Czech Technical University in Prague

Faculty of Electrical Engineering

Doctoral Thesis

August 2016 *Ing. Jiří Vecka*

Czech Technical University in Prague

Faculty of Electrical Engineering
Department of Economics, Management and Humanities

MODELLING OF IMPACTS OF CO_2 AUCTIONS ON THE DISTRICT HEATING SECTOR

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Prague, August 2016

Ph.D. Programme: Electrical Engineering and Information Technology
Branch of study: Business Management and Economics

Supervisor: ***prof. Ing. Jaroslav Knápek, CSc.***

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1 Acknowledgment

I would like to express my gratitude to my supervisor, prof. Ing. Jaroslav Knápek, CSc., for his valuable comments and contributions. I would also like to give thanks to my colleagues at work and to my family for their help and tolerance during my work.

I, Jiří Vecka, confirm that the work presented in this doctoral thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Jiří Vecka, 31st August 2016

2 Abstract

This doctoral thesis is describing major aspects of district heating technology and its position within energy sector in the context of the Czech Republic and EU as well and the most important district heating features. According to acknowledged European methodology, district heating networks delivering heat from CHP process could be regarded as one of the most efficient solution for covering heat needs. The core of the thesis is devoted to description and modelling the factors influencing the heat market, legislation factors could be seen as most important with potential to severely influence the market conditions. Optimization model of differential NPV was chosen as optimal solution for comparing the development in business-as-usual situation and under the new requirements and each relevant legislation effect is transformed into risk factor influencing future heat prices. Model outcomes are formulated in the two legislation and three CO_2 price scenarios and confirm non-symmetrical effects on the heat market participants arising from the size of installations. There are various approaches how this distortion could be addressed. Among possible solutions indirect carbon tax based tool was identified as the most appropriate way how to remedy distortions on the heat market towards inclusion of CO_2 costs into price of fuels for installations outside EU ETS. This solution could be easily realized by using existing legislation tools and application of possible remedial tool on the heat market is described. Results of these analyses support the idea of necessity to introduce this type of tool as soon as possible in order to avoid undue competition distortions on the heat market in the Czech Republic.

Shrnutí

Tato disertační práce popisuje hlavní aspekty technologie dálkového vytápění a její postavení v rámci energetického sektoru v kontextu ČR a EU, jakož i její nejdůležitější funkce. Dle uznávané celoevropské metodiky lze hodnotit sítě dálkového vytápění dodávající teplo vyrobené v rámci kombinované výroby elektřiny a tepla jako jeden z nejefektivnějších způsobů pokrytí potřeby tepla. Jádro práce je věnováno popisu a modelování faktorů ovlivňujících trh s teplem, kde jsou jako zásadní identifikovány legislativní faktory, které mají potenciál výrazně ovlivňovat podmínky na trhu. Optimalizační model rozdílového NPV byl zvolen jako vhodné řešení porovnávající situace bez vývoje opatření a dle nových požadavků, každý relevantní legislativní efekt byl transformován do rizikového faktoru s určitým vlivem na budoucí ceny tepla. Výsledky modelu jsou formulovány ve dvou scénářích vývoje legislativy a tří scénářích vývoje ceny CO_2 a potvrzují nesymetrické dopady na účastníky trhu s teplem odvíjející se od velikosti zařízení. Existují různé způsoby, jak by bylo možné toto narušení trhu řešit. Mezi možnými řešeními byl identifikován jako nejvhodnější nástroj založený na nepřímém zdanění uhlíku, umožňující napravit narušení na trhu s teplem díky začlenění nákladů na CO_2 do cen paliv pro zařízení mimo EU ETS. Toto řešení by mohlo být snadno realizované pomocí stávajících právních předpisů a jeho základní uplatnění je popsáno. Výsledky těchto analýz podporují tezi o nezbytnosti zavést tento typ nástroje co nejdříve, aby nedošlo k nepatřičnému narušení hospodářské soutěže na trhu s teplem v České republice.

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3.1 List of Figures

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4 Abbreviations

ADH CR	Association for District Heating of the Czech Republic
BAT	Best Available Technique
BREF	Best Available Techniques Reference document
CEN	European Committee for Standardization
CCC	Climate Change Committee
CHP	Combined Heat and Power
CO_2	Carbon dioxide
CZSO	Czech Statistical Office
DF	Discount Factor
DH	District heating
EC	European Commission
EIB	European Investment Bank
EIPPCB	European IPPC Bureau
ERO	Energy Regulatory Office of the Czech Republic
EU ETS	European Emission Trading Scheme
EUA	European Emission Allowance
GHG	Greenhouse Gas
IED	Industrial Emissions Directive
IPPC	Integrated Pollution Prevention and Control
LCA	Life Cycle Assessment
LCP	Large Combustion Plant
MAC	Marginal Abatement Cost
MCP	Medium Combustion Plant
MCPD	Medium Combustion Plant Directive
MIT	Ministry of Industry and Trade of the Czech Republic
MoE	Ministry of Environment of the Czech Republic

NIR	National Inventory Report
PEF	Primary Energy Factor
RES	Renewable sources
SEP	State Energy Policy of the Czech Republic
TNP	Transitional national plan
TWG	Technical working group
UNFCCC	United Nations Framework Convention on Climate Change
VAT	Value Added Tax

5 Motivation and focus of the doctoral thesis

5.1 Specification of the objective

The heat is one of essential human needs. If we strive for covering heat needs by most effective way we should assess the whole heat market and try to find out right balance between costs and benefits of chosen solutions.

The district heating could be identified among the range of heat solutions as one of most progressive and generally applicable. The district heating sector consists of heat installations of many different sizes. As a matter of fact, the heat market is always local and therefore district heating plants always compete with local heat installations. The environmental legislation mostly covers large scale installations, these having an accumulated impact on the environment due to their size and also being easier to monitor for competent authorities. It is anticipated that the current and the new environmental legislation will only impact district heating plants (as large scale installations) and not effectively regulate local heat plants. It is needed to assess the environmental measures and their impact on the prices of energy generated by the district heating plants. Should any undue distortions be identified, these need to be addressed (probably by suggestion of new remedial tools).

Primary target of the doctoral thesis is to assess position of district heating and effect influencing its development in the future.

Partial targets are:

- **to confirm district heating as effective method to cover heat needs while maintaining a high degree of flexibility, low overall energy consumption and limit environmental impacts of production of heat and power and thus deserving adequate protection against inadequate distortion effects,**
- **to develop possible tools for remedy of heat market distortions.**

5.2 Application of research methods

The methodology is oriented with respect to the main objective of the work. To achieve the main objectives of the thesis, I formulated four hypotheses in various areas, which were then used to determine and subsequently prove or refuse the individual parts of thesis. This approach thus essentially represents an application of the deductive method of research, which according to Lynham (2002) begins with theories or expressions generally formulated problem, based on the preferences of theoretical available knowledge.

