(i)} = t_{(i)} \times Q, \tag{1.2}$$

where

$Q^{pr}{}_{(i)}$ – the volume of the thermal energy produced in a heat source, MWh;

$t_{(i)}$ – the usage indicator of the capacity installed at the heat source, h;

Q – installed thermal energy production capacity, MW.

In a general case, the model operates on the assumption that the installed production capacity Q = 1 MW, but it is possible to input any value of installed production capacity in the fixed input indicators block if, to use the model in a more precise way, it has been envisaged to run simulations for multiple installed production capacity ranges, at the same time accordingly changing the values to be input in the input block of the indicators to be simulated for those parameters that show the scale effect, for example, for specific investment in equipment I_{ins} or fixed operating expenditure $C^{O\&Mf}$.

Fuel costs

The fuel cost component is calculated according to Formula (1.3):

$$C^f_{(i)} = P^f_{(i)} / \eta_{(i)}, \tag{1.3}$$

where

$C^f_{(i)}$ – fuel costs, EUR/MWh;

$P^f_{(i)}$ – fuel price at the time of being entered into the boiler, EUR/MWh;

$\eta_{(i)}$ – thermal energy production efficiency quotient.

The values of the thermal energy production efficiency quotient $\eta_{(i)}$ are obtained by using MCs. Whereas the fuel price $P^f_{(i)}$ represents the costs of fuel at the time when it is being entered into the boiler, i.e., this price comprises all the costs related to transporting the fuel to the boiler plant, taxes pertaining to the use of fuel, etc. Therefore, prior to the input of the fuel price into the tariff calculation block, preparatory calculations of the input data are carried out. Taking into consideration the substantial differences between the population datasets comprising data of the companies using natural gas and biomass, two unrelated calculation algorithms were created within the model: for thermal energy production using gas or biomass. This separation was necessary not only for calculations of fuel costs but also for many of the other parameters that are to be input into the algorithm.

If natural gas is used for thermal energy production, the calculation model envisages the following preparatory calculation for establishing the fuel price according to Formula (1.4):

$$P^f_{(i)} = (P^f_{r(i)} + P^f_w + P^f_{oc}) \times CV_g / CV_n + P^f_{co2}, \tag{1.4}$$

where

$P^f_{(i)}$ – the price of natural gas at the time of being entered into the boiler, EUR/MWh;

$P^f_{r(i)}$ – retail markup on natural gas, EUR/MWh;

P^f_w – wholesale price of natural gas, EUR/MWh;

P^f_{oc} – the sum of the other components of the price of natural gas, EUR/MWh;

CV_g; CV_n – gross heating value and net heating value of the combustion of natural gas in accordance with ISO standard 6976:2016, MWh/1000 m^3;

P^f_{CO2} – greenhouse gas emission permit cost component, EUR/MWh.

In the tariff calculation model, it is easier to carry out the calculation of fuel consumption and, accordingly, cost calculation as well, by using the net heating value of natural gas combustion. Whereas in the trading of natural gas and setting of the system tariffs, the gross heating value of natural gas is used; therefore, prior to the input of the total price of natural gas into the tariff model, a recalculation from gross heating value to net heating value is carried out.

Natural gas retail markup $P^{fr}(i)$ is the only element in the calculation of natural gas price for which MCs is carried out because it is assumed that some nuances in natural gas supply contracts may vary for each specific commercial operator, as multiple merchants that fiercely compete with one another and have different appetites for risk offer natural gas on the market, supply contracts are entered into at various points in time, the contracts may comprise prices that have been fixed according to different principles and for a term of different duration or the prices may fluctuate freely according to the European gas market indices.

However, at the same time, it can be concluded from the publicly available gas market reviews that the range of retail margins is not very wide and very small or very high surcharges above wholesale prices of gas are very rare on European gas trading platforms, and in most cases, the margins tend to approach a mean value. This can be explained as due to the well-integrated common market area of Latvia, Estonia and Finland, in which all merchants have equal access both to the entrance/exit points of the unified transmission system of these three countries and to the subterranean gas storage facility in Latvia. Taking into consideration the fact that physically, natural gas deliveries to the unified area mentioned above are only possible in the form of liquefied natural gas (LNG) from the Inkoo LNG terminal in Finland or from the Klaipeda LNG terminal in Lithuania through the border crossing between Latvia and Lithuania, gas wholesalers and retailers that operate in the region operate under highly similar conditions, and accordingly, price deviations from mean values are small.

In the Baltic states` natural gas market, a reference to the wholesale price of natural gas P^f_w in one of the European gas trading platforms is used in most retail contracts as the most significant element to define the price. Over the last couple of years, natural gas price indices in the Dutch *TTF (Title Transfer Facility*) natural gas trading platform, which is one of the three most important points in Europe for natural gas price formation, have been preferred more and more in the Baltic states` natural gas markets.

The wholesale price of natural gas is a figure that is independent from any of its individual consumers or even groups of consumers, and it is a changeable external value that reacts only to global objectives (climatic conditions, economic growth indicators, changes to energy policy, relevant geopolitical processes) or sometimes speculative processes. Current experience shows that it is not possible to identify any specific regularities in its formation, and even the most authoritative forecasts come true to a very limited extent. For example, over the last two to three years, gas prices were seen to fluctuate within a massive range from 9 EUR/MWh to 345 EUR/MWh (see Fig. 1.11).

If the record price levels seen in 2022, shown in Fig. 1.11, can be attributed to the market`s reaction to the war in Ukraine initiated by Russia and the collapse of several customary supply chains, finding an explanation for the price trends seen in 2020 to 2021 is difficult.

Therefore, in the tariff benchmark calculation algorithm, when modelling tariff levels for a specific period of time, the wholesale price of gas in this time period has been assumed to be identical for all DH companies. Accordingly, it has been built into the model as a single constant that is to be input separately, and that can be changed, if necessary, if the selected gas price index changes. In sample model calculations, it has been assumed that the *TTF* price index is being used.

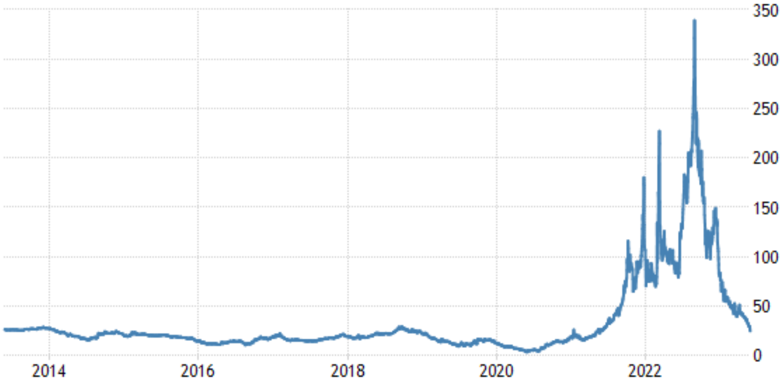

Fig. 1.11. Natural gas price (next month`s futures) fluctuations in the *TTF* trading platform over the past ten years, EUR/MWh (source: *Trading Economics*).

The sum of all the other components of the gas price P^f_{oc} consists of multiple elements, and it is calculated carrying out a data preparation calculation according to Formula (1.5):

$$P^f_{oc} = P^f_{sys} + P^f_T, \tag{1.5}$$

where

P^f_{oc} – the sum of the other components of the gas price, EUR/MWh;

P^f_{sys} – the sum of natural gas supply system usage tariffs, which comprises natural gas transmission, storage and distribution tariffs; these tariffs are regulated and therefore remain constant and identical over a specific time period for all the users of the natural gas supply system, EUR/MWh;

P^f_T – excise tax on natural gas, EUR/MWh.

If an energy producer uses fossil fuel and, as of 1 January 2023, biomass as well, and it is not possible for the energy producer to prove the compliance of its origin to the requirements set out in the EC directive on the promotion of the use of energy from renewable sources, the producer must obtain greenhouse gas emission permits according to the volume of CO_2 emitted during the fuel combustion process, i.e., it must participate in the European Emission Trading System (ETS).

Relatively long transition periods were granted for the heat production industry, during which the required volume of greenhouse gas emission permits was granted for free, but the volume of free permits was gradually reduced year on year, and currently, for 2023, it has been set at 30 % of the required number of permits. Accordingly, the remainder of the emission permits must be purchased on the market. As a result, purchasing the required emission permits constitutes an additional cost component, which must be included in the calculation of the fuel price. The component is calculated according to Formula (1.6):

$$P^{f}_{\mathrm{CO2}} = E_{co2} \times P_{EUA} \times (1 - k)/1000, \tag{1.6}$$

where

P^{f}_{CO2} – GHG emission permit purchase component, EUR/MWh;

E_{CO2} – the emission factor characteristic of the specific type of fuel, kg/MWh;

k – free-of-charge emission permit allowance quotient pursuant to the provisions of EC legal acts on greenhouse gas emission permit trading;

P_{EUA} – GHG emission permit price, EUR/t.

If emission factors and the free permit allowance quotient can be considered constants, P_{EUA} is a variable whose value forms in the external environment and tends to fluctuate quite a lot; however, over the last couple of years, it has been showing a tendency to increase (see Fig. 1.12).

Fig. 1.12. GHG emission permit price fluctuations over ten years, EUR/t (source: *Trading Economics).*

It is not sensible to carry out statistical analysis of the GHG emission permit price and to seek to define frequency distribution and regularities. The fluctuations and trends pertaining to this indicator comply with neither statistical regularities nor even with the stochastic process in open markets because the GHG emission permits are a financial product that was created by means of political decisions and is intended for circulation in a politically designed quasi-market, or, in fact, a parafiscal instrument for raising the cost of using fossil energy sources.