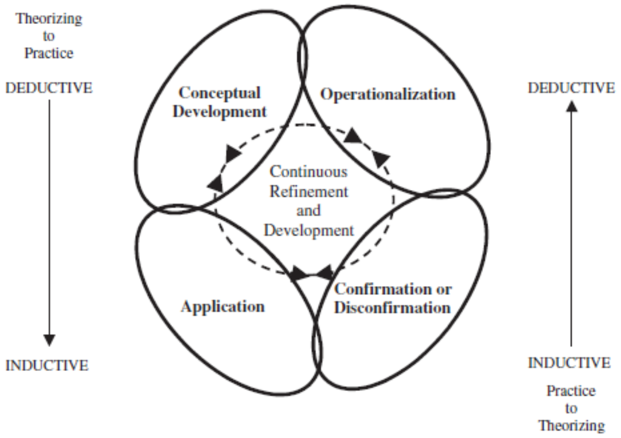

Figure 1. The General Method of Theory-Building Research in Applied Disciplines (Lynham, 2002)

At the beginning of the chapters I formulate hypotheses which is then further divided into sub-sections, and are confirmed whether true or not in the chapter summary. Deductive method mainly uses quantitative research and therefore logically evades the fundamental disadvantages of this type of investigation, including some reduction and simplification of reality and generality of the conclusions drawn. Therefore, it should be based on fundamental analysis called “mixed method research”, which is broadly used in recent research. This method is based on a combination of quantitative and qualitative methods (Östlund *et al.*, 2011). Since there are various hypotheses investigated through a combination of quantitative and qualitative indicators, the method is practically applied in this work.

Detailed study of the various main and side streams of opinion is especially important for understanding the current scientific knowledge about the investigated phenomenon. Subsequently doctoral thesis is trying to find relevant theoretical basis to each specified hypothesis, documents situation on examples and results in comparison and final analysis of the interaction of the stakeholders on the heat market. The research results are not only used to confirm or refute hypotheses, but also practically to model, build and formulate a series of recommendations for improving the functioning of monitored tools used primarily to remedy distortions on the heat market. Doctoral thesis effectively combines theoretical and empirical methods.

With a view to fulfill the primary and partial targets of the thesis and assess examined causalities, quantifying models are further applied relating to the district heating (eg. assessment of the objectives of the legislation, analysis of the positions of stakeholders on heat market etc.). The core business model is then compiled with the aim of evaluating the impact of environmental legislation (especially emission allowances) on the economy (costs) in the short-term and long-term decisions of the district heating industry. All models applied within the thesis are based on available real data and market prices.

5.3 The structure of the thesis

I divided this doctoral thesis into six logically interrelated chapters with concluding chapter.

I devoted Chapter 6 to introduction and description of current state of the art in the field of energy sector and future development of heat market. I identified two basic approaches to development of heat demand, where taking into account future building stock development and costs for improvement of existing buildings to near zero energy buildings, there will be a need to cover heat demand in buildings in the medium term or even long term perspective. Many studies are confirming the high efficiency of district heating compared to other heating options. I also describe position of district heating within energy sector in the context of the Czech Republic and EU as well. However despite the broadly recognizable positive effects, the district heating systems are facing problems with recognizing their true benefits, because each actor on the heat market sees the situation differently. Based on the fact that heat market is always by definition perceived at semi-local or district level, there is evident need to describe and interpret the factors (oriented on crucial emerging environmental legislation) influencing heat market.

In the Chapter 7, I am describing major aspects of district heating technology. District heating could be seen as an important requirement for effective application of Combined Heat and Power technology which is one of the most important energy efficiency measures, delivering significant primary energy savings. Possibility to utilize low quality fuels, positive systemic grid effects, lowering energy dependency could be listed among other DH’s effect. Second part of the chapter is devoted to consider the role of District Heating technology among other heating solution. I described acknowledged methodology of so called “Primary energy factors” used by European regulation how to assess different technologies and methodology for assessing emission efficiency as potential for production of particulate matter. According to own calculations based on these methodologies district heating networks delivering heat from CHP process could be regarded as one of the most efficient solution for covering heat needs.

The Chapter 8 is focused on the description of effects affecting the heat market. I identified legislation factor as the most important in this respect because it is politically driven and could severely influence conditions on the market. New environmental legislation requirements such as emission limits within the framework of Industrial Emissions Directive and Medium Combustion Plant Directive and EU ETS Directive are main effects causing uncertainties on the heat market. Especially EU ETS system entails complexity of different issues influencing free allocation of emission rights (allowances) and thus influencing impacts of the CO_2 price on the installations within. Currently ongoing revision of EU ETS for 4th trading period could cause additional problematic impacts on certain heat market participants. There are also other non-legislative factors influencing heat market, mainly strategies and concepts focusing on district heating technology. In the end of the Chapter I compared legislation requirements in relation to the installations’ size. Small scale emitters (below EU ETS thresholds) are usually in much favorable position compared to direct competitors on the heat market.

In the Chapter 9, I created economic model based on certain assumptions and summarized approach to modelling effects on the heat market. I chose optimization model of differential NPV as adequate solution for comparing the development in business-as-usual situation and under the new requirements. I transformed each legislation effect into risk factor influencing future heat prices. Structure of the model is thoroughly described and followed by fundamental assumptions and essential background data: my model consists of four segments derived from the size of installations (below 1 MW, 1 to 20 MW, 20 to 50 MW and above 50 MW of installed thermal input). However I identified no relevant legislation induced externalities for existing heat installations below 1 MW thermal input for reference case of the Czech Republic.

I formulated the findings from model application for reference case of the Czech Republic in Chapter 10 within two legislation scenarios (Strictest implementation and Pragmatic Implementation) on differentiated implementation of legislative tools accompanied by three CO_2 price scenarios (based on estimated price by Ministry of Environment, European Investment Bank and forecast based on market data from 3rd trading period). My model can also describe fuel-switch costs in 2 basic scenarios (lignite to biomass and fuel oil to natural gas). As I displayed, comparison of risk factors affirmed dominance of CO_2 costs in all the risk factors, presenting major disproportions between installations within and outside the EU ETS. Model sensitivity analysis pictures dependence of model results on different discount factor rates and energy efficiency (heat demand reduction) scenarios.

I dedicated Chapter 11 to finding the proper way how to eliminate non-symmetrical impacts on larger installations which are logically incorporated within the model itself. I discus various approaches how to address the issue unequal application of legislation tools to market participants. Among possible solutions indirect carbon tax based tool was identified as the most appropriate way how to remedy distortions on the heat market towards inclusion of CO_2 costs into price of fuels for installations outside EU ETS. This solution could be easily realized by using existing legislation tools in form of energy (“ecology”) tax. Application of possible remedial tool on the heat market is described in the end of the Chapter for the case of industrial consumers and for the case of households with differentiated assumptions. Results of these analyses support the idea of necessity to introduce this type of tool as soon as possible in order to avoid undue competition distortions on the heat market in the Czech Republic.

In concluding Chapter 12, I confronted model outputs with outcomes of the previous chapters and hypotheses that were set. I showed that the district heating accompanied by combined heat and power is effective solution for covering heat demand from energy and environmental perspective and has also other highly positive side effects on energy systems. Based on the outcomes from my economic model I demonstrated that the district heating sector as such will be influenced by a whole range of new environmental legislation with severe impacts on the prices of heat from district heating plants. To refrain from the future distortion of competition on the heat market, I found crucial to mirror CO_2 costs also to the price of production of plants outside the scope of the current legislation. Taking into account actual situation and modeled future scenarios, I recommend new carbon taxation tool as optimal solution which should be implemented as soon as possible.

5.4 Definition of hypotheses

For the doctoral thesis I set these following hypotheses:

1) New environmental legislation focuses on key environmental issues and all stakeholders on the heat market are covered in non-discriminatory way and its effects are not differentiated by the scale of emitter ("Polluter-pays-principle" is ensured)

2) Risk factors influencing heat market could be modeled by optimization model of differential NPV comparing situation business-as-usual and new circumstances.

3) Among environmental measures CO_2 costs are main driver for future development and refurbishment of district heating industry, other environmental legislation has limited impacts.

4) Indirect carbon taxation offers effective tool to address heat market distortions caused by future environmental legislation.

6 State of the Art

Energy conversion for covering energy needs has always its environmental impacts, thus with consideration of economic perspective leading to seek for most efficient solutions. Taking into account the essential human needs for covering heat demand, the process heat, space-heating and hot water preparation are necessary for all sectors of the economy.

Among possible alternatives, I identified two basic approaches:

- future low-energy buildings (or near zero energy buildings) could completely remove the need for heating or even, by the use of e.g. solar thermal energy, be plus energy houses producing more heat than they demand (Abel, 1994, Thomsen *et al.*, 2005, Passer *et al.*, 2016).
- taking into account future building stock development and costs for improvement of existing buildings to near zero energy buildings (Atkinson *et al.*, 2009), there will be a need to cover heat demand in buildings in the medium term or even long term perspective. The excess heat production from industries, waste incineration and power stations may also be used together with geothermal energy, large-scale solar thermal energy and large-scale heat pumps to utilise excess wind energy for house heating (Holmgren, 2006, Lund *et al.*, 2010).

Relevant studies have confirmed the high efficiency of district heating compared to other heating options (Ossebaart *et al.*, 1997, Bowitz and Trong, 2001) especially by tapping the potential to utilise heat that would otherwise be of limited use or using combined heat and power technology (Shi *et al.*, 2013, Yan *et al.*, 2016, Ghorbani, 2016).

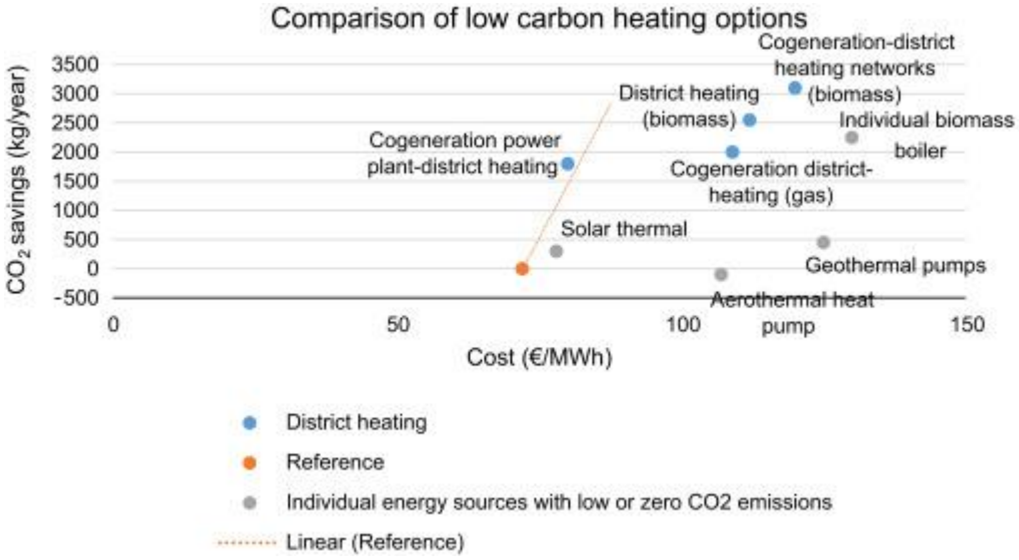

Figure 2. Comparison of different energy solutions with low emissions of carbon dioxide (Colmenar-Santos *et al.*, 2016)

Colmenar-Santos *et al.* (2016) considers district heating as one of the most cost-efficient low carbon heating option, able to deliver at its full economic potential based on an annualised investment in infrastructures of 315 billion euros, 95 billion euros savings per year on fuel costs and would save about 6,400 PJ of primary energy (representing about 15% of the total final energy consumption in the EU-28 in 2013).

6.1 Definition of the district heating sector

The district heating sector could be defined as a branch of the state energy policy responsible for heat supply via heating networks. District heating ("DH") covers heat needs of residential, amenity and industrial buildings and supplies heat for industrial processes as well.

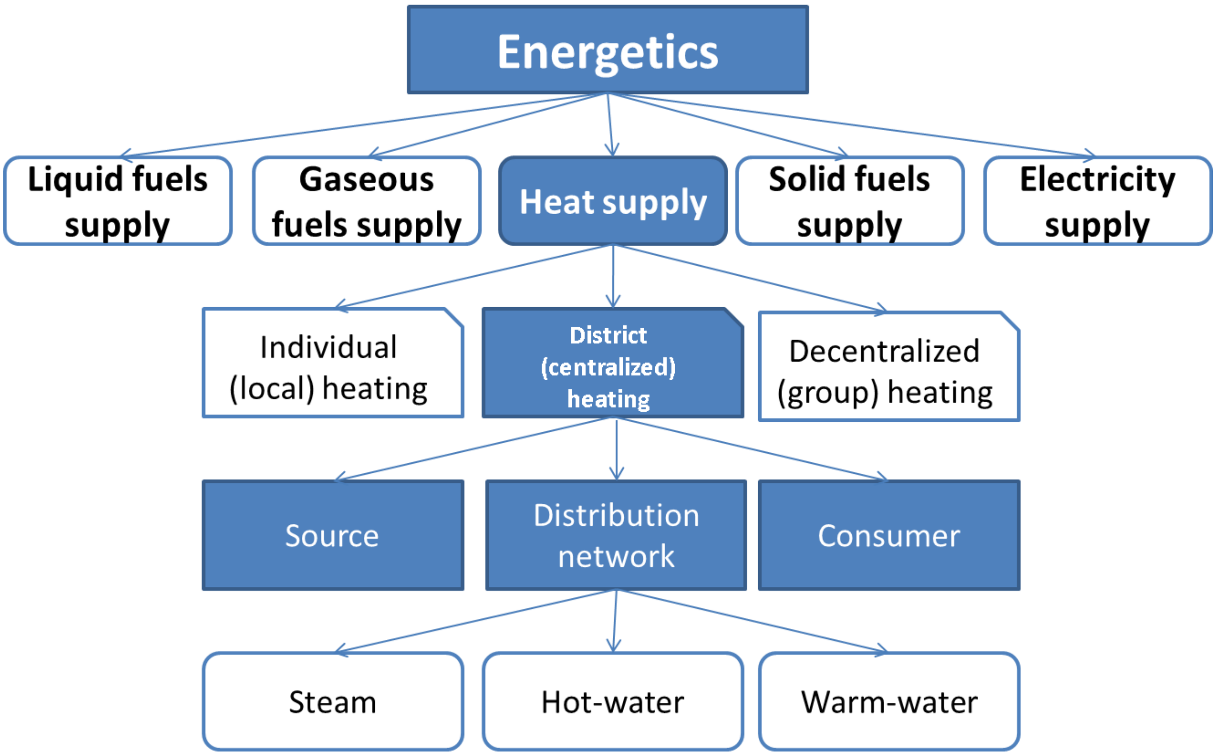

Figure 3. Definition of district heating in the energy sector (Karafiát, 2001)

6.2 District heating planning and future development

District heating is dependent on permanent connection with customers as other energy infrastructure networks – water networks, natural gas networks and electricity networks, thus there is need for proper development planning and optimization (Dorfner, 2014, Vesterlund *et al.*, 2016, Bordin *et al.*, 2016).