Like for any product on the market, there exists supply and demand for emission permits and, at first appearance, forces like those in an open market act influence them. However, both parties are, in fact, manipulated by means of legitimate political instruments:

- Demand is created by legislating that a number of subjects are obligated to use the product, i.e., must purchase GHG emission permits. Demand is gradually increased both by including new participants in the obligatory market and by gradually reducing the free quota allocations.

- The so-called market stability reserve has been envisaged for influencing supply. Its goal is to remove a volume of emission permits if climate policymakers believe that the GHG emission permit prices are too low.

Thus, it can be forecast that, although the political direction is directed towards raising the price of GHG emission permits, attempting to quantitatively forecast it is not expedient. Therefore, it is useful to enter the price into the model as it is at the time of running the simulation.

When biomass is used, the formula for calculating the fuel price to be input into the model is much simpler:

$$P^f_{(i)} = P^f_{bio(i)} + E_{\mathrm{CO2}} \times P_{EUA}, \tag{1.7}$$

where

$P^f_{(i)}$ – the price of fuel at the time of being entered into the boiler, EUR/MWh;

$P^f_{bio(i)}$ – biomass sales price with delivery at the heat source. MCs is carried out for this value, using information about the biomass market as raw data, EUR/MWh.

Whereas the addend $E_{\mathrm{CO2}} \times P_{EUA}$ must be used in the event when biomass that is compliant with the sustainability requirements set out in the EC directive on the promotion of the use of energy from renewable sources is not available on the market and the thermal energy producer must purchase GHG emission permits.

Costs of electricity

The electric power cost component is calculated according to Formula (1.8):

$$C^e_{(i)} = E_{(i)} \times P^e_{(i)}, \tag{1.8}$$

where

$C^e_{(i)}$ – electricity cost component, EUR/MWh$_{\mathrm{el}}$;

$E_{(i)}$ – specific consumption of electric power for thermal energy production, kWh$_{\mathrm{el}}$ / MWh$_{\mathrm{th}}$;

$P^e_{(i)}$ – the total price of electricity, EUR/MWh$_{\mathrm{th}}$.

The values of the specific consumption of electricity are obtained by means of MCs, in which data from the technologies database maintained by the Danish Energy Agency is used as input data. If the Regulator were to use the proffered benchmark model, input data for MCs shall be retrieved from reports received by the Regulator from real DH companies.

The total price of electric power is calculated according to Formula (1.9):

$$P^e_{(i)} = P^e_{w} + P^e_{r(i)} + P^e_{ns}, \tag{1.9}$$

where

$P^e_{(i)}$ – the total price of electricity, EUR/MWh;

P^e_{w} – the wholesale price of electricity, EUR/MWh;

$P^e_{r(i)}$ – retail markup on electricity, EUR/MWh;

P^e_{ns} – the sum of power supply system usage tariffs, EUR/MWh.

In a manner analogous to that of calculating gas prices, the wholesale price of electricity is a key element of the end price of electricity, and it can be assumed that it will be identical for all DH companies in one and the same time period and within a specific geographical area. Therefore, it is input into the model as a value that is constant within a specific time period, which is assumed from the data of electric power trading platforms.

In a manner analogous to that of calculating the prices of natural gas, MCs is carried out for calculating the retail markup on electricity, based on the assumption that various suppliers that compete with one another offer electricity to DH companies, offering slightly different electricity products.

The sum of power supply system usage tariffs consists of power transmission and distribution tariffs. The tariffs are regulated and, therefore, constant within a specific period of time and are identical for all the users of the electric energy supply system.

Capital expenditure

In the tariff benchmark calculation model, capital expenditure is calculated according to Formula (1.10):

$$C^{c}_{(i)} = wacc \times I_{(i)} / (1 - (1 + wacc)^{-n}), \qquad (1.10)$$

where

$C^{c}_{(i)}$ – capital expenditure, EUR;

$wacc$ – weighted average pre-tax price of the capital, %;

n – the economic life cycle of the heat source assets (investment made), years;

$I_{(i)}$ – the volume of investment into the creation of heat source assets, EUR.

Weighted average pre-tax price of the capital is a widely used parameter in a number of financial analysis calculations, and its calculated value comprises and reflects in a single number of the indicators of financial markets, countries, industries, as well as company capital structure and capitalisation indicators:

- risk-free rates of return on investment;
- premiums of various risks (of countries, industries, company size);
- various components of credit rates;
- ratios of correlation between the industry or company returns and security market returns (the so-called β-quotient).

The practice whereby the Regulator sets an identical *wacc* for specific groups of companies to be regulated or even industries for the purposes of regulation is rather widespread. Taking into consideration the fact that in the proffered tariff benchmark determination model, the *wacc* rate has been envisaged to be input as a single constant, the setting of it will remain within the competence of the Regulator and it will continue to be a sufficiently significant regulatory tool.

In the calculation model, the economic life cycle of the heat source assets (investment made) is used as a constant variable. In the sample calculation, the variable "15 years" has been used, which, on average, corresponds to the technical and economic life cycle of a modern heat source.

Investment into the creation of heat source assets is calculated according to Formula (1.11):

$$I_{(i)} = (I^{eq}_{(i)} + I^{ins}_{(i)}) \times Q \times (1 - s), \tag{1.11}$$

where

$I_{(i)}$ – the volume of investment in the creation of heat source assets, EUR;

s – co-funding support intensity ratio;

$I^{eq}_{(i)}$ – specific investment in equipment, 1000 EUR/MW;

$I^{ins}_{(i)}$ – specific investment in construction and fitting up, 1000 EUR/MW.

The co-funding support intensity quotient has been included in Formula (1.11) because co-funding support was rather easily accessible to DH companies in Latvia and in other Eastern European countries for a transition from power production from fossil to renewable energy sources. Within the regulatory practice, the exclusion of non-refundable co-funding from the capital expenditure to be included in the tariff is considered a balanced approach. In the sample calculation, the number 0.00 was assumed as the value for this parameter for heat sources that use natural gas, whereas for biomass, the value was assumed to be 0.30.

MCs is carried out for the values of specific investment in equipment because it has been assumed that the costs of heat source equipment vary case by case, but the technological solutions and composition of the equipment are rather homogeneous; therefore, the costs of the real projects should have a tendency towards an average value. The values required as input data for carrying out MCs were taken from the technologies data catalogue of the Danish Energy Agency; there is an extensive common European market for modern thermal energy production technologies; therefore, technology costs can be transferred for use in calculations under the conditions of another country without special adjustment. Whereas in case the Regulator were to use the method and benchmark model described herein, the input data could be created from the datasets accumulated by the Regulator from the reports submitted by the real companies.

MCs is also carried out for the values of specific investment in the construction and installation of equipment, and the technologies data catalogue of the Danish Energy Agency was used as the primary source of the input data values. However, in this case, an adjustment is made to account for the circumstances existing in Latvia because clearly, unlike the costs of technological equipment, the costs of construction and installation in Denmark differ substantially from those in Latvia. This is because of the vastly different levels of labour remuneration and the substantial proportion of labour costs in the costs of construction and installation. To adjust the data pertaining to Denmark to the circumstances existing in Latvia, the most simple variant of the benefit transfer method, which is widely used in environmental economics calculations, was used, whereby a value of a variable that has been expressed in terms of money and that has been determined in one country is transferred to another country, adjusting it by using a ratio of gross domestic products (see Formula (1.12)). The values of the indices of gross domestic product per capita in purchasing power standards (*PPS*)[7] for both countries from the Eurostat database are used for the calculation:

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[7] *Purchasing Power Standards.*

$$I^{ins} = I^{ins}_{DK} \times (GDP_{LV} / GDP_{DK}), \quad (1.12)$$

where

I^{ins} – the value of the specific investment in construction under the circumstances existing in Latvia, 1000 EUR/MW;

I^{ins}_{DK} – the value of the specific investment in construction sourced from the technology data catalogue maintained by the Danish Energy Agency, 1000 EUR/MW;

GDP_{LV} – the index of the Latvian gross domestic product in PPS;

GDP_{DK} – the index of the Danish gross domestic product in PPS.

Variable and fixed operational expenditure

Both the value of the variable operational expenditure component $C^{O\&Mv}_{(i)}$ and the value of the fixed operational expenditure $C^{O\&Mf}_{(i)}$ are obtained by means of the MCs method, using the data sourced from the technology data catalogue of the Danish Energy Agency as input data.

The most significant components of fixed operational expenditure are the costs of both operative and managerial personnel, including taxes, the costs of service agreements, real estate management expenses and taxes. The size of these expenditure items is substantially affected by the levels of prices, wages and taxes within a particular jurisdiction where thermal energy production takes place. Therefore, in a manner analogous to that of specific investment in construction, the Danish data pertaining to fixed operational expenditure is adjusted to account for the circumstances existing in Latvia by means of the value transfer method according to Formula (1.13).

$$C^{O\&Mf} = C^{O\&Mf}_{DK} \times (GDP_{LV} / GDP_{DK}), \quad (1.13)$$

where

$C^{O\&Mf}$ – the value of fixed operational expenditure under the circumstances existing in Latvia, 1000 EUR/MW;

$C^{O\&Mf}_{DK}$ – the value of the fixed operational expenditure sourced from the technology data catalogue maintained by the Danish Energy Agency, 1000 EUR/MW;

GDP_{LV} – the index of the Latvian gross domestic product in PPS;

GDP_{DK} – the index of the Danish gross domestic product in PPS.