District energy systems can be classified by (Rezaie and Rosen, 2012)

- circulating fluid,
- thermal application – heating or cooling, heating and cooling together,
- network size - populated areas, high-density building clusters, industrial complexes, low-density residential areas, etc., and
- energy source.

6.2.1 Heat distribution networks

Distribution networks consist of equipment allowing transport, accumulation, exchange and supply of heat. Heat transport from heat generation plants to heat consumers (or in special cases among generation plants themselves) is carried out through a distribution network filled with heat transporting medium (most commonly chemically treated water).

Medium parameters determine the type of distribution network:

- Steam heat distribution network – network for heat transfer via steam. It consists of a steam feeder line and a condensate return line accompanied with necessary equipment (condensate pumping station, steam reduction station, etc.),
- Hot-water distribution network – network for heat transfer via hot-water with the designed temperature exceeding 110 °C,
- Warm-water distribution network – network for heat transfer via hot-water with the designed temperature below 110 °C.

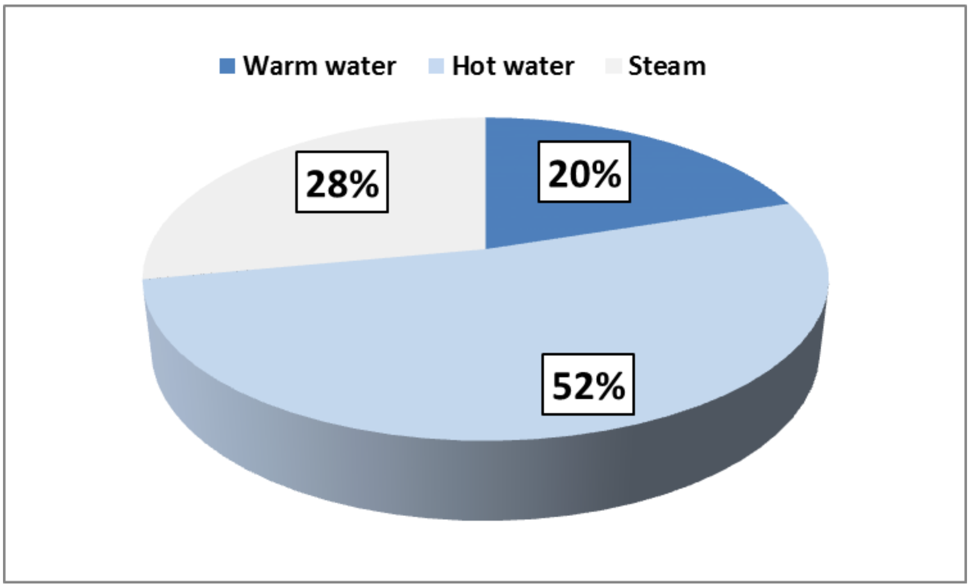

Figure 4. Share of heat transferred through district heating systems per individual media (ADH CR statistics)

Based on data from Energy regulatory Office ("ERO") and Association for District Heating of the Czech Republic ("ADH CR") there are more than 7,500 km of district heating pipeline routes in the Czech Republic and the total length is stable for last 5 years (fluctuation in period 2013-2014 was probably caused by error in Licence management system). There is significant trend in refurbishment of steam heat distribution networks towards hot water networks, which could bring significant energy savings. Assessment of potential for an increase of energy effectiveness of district heating infrastructure in the Czech Republic is described in Annex I.

Table 1. District heating distribution networks in the Czech Republic (ERO, 2015[1])

	Steam heat distribution network [km]	Hot-water distribution network [km]	Warm-water distribution network [km]	**Total length of network [km]**
Situation August 2015	1,458	2,619	3,440	**7,517**
Situation April 2014	1,487	2,733	3,501	**7,721**
Situation February 2013	1,531	2,730	3,477	**7,738**
Situation December 2010	1,584	2,531	3,437	**7,551**
Situation December 2009	1,617	2,517	3,420	**7,554**

Note: Based on ERO's Licence viewer data for subjects with valid licence for heat distribution

Distribution networks could be divided by the number of pipes:

- single-pipe network – rarely used, only for direct transport of heat-transfer medium to the consumer (without return line),
- two-pipe network – standard network for transport of heat-transfer medium from the heat generation plant through exchange stations to consumers and then back to the plant,
- four-pipe network – network for transport of heat-transfer medium from the heat generation plant through exchange stations to consumers and then back to the plant; these networks use two pairs of feeder and return lines – one for heating (only in seasonal operation) and one for warm water (year-round operation).

Distribution network could be also divided as follows:

- Heat feeder line – part of the distribution network from a heat plant to another heat plant or to exchange stations without any branch to customers,
- Primary network – part of the distribution network from the heat feeder line to heat exchange stations, potentially with braches to direct customers where heat-transfer medium parameters are high,
- Secondary network – part of the distribution network from exchange stations to customers with standard heat-transfer medium parameters.

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[1] Energy Regulatory Office, 2009-2015: Valid licences, licence.eru.cz

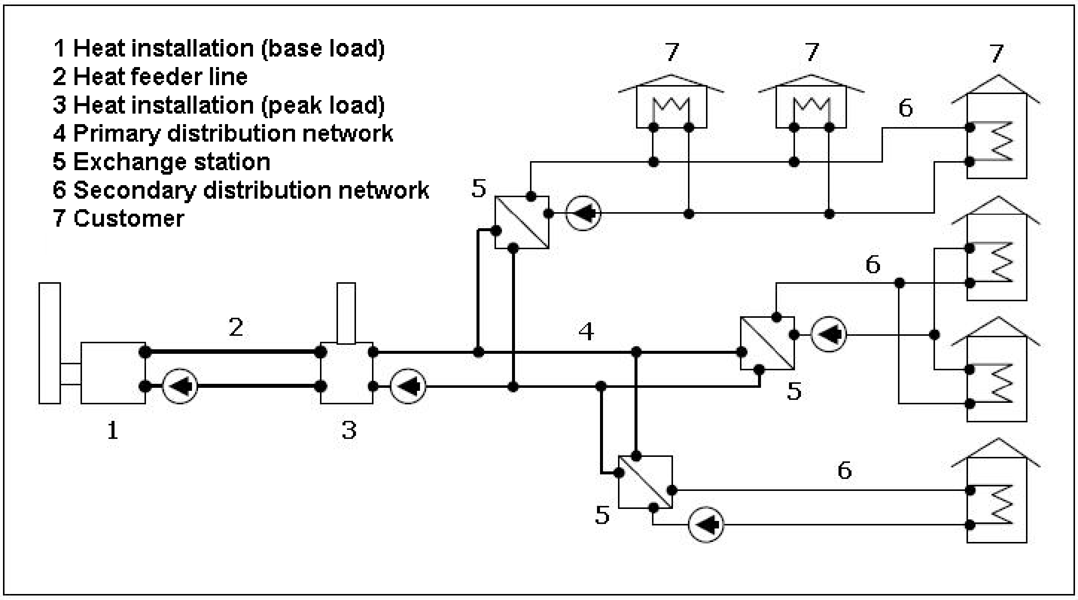

Figure 5. Typical district heating scheme (Karafiát, 2001)

Exchange (reduction) station is an installation for adjustment of heat-transfer medium parameters (particularly pressure and temperature). The equipment for measurement and regulation of heat supply to customers is commonly installed within the station.