If the regulatory authority chooses to use the proffered benchmark calculation method in practice, it will be possible to considerably improve the suitability of the input values for the simulation of operating expenses. If enough mutually comparable data from the reports of the real companies has been accumulated and is at the disposal of the Regulator, it will be possible to use the means and standard deviations of these real datasets as input data for MCs.

Calculation of tariffs and R_{tf} values

In the benchmark model, Formula (1.14) is used for calculating the thermal energy production tariff:

$$T^{pr}_{(i)} = C^{f}_{(i)} + C^{e}_{(i)} + C^{O\&Mv}_{(i)} + (C^{O\&Mf}_{(i)} + C^{c}_{(i)}) / Q^{pr}_{(i)}, \quad (1.14)$$

where

$T^{pr}{}_{(i)}$ – thermal energy production tariff, EUR/MWh;

$C^{f}{}_{(i)}$ – the fuel cost component (calculated according to Formula (1.3)), EUR/MWh;

$C^{e}{}_{(i)}$ – the electricity cost (calculated according to Formula (1.8)), EUR/MWh;

$C^{O\&Mv}{}_{(i)}$ – the variable operating expenses component, EUR/MWh;

$C^{O\&Mf}{}_{(i)}$ – fixed operating expenses (calculated according to Formula (1.13)), EUR;

$C^{c}{}_{(i)}$ – capital expenditure (calculated according to Formula (1.10)), EUR;

$Q^{pr}{}_{(i)}$ – thermal energy production volume (calculated according to Formula (1.2)), MWh.

All the variables included in Formula (1.14) that are required for calculating the tariff depend on the MCs that has been carried out and, accordingly, in the sample calculation, each of them has i = 1–1000 values. Thus, in the sample calculation, 1000 values are obtained for the thermal energy production tariff.

The calculation of the thermal energy production tariff benchmarks concludes with a calculation of dimensionless indicator R_{tf} that characterises thermal energy production tariffs, and it is calculated according to Formula (1.1).

The efficient thermal energy production benchmark that is to be input into Formula (1.1) – the fuel cost component in a BAT boiler plant is calculated according to Formula (1.15):

$$C^{f}{}_{bp} = P^{f}/\eta_{bp}, \tag{1.15}$$

where

$C^{f}{}_{bp}$ – the fuel cost component in a BAT boiler plant, EUR/MWh;

P^{f} – the price of the fuel prior to being entered into the furnace, EUR/MWh;

η_{bp} – the fuel use efficiency ratio in a BAT boiler plant.

When calculating the efficient thermal energy production benchmark, a variable that includes only those components forming the end price of fuel that the DH company is unable to influence is used as fuel price P^{f}, i.e., it does not comprise components the value of which may depend not only on the situation in the market but also on the commercial operator`s skills and wishes to find the most economically advantageous offers in the market, for example, retail margin and GHG emission permit price.

The efficiency ratio in a BAT boiler plant is one of the tools envisaged in the benchmark model that can be used by the Regulator to shape a specific policy of the industry by freely choosing the value of this parameter. If the policy envisages an aggressive stimulation of efficiency, a value that is close to the BAT indicator value available at that time or even identical to it should be chosen. Whereas if a policy aimed at gradually stimulating efficiency has been chosen, such a value for this parameter must be chosen that includes a tolerance in relation to the BAT indicator`s value while defining a trajectory for gradually increasing this indicator`s value.

2. RESULTS AND DISCUSSION

The calculation of the thermal energy generation tariff indicator R_{tf} was carried out in three scenarios according to the algorithm presented in Chapter 1:

1) thermal energy generation with the use of biomass;
2) thermal energy generation with the use of natural gas – moderate price scenario;
3) thermal energy generation with the use of natural gas – high price scenario.

The third scenario was developed due to the extremely rapid price increases observed after the full-scale war launched by Russia in Ukraine in February 2022 and the stabilisation of prices at a rather high level in the 2022/2023 winter season, which made us consider the hypothesis that the disruption of natural gas supply chains could sustain such high price levels (100–150 EUR/MWh) for a sufficiently long period of time.

Respectively, verification of whether the algorithm of the model would provide reliable prima facie results that were also sufficiently reliable over a very wide range of fuel prices had to be implemented. This is particularly relevant in the event of natural gas use, as the analysis of real company data demonstrated (see Chapter 1) that the fuel cost component of the thermal energy generation tariff was 80–85 % when using natural gas during the *moderate price* period, while processes in the wholesale natural gas market demonstrated that the price of natural gas could fluctuate by as much as 9–345 EUR/MWh over a two-year period.

2.1. Description of Results

For all three scenarios, result samples R_{tf}^{gbase}, R_{tf}^{ghigh} *and* R_{tf}^{bio} were calculated. Each of these samples contains 1,000 calculated R_{tf} values. From these result samples, the most important descriptive statistics parameters of the R_{tf} values corresponding to each scenario were calculated: the mean value, the standard deviation, the frequency distribution of the values in 10 bands, and an estimate of the probabilities of these frequencies.

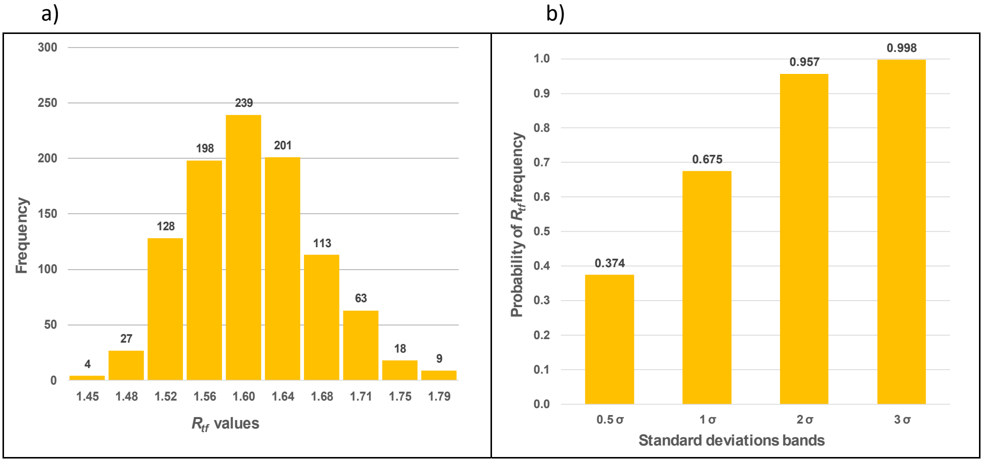
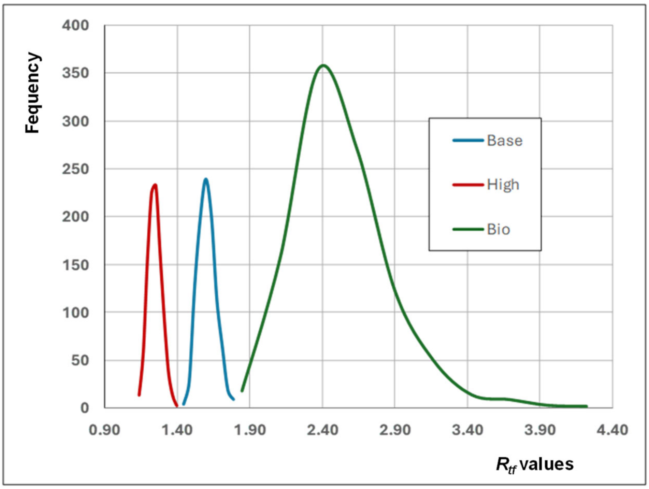


Fig. 2.1. Calculation results for the R_{tf} gas baseline scenario: a) R_{tf} frequency distribution; b) probability distribution of R_{tf} frequencies in standard deviation bands.

The illustration of the R_{tf}^{gbase} results in Fig. 2.1 shows that approximately 67 % of the R_{tf} values will be within ± 1 standard deviation of the mean value of the sample, and as many as 96% of the values will fall within the ± 2 standard deviation band. Thus, given the fact that the MCs of all the variables used in the calculation were requested to follow a normal distribution, the expected distribution of the R_{tf} frequencies is also close to a normal distribution and, therefore, sufficiently consistent with the set objective.

The results obtained in all three scenarios in graphical form are summarised in Fig. 2.2.

a)



b)

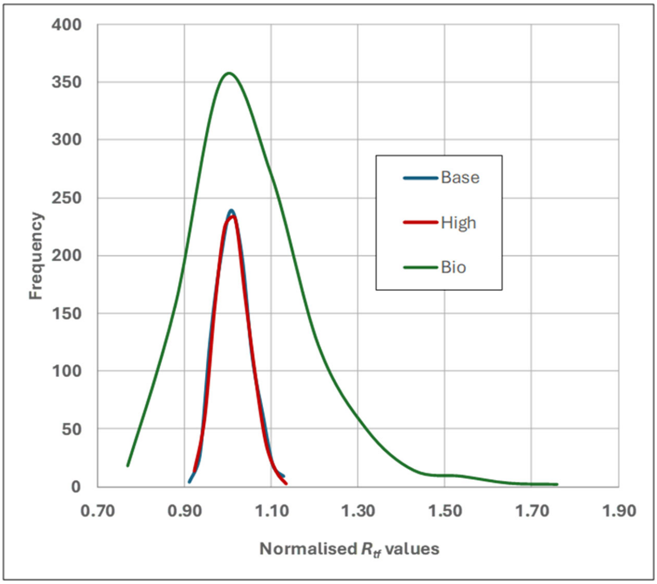


Fig. 2.2. Graphical summary of the results of the three scenarios: a) frequency distributions of absolute values of R_{tf}; b) distributions of normalised values of R_{tf}.