Customer (as part of the above scheme) represents inner heat distribution system and appliances installed inside the customers' buildings – for example central heating systems, warm water preparation system, air conditioning, etc.

District energy systems could accommodate variable energy sources, can reduce fossil fuel dependency and thus bring significant environmentally beneficial solutions in appropriate applications (Oñate *et al.*, 2014). This is in contrast with usually chosen local heat solution. While there is an increasing tendency towards renewable residential heating solution in newly built homes in recent years, driven especially by legal obligations to cover a certain share of heat from renewable sources, fossil fuel solutions still dominate the refurbishment decision in existing buildings (Michelsen and Madlener, 2012, BMVBS, 2013[2]). Increase of the share of renewables in heating solutions in existing homes is of high relevance if the climate and protection targets should be met (Hast *et al.*, 2016, Bauerman, 2016, Michelsen and Madlener, 2016).

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[2] Bundesministerium für Verkehr, Bau und Stadtentwicklung (BMVBS), 2013: Gutachten zur Umsetzung von Artikel 14 der Richtlinie über die Gesamtenergieeffizienz von Gebäuden, BMVBS-Online-Publikation, Nr. 19/2013.

Paiho and Reda (2016) thoroughly assess future district heating systems development scenarios and challenges facing due to legislation effects (focusing on legislation affecting energy performance requirements on buildings) and concluded to the necessary transition from "existing district heating systems" with following major characteristics:

- strong role of non-renewable energy sources,
- based mainly on centralized production,
- typically municipal production monopolies,
- Existing stakeholders,
- supply water temperature supporting high- or medium- temperature radiators,
- buildings with varying energy efficiency connected to district heating,
- traditional technologies and business models,

into "future district heating systems" with features as follows:

- increasing share of renewable energy sources,
- enabling trigeneration (production of electricity, heating and cooling energy),
- increasing share of distributed and local production,
- networks opened for all heat suppliers,
- supply water temperature supporting low-temperature heating,
- increasing share of nearly zero-energy buildings connected to district heating,
- utilization of supportive technologies,
- new business models.

Most of the identified transition aspects is relevant on the demand side (building level), where new technologies should emerge. However based on the outcomes from assessing the barriers in decision making process towards application of near zero energy buildings and the relating challenges in the retrofit process, this transition process on the building side will take several decades (Karlsson *et al.*, 2013, Lindkvist *et al.*, 2014, Diefenbach *et al.*, 2016).

6.3 District heating position on heat market in the EU

District heating sector is important part of EU energy sector, responsible for heat delivery to 60 million of EU inhabitants. Whole EU heat market for residential and service sector buildings based on IEA data has a volume about 11.5 EJ per year[3], share of district heating is 12% which equals to heat deliveries 1,370 PJ per year. DH sector also delivers heat to industry, 830 PJ per year. Industrial combined heat and power installations deliver another 790 PJ per year. Total heat delivery of EU DH sector is 2,990 PJ per year.

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[3] Aalborg University, Halmstad University, PlanEnergi, 2012: *Heat Roadmap Europe 2050*, first pre-study, 2012

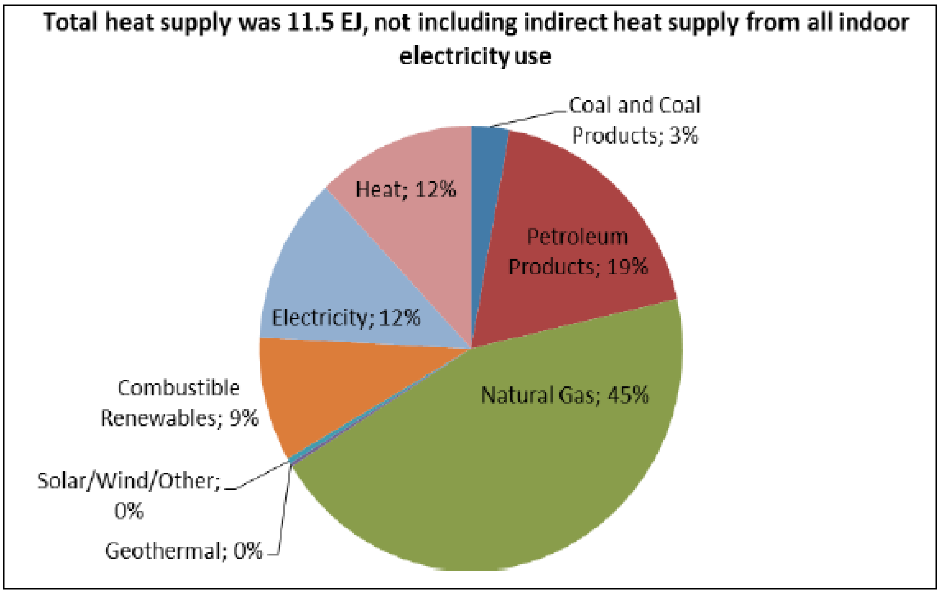

Figure 6. EU 27 - Origin of heat supply for heat demands in residential and service sector buildings

6.4 District heating position on heat market in the Czech Republic

Situation in the Czech Republic (and in certain other countries) is specific subject to the fact that there is high penetration of district heating technology on the heat market as shown in EHP Country-by-Country survey[4].

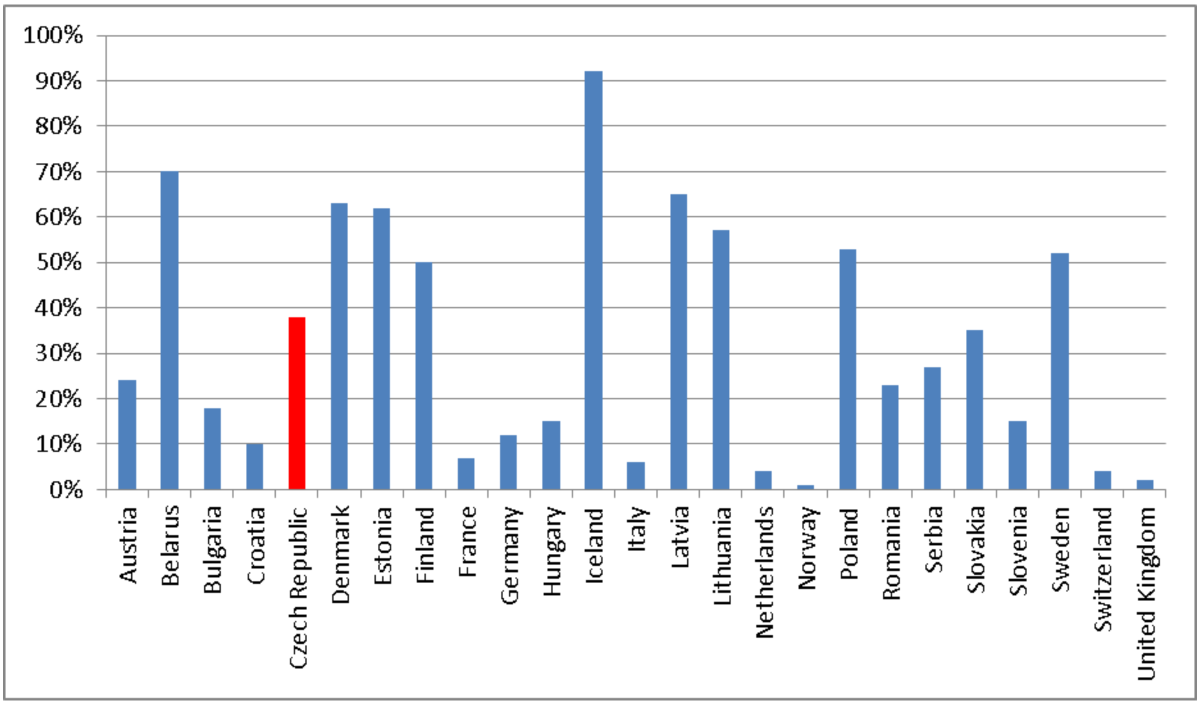

Figure 7. Percentage of citizens served by District Heating (EHP, 2015)

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[4] Euroheat & Power, 2015: District heating and cooling, Country-by-country survey 2015

6.4.1 Heat consumption in the Czech Republic

According to MIT (2015)[5] the heat consumption in the Czech Republic in 2013 was approximately 583 PJ. A considerable part of this heat (124 PJ) was consumed in the form of process heat (consumption of fuel and energy in the furnaces and burners of production lines).