The summary of results is represented in two ways:

1. Frequency distribution of absolute values of R_{tf} (see Fig. 2.2 a)). The graphs of the absolute values of R_{tf} can be assessed as sufficiently consistent with the prima facie results, as they fit well into logical patterns. With the use of biomass, the values of the R_{tf} dimensionless characteristic of the thermal energy generation tariff range from 1.9 to 3.9 but are most commonly found at around the mean value of 2.4. These values are significantly higher than in the baseline scenario of natural gas use: 1.5–1.7 and 1.6, respectively, and even more so – in the extreme natural gas price scenario: 1.2–1.4 and 1.3, respectively. These ranges of values are very easy to explain if the actual tariff structure of real companies is examined. The share of capital and operating costs in the thermal energy generation structure most often fall within the range of 30–50 % when using biomass, but there are cases where it even exceeds half. In contrast, the share of capital and operating costs for natural gas, at reasonable prices for natural gas and emission permits, is most commonly below 20 %. Meanwhile, at very high fuel prices, this share falls even further. Respectively, the resulting R_{tf} values reflect the tariff structures reasonably well in the event of different fuel use and price levels – the higher the fuel price and the lower the share of capital and operating costs in the tariff, the lower the R_{tf} values.
2. Frequency distribution of normalised values of R_{tf} (see Fig. 2.2 b)). Evaluation of normalised R_{tf} values is also useful for better interpretation of the results. The normalised values are calculated by relating each real value against the mean value of the result sample, and the distribution graphs thereof provide a good indication of the dispersion of values in different scenarios. The conclusion can be made that the lower the fuel price and the higher the share of capital and operating costs in the cost structure, the higher the frequency dispersion of R_{tf} values. In the high natural gas price scenario, all 1,000 R_{tf} values fall within the range of 0.9–1.15 of the mean value of the sample, while in the biomass scenario, they fall within the range of 0.75–1.58 of the mean of the sample. The large difference in these dispersions can be explained by the differences in the cost structures of the different modelled scenarios. When using natural gas, the full price of natural gas has a decisive influence on the thermal energy generation tariff and, consequently, on the R_{tf} values. Meanwhile, the determining parameter of the fuel price is the price of natural gas on the wholesale market, which is the same in all MCs 1000 calculations. At the same time, the fuel cost component of the heat source with the so-called BAT, which is again directly dependent on the price of natural gas on the wholesale market, has an equally large impact on the R_{tf} values. The values of all other cost items, on the other hand, have much less of an impact on the results, despite the fact that 1,000 values of the constituent parameters obtained with MCs and the values of each parameter have a certain dispersion. Thus, the high share of fuel costs and the relatively small impact of operating and capital costs on tariff values also result in a low dispersion of R_{tf} values (the value of standard deviation is low). The opposite is true for biomass: the cost items for which MCs were carried out account for

approximately half of the production tariff. Accordingly, the dispersion of these cost items significantly disperses the R_{tf} values as well (the standard deviation value is high).

The graphical representations of the results of the R_{tf} calculations in Fig. 2.2 clearly demonstrate the positive asymmetry of the graphs: the result samples also contain R_{tf} values that are greater than the mean value by more than two standard deviations (right branch of the distribution graph), while not containing symmetrically lower R_{tf} values (left branch of the distribution graphs). This asymmetry is observed in the results of all three scenarios, and the prima facie distributions of the R_{tf} results resemble a log-normal distribution function. When analysing real economic processes, empirical distributions are quite often asymmetric and log-normally distributed, as various sample limitations are possible in the real economy. These are usually determined administratively: national governments tend to legislate minimum wage levels or, conversely, maximum levels, for instance, price caps and such.

If such an asymmetric distribution were obtained by processing the empirical data, according to statistical data processing theory, it is obvious that some methods of smoothing the empirical distribution will have to be used: logarithmic, square root, etc. However, the results of the tariff calculation model are derived from parameter values obtained with MCs.

In general, the MCs random number generator can generate any rational number. Depending on the nature of the input data – the mean value and standard deviation of the respective parameter – MCs can also generate negative values. However, a number of parameters (prices,[8] costs, consumption) are unlikely to have negative values under real conditions. Therefore, a restrictive selection is built into the calculation model for the MCs for these parameters – negative values are discarded. In assessing the potential impact of this limitation, it was found that the number of negative discard values for some parameters ranges from 0 to 20. If 1,000 values are generated by MCs, a 0.5–1.5 % shortage of values in the low-value branch of the R_{tf} beyond two standard deviations from the mean arises as a result of this limitation, but this does not significantly affect the frequency distribution of values up to two standard deviations from the mean value.

At the same time, the eventual result sample, with the very low values of R_{tf} being absent, is an adequate reflection of the economic nature of R_{tf}. The calculation of R_{tf} (see Formula (1.1)) shows that $R_{tf} = 1.0$ in the event that the heat is sold at a price that corresponds to the fuel cost component of the BAT boiler plant. This would mean that all other costs (operating, capital, etc.) are equal to zero. This could be considered as a borderline case that, in practice, could only occur in a few specific cases where a number of factors coincide: the assets are fully depreciated, but the operation thereof continues, fuel has been purchased at a particularly favourable price, and the efficiency of the boilers is higher than at the BAT boiler plant. Values that are even lower ($R_{tf} < 1$) should already be considered impossible under real circumstances, which would imply that the trader sells their product at a price below the cost component of the main input. However, such extremes could be observed in cases where the regulated merchant

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[8] In practice, there are exceptions. For instance, electricity wholesale platforms sometimes, at certain hours, experience negative *spot* prices. However, the tariff calculation model uses average prices observed over a longer period of time where short-term fluctuations are smoothed out.

is *overregulated* to the point where it is no longer able to recover the full economic cost of production while using the regulated tariff. Such extremes are caused by subordinating regulation to short-term political or even populist objectives, which in the long run would inevitably lead to a reduction in the quality and security of supply of the regulated service and even to the inability of the service provider to continue its operations.

2.2. Assessment of the Adequacy of Results

When assessing the results obtained as a result of a simulation, it is important to make sure they are sufficiently adequate to be accepted as representative of the actual situation.

It was initially assumed that running 1,000 simulations for each parameter would result in a number that is sufficient to ensure that the sample obtained as a result of simulations would not deviate significantly from the master set. In order to assess whether the assumption was sufficient, the required calculation of the sample size was carried out for the modelling result samples R_{tf}^{gbase}, R_{tf}^{ghigh} and R_{tf}^{bio}.

A significance level of $\alpha = 0.05$ was assumed, and in this case, the probability that the mean value of the sample does not differ from the mean of the population dataset by more than the random error $\Delta_{\bar{x}}$ is $P = 1 - \alpha = 0.95$. At $P = 0.95$, the critical value of the standardised normal distribution z_α = 1.96. It was assumed that the permissible random error $\Delta_{\bar{x}}$ in relative terms should be no more than 1.0 % of the mean value of the sample. The standard error describes the dispersion of the mean value of the set around the mean of the population dataset, or how high error is introduced by replacing the population dataset by the result sample, which, in our case, means replacing the real parameters by parameters obtained by means of MCs. The required sample size under the above assumptions is calculated by using Formula (2.1):

$$n = \frac{Z_\alpha^2 \times \sigma^2}{\Delta_{\bar{x}}^2}, \tag{2.1}$$

where

n is the required sample size;

Z_a – the critical value of the standardised normal distribution at the probability of $P = 0.95$;

$\Delta_{\bar{x}}$ – random error;

σ – standard deviation of the sample.

An inverse test calculation was performed for the R_{tf} result samples of all three scenarios in order to determine the size of the random error if a sample size is 1,000 simulations. The results summarised in Table 2.1 demonstrate that the results obtained by 1,000 MCs are sufficiently adequate, as the deviation of the mean of the set of simulated values from the mean of the master set is less than 1.0 % in relative terms at the probability of 0.95 %.

Table 2.1

Assessment of the Adequacy of Results

	Calculation of the required sample size at a given random error			Random error calculation at the number of simulations performed		
Scenario	Permissible random error in relative terms	Permissible random error	Required number of simulations	Number of performed MC simulations	Actual random error	Actual random error in relative terms
R_{tf}^{ghigh}	1.00 %	0.0123	57	1,000	0.0030	0.24 %
R_{tf}^{gbase}	1.00 %	0.0159	60	1,000	0.0039	0.25 %
R_{tf}^{bio}	1.00 %	0.0242	734	1,000	0.0208	0.86 %

2.3. Adaptation of the Benchmark Model for Use with a Mixed Fuel Structure

The benchmark model algorithm was originally developed for the cases where the structure of fuels used for thermal energy generation is homogeneous.

In practice, however, the number of DH companies using only one fuel for thermal energy generation is low. In Latvia, the most common fuel structure used by DH companies includes both fuels discussed above: biomass and natural gas. Typically, biomass accounts for the most significant fuel used in the fuel structure, which is typically used to power the major heat sources of a given DH system and provide the bulk of the base load of the respective system. Natural gas is used to cover peak loads and at smaller capacity fully automated unmanned boiler plants, where building a rational biomass logistics system is impossible due to technical and territorial constraints. There are also cases where gas is used because of its exceptional flexibility, for instance, along with a solar collector thermal system to cover for summer heat loads.

Respectively, most DH companies in Latvia that are using both fuels have in practice developed a fuel structure where 50–85 % of thermal energy is produced from biomass. Therefore, in order to make the developed benchmark algorithm applicable in practice, an adaptation for its use in the event of a mixed fuel structure needs to be developed.

As already concluded in Section 1.1, the type of fuel chosen for thermal energy generation determines all the parameters of such thermal energy generation: technological as well as financial. Furthermore, all correlations for the calculations of the cost of thermal energy generation are linear. Therefore, the assumption that it is adequate to base the algorithm for the case of a mixed fuel structure on the proportion of energy produced from different fuels was set as the guiding principle for the adaptation of the benchmarking algorithm. This approach is also consistent with the methodology of the Regulator used for calculating the thermal energy generation tariff in Latvia.

In accordance with this approach, a simple conditional limit case was selected for the algorithm adaptation calculations. It was assumed that the DH company has only two heat sources: one that uses biomass and the other that uses natural gas. Respectively, in this borderline case, the thermal energy generation tariff benchmark simulation algorithm for the heat source that uses natural gas is used for one heat source, and the thermal energy tariff benchmark simulation algorithm that uses biomass as fuel – for the other heat source.

In accordance with the algorithm described in Section 1.2, two sets of thermal energy generation tariff values are obtained as a result of MCs, each containing an *i* number[9] of distinct generation tariff values. Using the elements of both samples and applying an approach analogous to the methodology for calculating the thermal energy generation tariff, the *i* number of weighted average thermal energy generation tariff values is calculated according to the formula:

$$T^{pr}_{mix(i)} = T^{pr}_{bio(i)} \times q_{bio} + T^{pr}_{gas(i)} \times (1 - q_{bio}), \tag{2.2}$$

where

$T^{pr}_{mix\,(i)}$ – the weighted average thermal energy generation tariff, EUR/MWh;

$T^{pr}_{bio(i)}$ – thermal energy generation tariff for thermal energy generated from biomass, EUR/MWh;

$T^{pr}_{gas(i)}$ – thermal energy generation tariff for heat generated from natural gas, EUR/MWh;

q_{bio} – the proportion of heat produced from biomass, calculated according to the structure of thermal energy generation according to the formula:

$$q_{bio} = Q_{bio} / (Q_{bio} + Q_{gas}), \tag{2.3}$$

where

Q_{bio} – the amount of thermal energy generated from biomass, MWh;

Q_{gas} – the amount of thermal energy generated from natural gas, MWh.

Meanwhile, in order to establish benchmarks and to be able to assess heat tariffs according to this approach, it is also necessary to calculate the values of the dimensionless tariff variable R_{tf} for the mixed fuel case according to Formula (1.1) by attributing the thermal energy generation tariff values to the mixed fuel cost component of the heat source with the best available technology. In separate calculations for natural gas-only and biomass-only heat sources, the relevant BAT fuel components have already been calculated. By using these values and the characteristics of the fuel structure used by a particular DH company, the fuel cost component of a heat source with the best available technology in the case of a mixed fuel structure can be calculated in accordance with the formula:

$$C^f_{bpmix} = C^f_{bpbio} \times q_{bio} + C^f_{bpgas} \times (1 - q_{bio}), \tag{2.4}$$

where

C^f_{bpmix} – the fuel component at the BAT heat source at the specific share of biomass in the fuel structure of the DH company, EUR/MWh;

C^f_{bpbio} – fuel component at a biomass-only heat source with BAT, EUR/MWh;

C^f_{bpgas} – fuel component at a natural gas-only heat source with BAT, EUR/MWh.

The calculation of benchmarks in the case of a mixed fuel structure, as with a single fuel, is completed by the calculation of the set of R_{tf}^{mix} *i* number, which is carried out according to Formula (1.1). For illustration, Fig. 2.3 demonstrates the resulting frequency distributions of

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[9] In accordance with the conclusions of Section 2.2, the number of MC simulations performed in the benchmark model to obtain sufficiently adequate results is assumed to be $i = 1{,}000$.

absolute R_{tf} values for the cases of a mixed fuel structure at different biomass proportions compared to the frequency distributions of R_{tf} values, if only natural gas or only biomass is used for thermal energy generation.

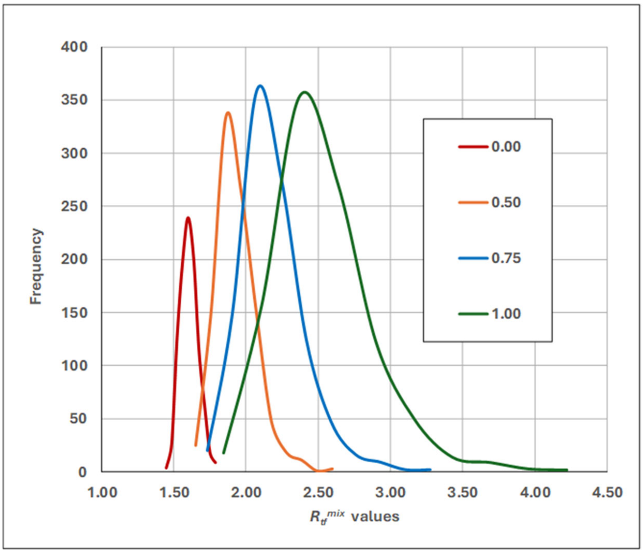

Fig. 2.3. Graphical comparison of the absolute frequencies of R_{tf}^{mix} with R_{tf}^{gbase} (q_{bio} = 0.00) and R_{tf}^{bio} (q_{bio} = 1.00) if the biomass share in the fuel structure is: q_{bio} = 0.50 and q_{bio} = 0.75.

The principal parameters that characterise the sample were calculated for all four R_{tf} result samples as well. These parameters are summarised in Table 2.2.

Table 2.2

Characteristics of R_{tf} Result Samples

	R_{tf}^{gbase}	R_{tf}^{mix}, $q_{bio} = 0.50$	R_{tf}^{mix}, $q_{bio} = 0.75$	R_{tf}^{bio}
Mean value	1.588	1.875	2.090	2.389
Standard deviation	0.062	0.126	0.198	0.305
Min – Max	1.409 – 1.860	1.603 – 2.500	1.642 – 3.114	1.692 – 3.969
Kurtosis	0.157	1.831	1.958	1.904
Skewness	0.208	0.916	0.999	1.000

The numerical values of the parameters of the result samples demonstrate that for a mixed fuel structure, the modelled frequency distributions of the absolute R_{tf} values and the nature of these distributions reflect a logical dependence on the q_{bio} parameter that characterises fuel structure.

1. If R_{tf}^{gbase} and R_{tf}^{bio} are assumed to be borderline cases, then both the frequency distribution graphs of the R_{tf}^{mix} values and the parameters of the result samples lie between the corresponding parameters of R_{tf}^{gbase} and R_{tf}^{bio}. Furthermore, as the value of q_{bio} increases, both the graphs and the aforementioned values move in the direction of R_{tf}^{bio}.

2. *Skewness*, which describes the symmetry of the distribution of values, is positive in all cases. This means that the graphs have an extended right branch and a reduced left branch. The distributions of R_{tf} scores have this character due to the constraints introduced in the benchmark algorithm, which are explained in Section 1.2. As the value of q_{bio} increases, the asymmetry ratio increases slightly. This trend can be explained by a greater dispersion of values as q_{bio} increases, which is also evidenced by the trend in the standard deviation.
3. *Kurtosis* in all scenarios is positive, which means that the graphs are more peeked compared to the ideal normal distribution, but within acceptable limits (do not exceed 2).

2.4. Assessing Tariffs for the Transmission and Distribution of Thermal Energy

If the benchmark model is applied to thermal energy generation tariffs, regulatory simplification would affect at least 70–80 % of the total heat supply tariff. The remaining 30–20 % of the total tariff is constituted by the thermal energy transmission and distribution tariff, which is an important component, and therefore, it should be considered whether the regulation of this tariff could also be simplified and how.

The modelling and research of the costs of the transmission and distribution network of DH systems have led to the conclusion that the technological and economic process of thermal energy generation is fundamentally different from that of heat transmission and distribution, as described in Table 2.3.

Taking the aforementioned important differences into account, it has been concluded that the dimensionless solution R_{tf}, which is adequate for thermal energy generation, is unsuitable for the analysis and modelling of the costs of heat transmission and distribution systems. Therefore, the *R* programming environment and the so-called *black box*[10] modelling approach were used as a tool to find relationships between parameters characterising heating networks and transmission and distribution costs. As a result, relationships were found to determine the total cost of heat transmission and distribution in both linear and non-linear forms (see Formulae (2.5) and (2.6)) by using only two input parameters.

$$C_{TOT} = -176.71 + 2304 \times L + 0.99 \times D_{max} , \tag{2.5}$$

$$C_{TOT} = 25.41 + 22.99 \times L + 5.77 \times 10^{-9} \times D_{max}^4 , \tag{2.6}$$

where

C_{TOT} is the cost of heat transmission and distribution, EUR 1,000 per year;

L – total length of the heat network system, m;

D_{max} – the largest diameter of piping in the heat network, mm.