The remaining part of the heat can be divided into:

- own technological consumption of heat for heating and hot water, ie. Consumption directly in production without supply contracts to third parties
- heat supplied to third parties which includes all sales (not including own consumption by producers):
  - for delivery to the district heating (licensed entities)
  - sales of heat within the licensed activity,
  - heat delivery within the housing cooperative, etc.,
  - a supply within the premises of the manufacturer to foreign entities (unlicensed operators, unlicensed activity); heat supplied by the boiler room in case of operation by third parties, etc.,
- losses and balance differences.

The structure of the heat consumption in total in the Czech Republic in 2013, broken down by specified categories is indicated in the following figure. Total gross heat production in Czech Republic was 583 PJ in 2013.

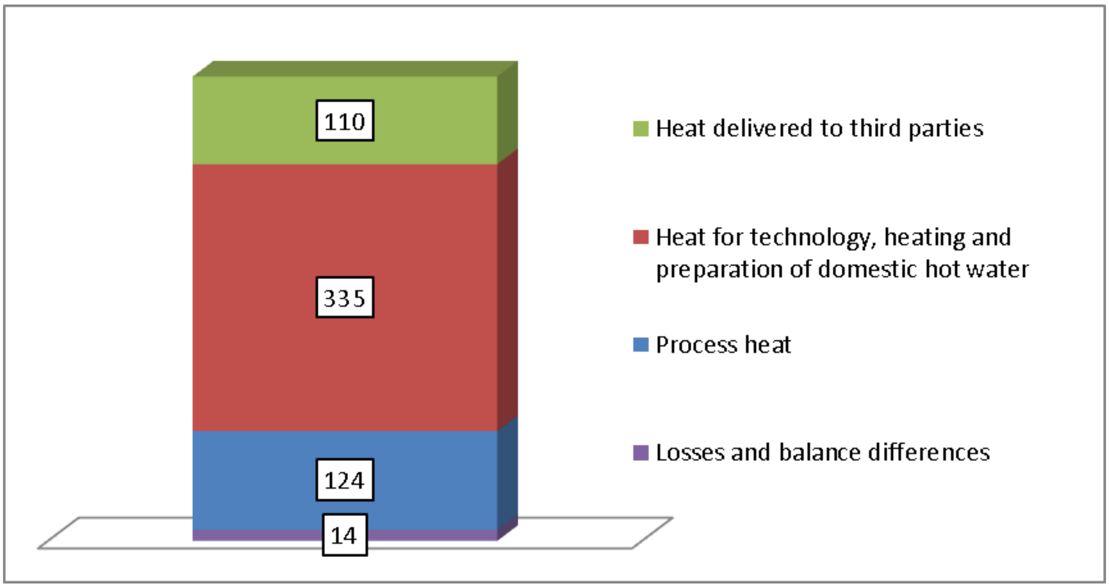

Figure 8. Gross heat production in Czech Republic in PJ (MIT, 2015)

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[5] Ministry of Industry and Trade, 2015: *Assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling according to Article 14 of Directive 2012/27/EU on energy efficiency*, December 2015

In terms of the breakdown of heat consumption to individual sectors (without considering their own consumption of process heat) the largest consumption in 2013 was in households roughly 189 PJ (heat outside the needs for heating and domestic hot water preparation is not considered). Approximately 176 PJ was consumed in the industrial sector. The remaining 80 PJ heat consumption was realised in the service sector, transportation and within other unspecified consumption as well.

The total annual heat consumption (445 PJ) is covered by the heat produced for district heating supplies by of approximately 150 PJ. Of that, approximately 110 PJ are centrally produced heat supplied by third parties via the district heating networks. The remaining 40 PJ of heat is consumption of auto-producers (eg. own consumption in technological processes within the facility which supplies heat outside the plant, supply of heat from the house boiler rooms within one building except heat sales to other objects, etc.). This heat is not considered as individual heating in the MIT statistics and forecasts of individual heat remains in the category of centrally produced heat.

Aggregate data on heat consumption broken down by sector and type of production and supply of heat (individually or centrally produced heat) in 2013 are shown in the following table.

Table 2. Heat consumption according to type of production and sector (MIT, 2015)

Sector	**District heating production [PJ]**	**Local heating [PJ]**	**Total [PJ]**
Industry, agriculture	69	107	176
Households	54	135	189
Services and other	27	53	80
Total	**150**	**295**	**445**

According to CZSO (2015)[6] in 2014 of the total fuel input 201 PJ for heat production in the Czech Republic was 107 PJ covered by solid fuels, 1 PJ by liquid fuels, 59 PJ stands for gaseous fuels and 34 PJ for renewables and other fuels. Total heat supply from heat sources to all sectors was 171 PJ in 2014[7], total heat supply from district heating installations was 98 PJ. Difference was used on-site in industrial processes (in production of iron and steel, paper industry, manufacture of chemicals products etc.).

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[6] Czech Statistical Office, 2015: *Total fuel consumption used for heat generation (GJ)*, Period 2014, Table 29, 2015

[7] Czech Statistical Office, 2015: *Net heat production (GJ)*, Period 2014, Table 19, 2015

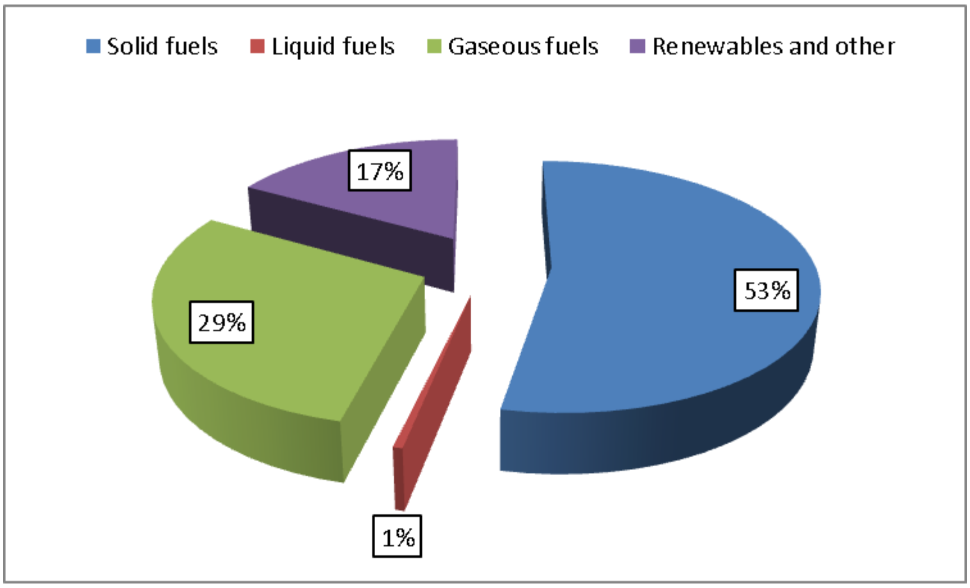

Figure 9. Gross heat production in Czech Republic in PJ (MIT, 2015)

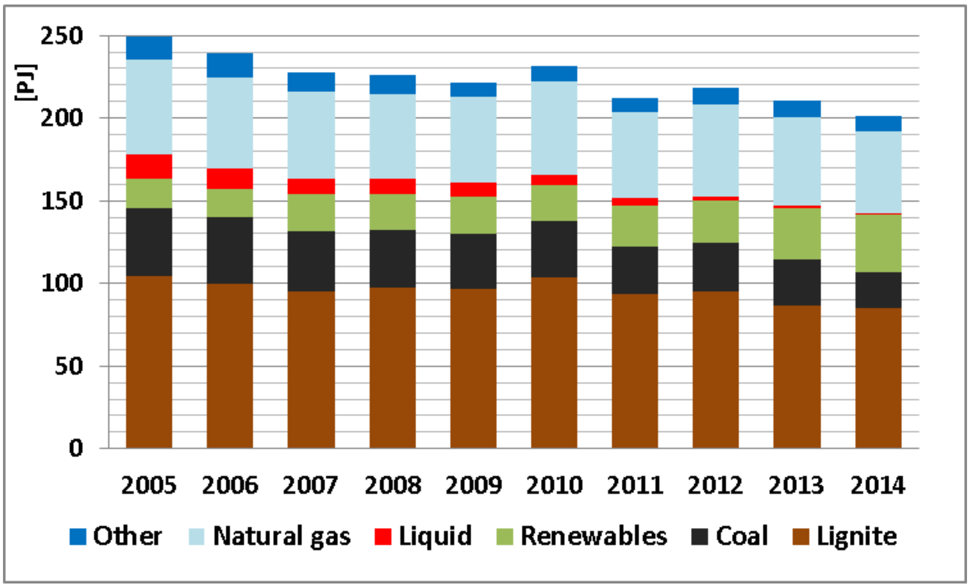

Figure 10. Total fuel consumption used for heat generation in the period 2005 to 2014 (CZSO, 2015)

6.5 District heating acknowledgment and modelling approaches

Despite the abovementioned facts district heating systems are facing problems with recognizing their true benefits, because each actor on the heat market sees his/her situation differently. In assessment of complex and large-scale design problems in uncertain environment (Prasad *et al.*, 2014), it is necessary to generate knowledge about relevant actors so as to understand their interests, objectives and the influence or resources they have brought or could bring to bear on the decision-making process by Multi-Actor Analysis (Brugha and Varvasovszky, 2000).

Patil *et al.* (2006) used for this actor-analysis DANA[8] modelling and identified the perceived relevant actors on the heat market as follows: the Municipality, the Plant, private parties-banks, housing companies, private project developers, energy companies and energy consumers. According to Patil *et al.* (2006) the Municipality should be the initiator of the District heating system project, because there are very few incentives for other relevant stakeholders to participate in the project. As pictured in Table 1. Private parties, Housing companies and the Plant share most of factors with the Municipality, thus the success of the district heating project is dependent on the interest of these actors.

Table 3. Shared factors among actors in district heating system project (Patil *et al.*, 2006)

	Municipality	Plant	Private Parties	Housing Companies	Private Project Developer	Energy Companies	Consumers
Municipality	100	44	50	50	44	0	31
Plant	88	100	75	62	62	0	12
Private Parties	73	55	100	55	55	27	18
Housing Companies	89	56	67	100	78	0	56
Private Project Developer	64	45	55	64	100	9	27
Energy Companies	0	0	60	0	20	100	40
Consumers	56	11	22	56	33	22	100

Case studies have confirmed significant potential for an increase in energy efficiency and considerable energy and emissions savings if all relevant actors are addressed and potential of district heating deployed (Delmastro *et al.*, 2015, Gustafsson *et al.*, 2016).

I identified several approaches to the problem of assessment of development of energy systems. Main approaches could be summarized into 4 basic groups:

- life-cycle assessments ("LCA") – LCA is broadly used in policymaking processes (Wardenaar *et al.*, 2012). However the LCA analysis commonly faces several methodological problems, inter-alia data gaps and the requirement of forecasting and anticipation of future developments (Pehnt, 2003). Issue of multifunctional processes and their allocation could be overcome by well-chosen allocation method.
- large-scale dynamic optimization modelling – models is capable of describing whole energy flows (energy management systems as networks of a series of energy flows), from source to end users even through a different conversion and transmission technologies (Cai *et al.*,

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[8] Dynamic Actor Network Analysis.

2008). It can be further enhanced by optimization models, like multi-layer scenario trees (Li *et al.*, 2011) etc. Within a general framework offers precise outcomes at macro-level, but less effective at micro-management (individual installation) level.

- energy cluster modelling (McCauley and Stephens, 2012) – Based on central management system with production in the network subordinated at different clusters of distributed utilities, with a local management. Clusters are integrated in one energy system (Kuplais *et al.*, 2010). Within general perspective based on precise input data on micro-level, which could hinder applicability in situations with lack of real data.
- scenario-based analyses – These analyses could benefit from other approaches as well, main issue is definition of scenario applicability, presumptions and borders (Shrestha et al., 2007). Precisely defined scenarios could overcome data gaps, offers sufficient variability and provides substantiated outcomes (Hadley and Short, 2001).

6.6 Assessing the situation of district heating on the heat market

Subject to the fact that heat market is always by definition perceived at semi-local or district level, only a minority of scientific work is focused at assessment of position and relationship of different actors there (Li, 2013, Dirckinck-Holmfeld, 2015 Gustafsson *et al.*, 2015, Fudge *et al.*, 2016). This doctoral thesis is then devoted to description and interpretation of factors (oriented on crucial emerging environmental legislation) influencing heat market with focus on district heating systems as one of the major actors.

7 District heating features and efectivity

The district heating technology could provide whole range of highly positive aspects for energy sector while maintaining a high degree of flexibility and limit environmental impacts of production of heat and power.

7.1 Features of district heating

7.1.1 Combined heat and power

District heating enables efficient combined heat and power generation ("CHP", also referred to as cogeneration) because heat could be effectively distributed via the networks to consumers. CHP technology leads to a primary energy saving of about 10 – 30 % compared to separate production of electricity and heat. CHP brings higher efficiency of national economy and lower emissions of all pollutants. CHP savings is calculated according to provisions laid down by Energy Efficiency Directive (EED)[9].

Calculation of primary energy savings:

- Primary energy savings (PES) from cogeneration can be calculated using the following formula:

$$PES = \left(1 - \frac{1}{\frac{CHP\ H\eta}{REF\ \ H\eta} + \frac{CHP\ E\eta}{REF\ \ E\eta}}\right) \cdot 100\% \tag{1}$$

Where:

PES	Primary energy savings.
CHP Hη	Heat efficiency of the cogeneration production defined as the annual useful heat output divided by the fuel input used to produce the sum of useful heat output and electricity from cogeneration.
Ref Hη	Efficiency reference value for separate heat production.
CHP Eη	Electrical efficiency of the cogeneration production defined as the annual electricity output from cogeneration divided by the fuel input used to produce the sum of useful heat output and electricity from cogeneration.
Ref Eη	Efficiency reference value for separate electricity production.