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[10] An approach to process and system modelling that looks for relationships between known input parameters (in this case – technical and operational performance of heating networks) and known output parameters (in this case – the costs of heat transmission and distribution), without studying and describing the internal aspects and relationships of the system under study.

The obtained results are illustrated in Fig. 2.4 and reflect the relationship between the actual total heat transmission and distribution costs of specific DH companies (represented by the dots) and the costs estimated by using the obtained relationships (the line in the graph represents the results obtained by a linear relationship).

Table 2.3

Comparison of Heat Supply Processes

Generation	Transmission and distribution
Elements of competition can be observed; in large systems, they can be approximated to market principles	A local and natural monopoly
Dynamic business environment, investments are coming in fast	The business environment is relatively stable over time
The economic life cycle of technologies is 10–15 years	The economic life cycle of technologies is 30–40 years
A very wide range of capacities and technologies, but, in fact, technologies can be divided into large nominal groups by fuel type	Each specific system is unique in terms of configuration, but at the same time, the systems are homogeneous and can be accurately described by geometric parameters (pipeline lengths and diameters)
All cost groups are subordinated to the choice of fuel type	All cost groups are subordinated to geometrical parameters
One technical indicator – efficiency ratio – affects 60–85 % of the cost of the production tariff	There is no single indicator with such a large and pronounced impact on the tariff. Technical indicator that is analogous to the production efficiency ratio – specific losses affect up to 30 % of the transmission and distribution tariff costs
Simple mathematical tools are sufficient for analysis and modelling	Sophisticated mathematical methods must be used for analysis and modelling

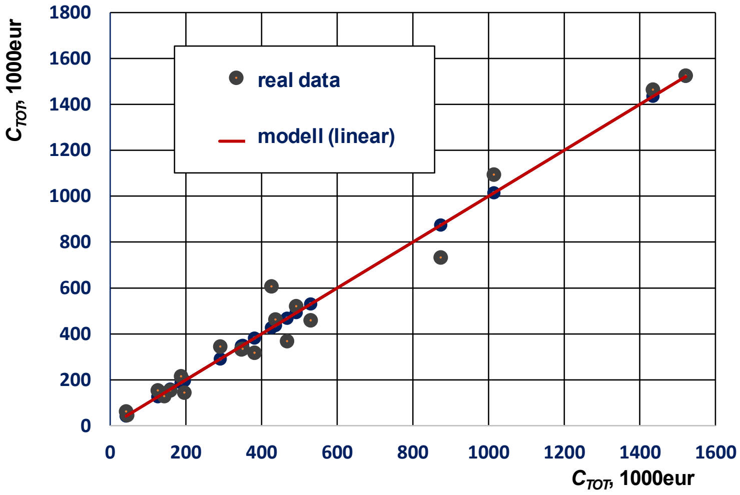

Fig. 2.4. Results of modelling the total costs of heat transmission and distribution.

Despite the fact that only two parameters are used as inputs in these relationships, the characteristics of the two relationships shown in Table 2.4 not only demonstrate that the relationships found between the modelled and actual values of the target indicator are very strong but also that the two inputs have a decisive impact on the results.

Table 2.4

Characterisation of Relationship of Modelling the Costs of Heat Transmission and Distribution

Type of relationship	R^2	p-value
Linear regression	0.9636	5.9E–13
Non-linear regression	0.9747	7.9E–16

Thus, adequate modelling results can be obtained with a small number of input parameters, provided they have a significant impact. Respectively, modelling and benchmarking of heat transmission and distribution costs and tariffs is feasible and could be based on a small number of the most relevant parameters. This approach could be developed further in an attempt to strive for even greater precision if the heat transmission and distribution tariff is considered as the sum of its most important components. In general, the heat transmission and distribution tariff can be broken down into three main components:

$$T^{td} = (C^{hl} + C^{O\&M}_{nw} + C^{c}_{nw}) / Q^{ec}, \tag{2.7}$$

where

T^{td} – tariffs for the transmission and distribution of thermal energy, EUR/MWh;

Q^{ec} – the amount of heat energy supplied to end-users, MWh;

$C^{O\&M}_{nw}$ – operating costs of the DH network system, EUR;

C^{c}_{nw} – capital cost of the DH network system, EUR;

C^{h} – cost of heat losses, EUR, calculated according to Formula (2.8):

$$C^{hl} = Q^{hl} \times T^{pr}, \tag{2.8}$$

where

Q_{hl} – heat losses in networks, MWh;

T^{pr} – thermal energy generation tariff, EUR/MWh.

In this approximation, the heat loss component can be assumed to represent the variable costs of heat transmission and distribution, while the operating and capital costs of the heating network system can be assumed to be fixed.

Cost modelling studies of heating networks and analysis of the actual tariff structure for heat supply make it clear that heat loss costs typically account for around 25–45 % of total heat transmission and distribution costs. Meanwhile, Formula (2.8) demonstrates that this value is determined equally by the thermal energy generation tariff and the heat losses in the networks. Losses in the networks are, in practice, usually characterised by the relative indicator q_{hl}, which shows the % of the heat input to the system that is lost in the networks. In modern DH systems, relative network losses in high-density building areas do not exceed 5–8 %, while in lowdensity areas, they can reach 15–25 %. The heat losses of the systems covering areas of different building densities typically account for 9–10 % of the heat. The main factors that determine this figure are the technical condition of the heating networks and the load. Thus, similar to the efficiency ratio of a heat source in heat generation, the relative losses in heat transmission and distribution could be the most important indicator that characterises the technology itself and the efficiency of its use. Like the efficiency ratio of thermal energy generation, the Regulator could set an adequate reference value for this indicator, which, in combination with the benchmark for thermal energy generation, would effectively lead to a benchmark for the variable costs of heat transmission and distribution.

Thus, it can be assumed that if the model of thermal energy generation tariff levels facilitates the regulation of 70–80 % of the total tariff, the direct extension of this approach to the variable costs of heat transmission and distribution would already cover 85–95 % of the total heating supply tariff.

As regards the remaining part of the tariff – the fixed costs of heat transmission and distribution – the Regulator could use the findings of the heat network parameter modelling studies referred to in this chapter for obtaining sufficiently adequate results by using a small number of parameters, which are, however, crucially important. In addition, the Regulator has the advantage of possessing complete information on all regulated DH network systems,[11] while the voluntary participation of the most responsive members of the Latvian Association of Heat Supply Companies in a survey was used for the analysis in this chapter, resulting in data on 21 DH transmission and distribution systems.

2.5. Basic Principles for the Practical Use of the Benchmark Model

The following assumptions were made to define the basic principles for the practical use of the tariff benchmark model:

1. The Regulator shall continue to perform the monitoring function of DH companies and to receive annual performance reports from all energy sector merchants, which include both technical and financial data. Thus, the Regulator obtains accurate data on the real values of all parameters required for the determination of the heat tariff during the same reporting period from all regulated merchants, including not only the real data of all DH companies but also the actual values of the parameters that characterise the principles of price formation for the external resources that affect DH (natural gas, biomass, electricity).
2. The condition that the calculation of the heat production tariff must consistently follow a certain methodology is maintained. The algorithm formulas of this methodology are built into the benchmark model. The format of the annual reports of the heat supply merchants is also consistent with the tariff calculation methodology.

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[11] More than 60 in Latvia.

For the practical application of the benchmark model, the Regulator should perform the following activities:

1. By using the information contained in the reports of DH companies, the Regulator establishes and maintains a database of parameters required for the calculation of thermal energy generation costs.
2. For the sets of real parameter values accumulated in the database, simple descriptive statistical analysis methods are used to calculate the characteristics of these sets (mean value, standard deviation), which are further used as inputs for the MCs of these parameters to obtain, for instance, a 1,000 value variations, which, as concluded in Section 2.2, is a sufficient number to recognise that the resulting distribution of values is an adequate reflection of real market-like conditions.
3. The thermal energy generation tariff result samples are calculated according to the formulae described in Section 1.2.
4. The Regulator shall select the thermal energy generation efficiency ratio for the thermal sources with BAT that are using natural gas and biomass as fuel, respectively, and calculate the result samples of dimensionless indicator R_{tf} that characterises the thermal energy generation tariff and the probability distribution of these results. The considerations and recommended approach for the selection of the BAT efficiency ratio are described in Section 2.6.

As a result, the Regulator, with the use of MCs, has obtained an overall view that adequately reflects the market in the situation where 1,000 companies produce heat from natural gas or biomass and keep accounts and calculate their costs according to common principles. Real data from any single trader is not decisive but it influences the overall data set and shapes trends, just as it would do in a real market.

Next, the Regulator selects and sets the benchmark R_{tf}^{bm} for the frequency probability distribution of R_{tf} values. This selected benchmark would, in fact, be the resulting decision of the Regulator, as it would set a threshold up to which the Regulator would consider the R_{tf} parameter characterising the tariff of a given operator to be appropriate for the market situation and beyond which the Regulator would have to intervene.

However, the actions and obligations of a DH company under the proposed regulatory model would be as follows:

1. The companies shall structure and account for the costs of thermal energy generation in accordance with the methodology established by the Regulator and shall submit to the Regulator reports on their performance parameters in accordance with the established form and within the established deadlines.
2. The tariff (sales price) of the thermal energy produced shall be determined by the merchants themselves in accordance with the methodology established by the Regulator.
3. The companies shall submit the tariff determined by them and the information on the actual fuel structure indicator, q_{bio}, to the Regulator.

Next, the Regulator shall examine the tariffs submitted by the merchants against the benchmark. If the particular merchant uses a mixed fuel structure, the Regulator shall first, from the R_{tf}^{gas} and R_{tf}^{bio} data samples, calculate the R_{tf}^{mix} dataset corresponding to the actual fuel mix indicator q_{bio} of the respective merchant according to the principles proposed in Section 2.3. From the tariff determined by a particular operator (for instance, operator *A*), the Regulator shall calculate the corresponding R_{tf}^{A} and compare it with R_{tf}^{bm}. The evaluation of tariffs against the determined benchmark is illustrated graphically in Fig. 2.5.

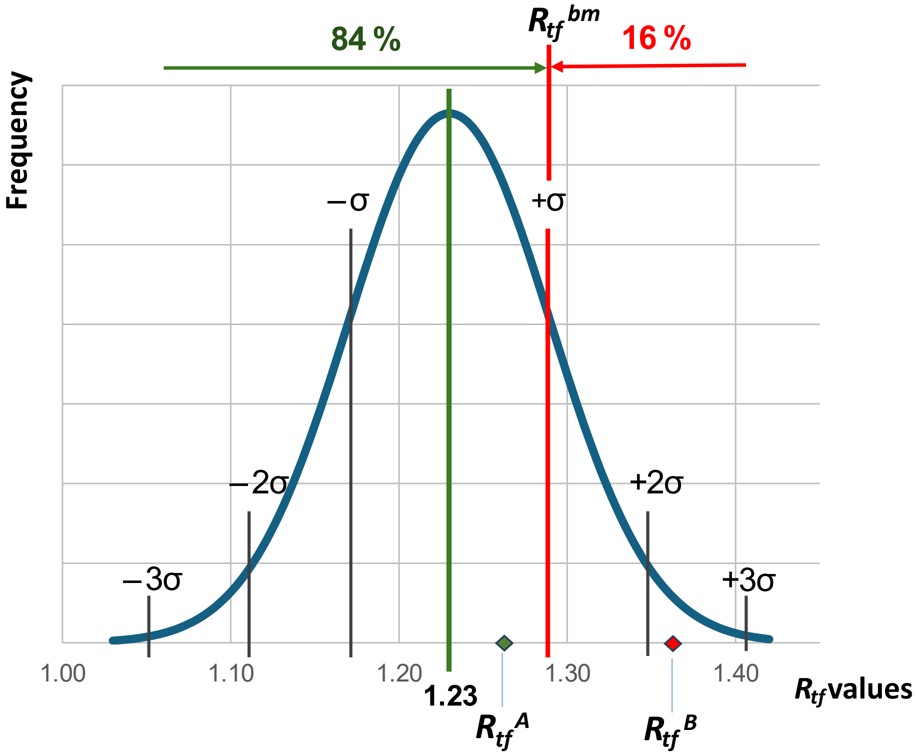

Fig. 2.5. Evaluation of specific merchant tariffs against the Benchmark.

The schematic illustration of tariff evaluation provided in Fig. 2.5 demonstrates the R_{tf} values corresponding to the tariffs of two DH companies (merchant *A* and merchant *B*) relative to the frequency probability distribution and benchmark R_{tf}^{bm} of the entire set of R_{tf} values:

- If $R_{tf} \leq R_{tf}^{bm}$ (for the tariff of the merchant *A* in Fig. 2.5), then the Regulator concludes that the tariff for thermal energy generation established by the merchant in question corresponds to the market situation, the operations of the merchant are sufficiently efficient, and the profit is reasonable.
- If $R_{tf} > R_{tf}^{bm}$ (for merchant tariff *B* in Fig. 2.5), then the Regulator concludes that the particular case does not fit within the framework of optimal operation, and the intervention of the Regulator is required.

2.6. The Benchmark Model as a Regulator’s Tool for the Implementation of Energy Policy

The development and use of a heat tariff benchmark model would enable a fundamental change in the regulatory regime – moving away from scrupulous *ex-ante* regulation and focusing the activities of the Regulator on monitoring and providing incentives for the efficiency of DH companies. The use of the proposed benchmarking algorithm would also drastically simplify and speed up the regulatory procedure, as the proposed approach would no longer require the Regulator to scrutinise the detailed calculations of the draft tariffs of each DH company and the huge volume of supporting documents, which would free up resources of both DH companies and the Regulator to address more important issues.

The Regulator, as an energy policy enforcer, could use the benchmark model for incentive regulation, as the mechanisms built into the algorithms of the model provide the Regulator with the tools that enable the Regulator to direct DH companies towards efficiency improvements.

By setting certain thresholds for the calculation of benchmarks in line with *best practice* indicators, as well as tolerances for deviations from the model results, the Regulator can achieve benchmarks that promote efficiency on the one hand and are realistically achievable on the other. Furthermore, as technology advances, the Regulator may gradually notice them, thus stimulating DH companies to move closer to *best practice* examples.

With the use of the proposed benchmarking model, the Regulator has four tools or activities for the implementation of incentive regulation:

1. Updating the input data needed by MCs in line with the upward trend in the actual performance of DH companies. The Regulator should update the data used for the MC simulation and recalculate the benchmarks with certain regularity, including the use of certain parameter values as a specific incentive tool by the Regulator (for instance, the standard deviation $t_{(\sigma)}$ of the installed capacity utilisation parameter mentioned above). This would ensure that the benchmark model is always up-to-date and adequately reflects trends occurring in the sector. In practice, it would be useful to align this process with the periodicity of reporting by regulated companies.
2. Incorporating new thermal energy generation technologies into the benchmark model. The design of the model for the benchmark algorithm was based on the analysis of real data. Therefore, the model elaborates on the formation of thermal energy generation costs in detail in the situation where the dominant energy resources used in heat supply in Latvia – natural gas or biomass – are used. At the same time, new technologies for thermal energy generation are developing rapidly and are likely to make a decisive contribution to the conversion of DH to climate-neutral solutions. Accordingly, with the use of the algorithm for the cases of mixed fuel structure, the benchmark model can be extended with new calculation modules to simulate the use of new thermal energy generation technologies.
3. Energy production efficiency parameter at a BAT heat source. The Regulator must follow the technological developments in the sector and, if necessary, update the BAT efficiency figures for thermal sources used in the benchmark model.

4. Defining the R_{tf}^{bm} benchmark. This value is the decisive and aggregating instrument for incentive regulation. It depends on all inputs to the benchmark model and summarises the impact of the three previous instruments. On the other hand, the definition of this value is a comprehensive formulation of the opinion of the Regulator, as an implementer of sectoral policy, regarding the efficiency of thermal energy generation.

Based on the characteristics of these regulatory instruments, a conclusion can be drawn that, when using the benchmark model, the decisive choices of the Regulator involve the definition of the BAT efficiency indicators and R_{tf}^{bm}. Both of these values cannot be defined in exact terms, but, in practice, they should be used by the Regulator to simulate the *behaviour of market forces*.

In an absolutely competitive market, which is only a theoretical construct, the R_{tf} values characterising the tariffs of all companies would tend towards a single R_{tf} value – in the graph provided in Fig. 2.5, this would be the mean value of the R_{tf} distribution. However, in the real market, there is quite a lot of diversity. Suppliers of fuels, technologies and other goods and services required by DH companies compete in these markets. Thus, the market is subject to interacting forces of suppliers, buyers, as well as many other variables (consumer behaviour and habits, general business regulations, industry policies, national and local taxes and duties, etc.). Therefore, in the real market, the distribution of the indicator that characterises tariffs would be similar to that obtained in the benchmark model.

In a real competitive market, the strongest and most efficient players should *survive*, as *market forces would also conditionally draw a benchmark line*. In reality, of course, no such single marker exists, but the most efficient market members or new entrants exert the most pressure on the less efficient. In the R_{tf} distribution graph (see Fig. 2.5) obtained with the help of the benchmark model, these are most likely to be represented by the right-hand branch of the plot beyond 1–1.5 standard deviations from the mean value of the distribution, i.e., 9–16 % of most inefficient companies out of the total number of merchants.

Similarly, as the Regulator simulates *market forces*, the pressure to become more efficient should be exerted on the DH companies exactly in this range. By drafting R_{tf}^{bm} at the distance of one standard deviation, the Regulator would effectively have decided that around 84 % of the tariffs of DH companies are compliant, and the Regulator could authorise their use without scrutiny. However, the Regulator may gradually shift the boundaries of this range to stimulate improvements in efficiency.

The regulator, when using the tools offered by the benchmarking model, should act in a balanced way, both in terms of increasing the efficiency of existing technologies, as well as introducing new innovative solutions.

In terms of improving the efficiency of already proven and widely used technologies, incentive-based regulation would work quite simply in a purely technical sense. By regularly updating the inputs to the benchmark algorithm, the algorithm will gradually incorporate both the latest up-to-date technology performance indicators and market-appropriate investment and operating costs. Accordingly, the benchmark model would follow the real developments in the sector, and the simulated values would incorporate the impact of both technological developments and changes in price indices.

The most complex issue in motivating DH companies to adopt newer efficient technologies lies in the balance of efficiency requirements and the ability of companies to recover the investments made in adopting these technologies and in the question of how to simulate the conditions under which a free-market company would make investment and innovation decisions.

However, in an over-regulated business environment, like the one observed in the regulation of heat supply in Latvia, it is not expected that merchants will have a genuine initiative to innovate and seek efficiency solutions. An over-regulated environment creates a stationary, reactive and self-replicating economic process that, in fact, only reproduces existing assets at a very limited rate of return, often not even covering the true cost of funding.

Incentive regulation should, therefore, ensure that those companies that invest first in new efficient technology, while at the same time incurring new capital costs, benefit from a sufficiently rapid return on investment and also make a reasonable profit – as an adequate reward for investing in innovation and risk-taking. This could be achieved if a new technology benchmark module or a dramatic improvement in efficiency parameters of a traditional technology were not included in the benchmark model as soon as the relevant data is collected and accumulated, but with a certain time lag.

A similar process naturally occurs in competitive markets. Early adopters can make significant profits for a certain period of time, until the technology is gradually taken up by competitors, and their pressure reduces prices and the profit of the early adopter.

Respectively, when using the benchmark model, new technologies should be included as a new calculation module in the algorithm once their use and distribution have become more widespread. From then on, the tariff characteristics simulated in the benchmark model will also reflect the impact of the new technology, which will result in DH companies having to gradually reduce their product prices, which will, in effect, mean that the benefits of the new technology will start to be redistributed to the benefit of consumers.

Although the proposed method for the benchmark model is not complex in principle, in practical terms, it requires work with large data sets. At first sight, this would seem to contradict one of the original requirements of the envisaged regulatory model – a reduction in the consumption of Regulator resources. However, on the other hand, once the benchmarking algorithm is set up, further data processing can be broken down into simple, repetitive procedures. In practice, therefore, both the extraction of data from DH companies and the processing of the obtained data should be fully supported by modern information technology solutions. Furthermore, it can be presumed that data processing, simulations, R_{tf} calculations and analyses necessary for the decisions of the Regulator should be entrusted to AI tools.

In turn, the creative expertise, competence and experience of the Regulator should be used to select the benchmark itself and the decisions on action to be taken regarding DH companies above the benchmark that have been outlined below.

In cases where the tariff applied by a particular DH company would fail the test built into the benchmarking algorithms, the Regulator shall conclude that the particular company has earned income that is unreasonable for the market situation and order a tariff reduction sufficient not only to meet the benchmark test requirements but also to compensate for the excess income earned in the previous period.

The way forward could be twofold: either the DH company agrees to revise its tariff, find ways to reduce it and resubmit it for retesting, or the respective company submits the full tariff calculation to the Regulator for due diligence that follows the full tariff test procedure. When reviewing the full draft tariff, the decisions of the Regulator could take three forms:

1. The Regulator verifies that the DH company in question is currently unable to provide heat at a benchmark-compliant tariff but, at the same time, concludes that it is possible to implement improvements and bring the tariff into compliance within a certain timeframe. In this case, a fixed-term tariff may be approved, specifying a transitional period within which compliance must be reached.
2. The Regulator verifies that the DH company in question is subject to objective circumstances that are beyond its control which make it impossible for the company to provide heat supply at a tariff that complies with the benchmarks and shall approve the tariff.
3. The third could be an extreme case where the Regulator concludes that there is no economic justification for maintaining a DH system in the particular location (for instance, DH systems with critically low load factors in small settlements with a strong depopulation trend). In such cases, the Regulator should make a drastic recommendation – to carry out planned decentralisation of the DH system and the construction of local heating sources.

Finally, the Regulator should also pay due attention to those cases where the tariff indicator R_{tf} is skewed to the extreme left of the R_{tf} distribution graph. Such cases may point to a risk that the company in question is unable to recover all the costs necessary for sustainable heating supply due to some circumstances. Given the fact that the Regulator is responsible not only for consumer protection but also for the sustainability and development of the business activities.

3. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. In a context where the whole European energy sector is undergoing a fundamental transformation towards decarbonisation, DH regulation also needs to transform and move as closely as possible to market principles, not only to stimulate DH companies to raise their operational efficiency but also to guide them towards investing in technologies relevant for achieving climate neutrality, while adapting to new consumer demands.
2. The analysis of regulatory theories, methods and practices leads one to the conclusion that no ideal approach can be defined for the regulation and no universal and ideal method of regulating prices and tariffs can be found. Both a fully liberalised heating supply market and strong regulation of the heating sector have multiple drawbacks. Therefore, an optimal middle ground between these two alternatives must be sought, and the approach to the regulatory regime must be subject to certain objectives.
3. The DH tariff benchmarking method developed within the framework of the Thesis, based on the simulation of virtual DH market conditions using a Monte Carlo simulation model, is proposed as an optimal compromise between the *over-regulation* and full liberalisation of the DH sector.
4. From the results of the analysis of actual DH company data used to design the tariff benchmarking model, it was concluded:
   - The design of a benchmark model cannot be based solely on empirically derived regression equations, and tariff setting cannot be simplified, for instance, by trying to find a single tariff ceiling benchmark expressed in absolute value that all DH companies should aspire to or some different benchmarks for the most representative groups of DH companies or systems.
   - The processing of real company data with more sophisticated statistical analysis tests shows that the samples of both the tariff values and the values of the most important elements of their calculation, stratified by the type of fuel used, possess statistically significant differences and that the empirical distribution of these values follows a normal distribution with a high degree of confidence. Therefore, for benchmarking purposes, calculation modules for MCs should be created separately for each fuel type that is used.
5. The key element of the tariff benchmark model is a dimensionless value of R_{tf}, which describes the ratio of the thermal energy generation tariff of each DH company to an efficient heat generation benchmark – the fuel cost component of the BAT heat source. Frequency distribution of R_{tf} values generated by MCs simulates the situation that would arise in a specific DH supply market under competitive conditions.
6. The assessment of the obtained results shows that they are sufficiently adequate:
   - The evaluation of the random error of the results is estimated to be less than 1 % for all calculation scenarios, and thus, the general results generated by the MCs can be accepted as adequately describing real-world conditions.

- The values of the parameters that characterise the samples of results obtained by different calculation scenarios correctly reflect the specific nature of the thermal energy generation costs depending on the structure of the mix of fuels used. The higher the share of fuel costs in the cost of thermal energy generation, the narrower the range of R_{tf} values and the lower the standard deviation. In the moderate natural gas price scenario, with the use of natural gas only, the R_{tf} averages at 1.875 and the standard deviation is 0.126. As the share of biomass in the structure of the fuel mix increases, both the mean R_{tf} value and the dispersion of these values gradually increase until the mean R_{tf} value reaches 2.389 and the standard deviation – 0.305, if biomass alone is used. This trend reflects real-world conditions, where using biomass for heat production increases the impact of operating and capital costs, resulting in more dispersion of heat tariff values.

7. The model of heat tariff benchmarks developed within the framework of the Thesis is not complex, and widely available everyday IT solutions are sufficient to support its use. Thus, it is not difficult to add user-friendly interface solutions to the model and put such into practice. Practical use of the benchmark model enables the Regulator to easily calibrate it to a higher degree of accuracy, as the Regulator has access to all the real data of all regulated companies that can be used to determine the inputs to the MCs.
8. An overall conclusion can be made that the developed benchmark model, its properties and possibilities of application bear evidence that the hypothesis is fulfilled, the objective of the Thesis is achieved, and the tasks are fulfilled.

Recommendations

1. The development and use of the proposed algorithm for setting the thermal energy tariff benchmarks would drastically simplify and speed up the regulatory procedure. The Regulator could fundamentally change the regulatory regime – moving away from scrupulous *ex-ante* regulation and scrutiny of the detailed calculations of the draft tariffs of each DH company. This would free up the resources of both the DH company and the Regulator to address more important issues.
2. The Regulator, as an energy policy enforcer, could use the benchmark model to provide incentive regulation, as the mechanisms built into the benchmark model algorithms provide the Regulator with the tools to drive DH companies towards efficiency improvements. By setting certain thresholds for the calculation of benchmarks in line with *best practice* indicators, as well as tolerances for deviations from the model results, the Regulator can achieve benchmarks that promote efficiency on the one hand and are realistically achievable on the other. Furthermore, the Regulator may gradually reduce them in line with technological developments, thus stimulating DH companies to move closer to best practices.
3. Meanwhile, for DH companies, the introduction of a DH regulation method that mimics market conditions would:
   - improve long-term business planning;

  - increase incentives to invest on a commercial basis in efficiency and emission reduction technologies such as heat pumps, use of low potential *residual heat*;
  - create the conditions for a flexible pricing and tariff structure to adapt to new consumer demands and the integration of *active consumers* into DH systems;
  - facilitate the preparation of DH systems as large-scale and controllable energy storage elements for synergies with the electricity supply system to increase its resilience, which will be a key factor in transforming the electricity supply and integrating fluctuating and non-controllable RES generation sources as efficiently as possible.
4. The algorithm and model developed in the Thesis also open further research opportunities, as they can be used not only for practical regulation of DH but also for studying the dynamics of tariffs under the influence of changes in various external factors.

Uģis Sarma was born in 1965 in Riga. He obtained an energy engineering diploma (1990) and a Master's degree in Environmental Science (2005) from Riga Technical University. He also graduated with a professional degree in Economics from BA School of Business and Finance (2003). His experience in the energy sector started with work at an energy consultancy company more than 30 years ago. From 2001 to 2009, he headed the Energy Department of the Ministry of Economics, and from 2010 to 2013, he worked at the Public Utilities Commission, managing district heating and cogeneration regulation affairs. Since 2013, he has been working with Latvenergo Group strategy issues, holding the position of Director of Corporate Strategy of Latvenergo AS. His scientific interests are related to the socioeconomic aspects of energy sector.