Highly efficient cogeneration shall provide at least 10 % primary energy savings compared to the reference values for separate heat and electricity production.

According to CZSO (2015)[10] total installed electrical output of CHP installations in the Czech Republic was 4.8 GWe and 20.5 GWth in 2014. CHP installations produced 12.2 TWh of electrical energy which

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[9] Directive 2012/27/EC of the European Parliament and of the Council of 25 October 2012 on energy efficiency

[10] Czech Statistical Office, *Installed capacity of power plant sets on 31 December (MW)*, Period 2014, Table 3, 2015

equals to 14.2 % of total gross electricity generation and 135 PJ of heat which equals to 67.2 % of total heat production for district heating.

Table 4. CHP plant according to size and technology in December 2014 in the Czech Republic (MIT, 2015)

CHP installation	**Technology**	**Installed electrical output**	**Installed thermal output**
Up to 1 $\mathrm{MW_e}$	Thermal power plants	13	537.4
	Combined cycle power plants	0	0
	Natural gas fired plants	296.6	341.9
	Total	**309.6**	**879.4**
1 - 5 $\mathrm{MW_e}$	Thermal power plants	82.8	1,266.9
	Combined cycle power plants	0	0
	Natural gas fired plants	239	283.4
	Total	**321.8**	**1,550.3**
Above 5 $\mathrm{MW_e}$	Thermal power plants	9,792.2	18,080
	Combined cycle power plants	118	119.9
	Natural gas fired plants	5.4	7.9
	Total	**9,915.6**	**18,207.8**
Total	Thermal power plants	9,888	19,884.4
	Combined cycle power plants	118	119.9
	Natural gas fired plants	541	633.1
	Total	**10,547**	**20,637.4**

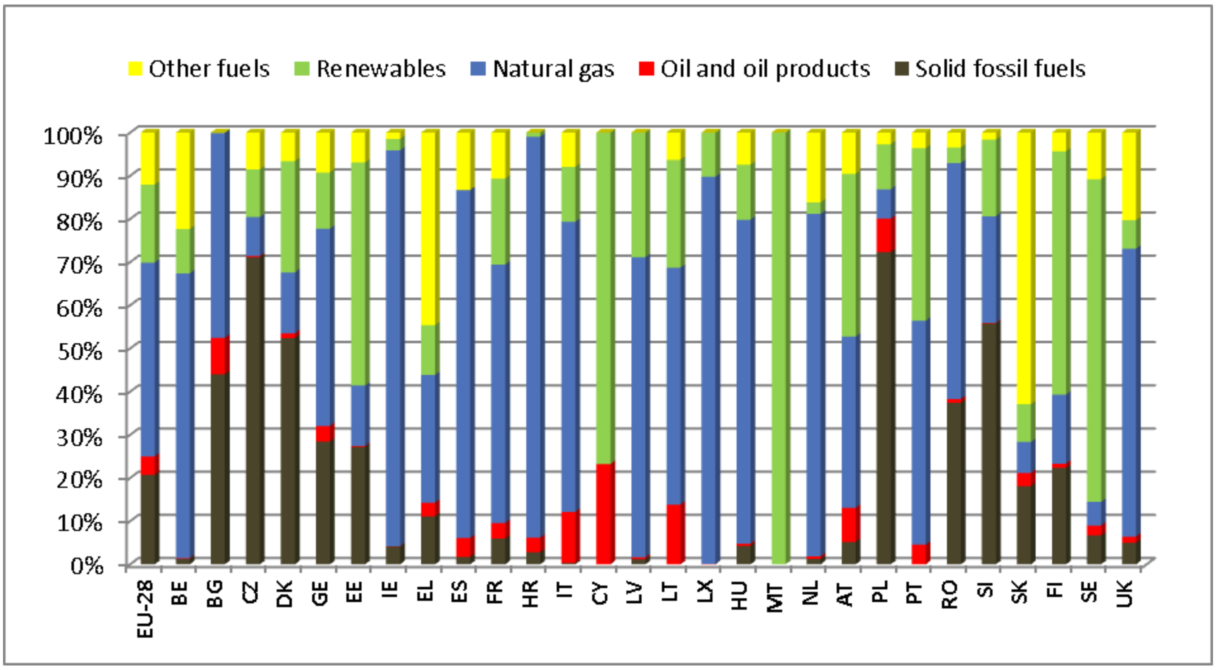

Figure 11. Share of fuels on CHP production in EU-28 in 2013 (EUROSTAT, 2015)

Table 5. Combined Heat and Power data for EU-28 (EUROSTAT, 2015[11])

	CHP electricity generation, [TWh]	Main activity producers	Auto-producers	Share of CHP in total electricity generation	CHP Electrical capacity, [GW]	CHP Heat production, [PJ]
EU-28	**382.02**	**67.3%**	**32.7%**	**11.7%**	**112.97**	**2,899.30**
Belgium	12.67	46.3%	53.7%	15.2%	2.34	27.14
Bulgaria	3.73	96.0%	4.0%	8.5%	1.20	40.36
Czech Republic	11.97	70.8%	29.2%	13.7%	4.65	120.92
Denmark	17.58	90.1%	9.9%	50.6%	5.88	103.15
Germany	78.67	63.2%	36.8%	12.4%	27.27	654.01
Estonia	1.23	96.5%	3.5%	9.3%	0.47	12.57
Ireland	2.03	100.0%	0.0%	7.8%	0.31	12.39
Greece	1.95	6.6%	93.4%	3.4%	0.56	10.49
Spain	24.10	100.0%	0.0%	8.5%	3.36	174.88
France	13.90	49.7%	50.3%	2.4%	4.80	150.65
Croatia	1.70	87.1%	12.9%	12.6%	0.69	13.26
Italy	36.66	68.9%	31.1%	12.7%	8.29	212.77
Cyprus	0.06	100.0%	0.0%	1.4%	0.01	0.15
Latvia	2.38	91.0%	9.0%	38.3%	1.24	11.31
Lithuania	1.67	77.2%	22.8%	35.0%	1.18	15.35
Luxembourg	0.42	56.1%	43.9%	14.7%	0.51	3.38
Hungary	3.88	89.1%	10.9%	12.8%	1.67	27.00
Malta	0.00	0.0%	0.0%	0.0%	0.00	0.02
Netherlands	34.77	49.1%	50.9%	34.5%	9.39	217.92
Austria	9.87	100.0%	0.0%	14.4%	5.57	110.83
Poland	26.12	74.6%	25.4%	15.9%	8.29	257.42
Portugal	7.15	76.8%	23.2%	13.8%	1.40	68.37
Romania	6.61	81.2%	18.8%	11.2%	2.07	57.93
Slovenia	1.15	79.4%	20.6%	7.1%	0.35	10.83
Slovakia	22.20	93.0%	7.0%	77.0%	4.38	27.76
Finland	24.32	66.2%	33.8%	34.1%	6.10	251.21
Sweden	15.59	64.9%	35.2%	10.2%	4.80	165.07
United Kingdom	19.66	1.5%	98.5%	5.5%	6.22	142.50

According to calculation described in Annex II, CHP technology is currently saving in the EU-28 approx. 1,035 PJ of primary energy (fuel input).

7.1.2 Positive grid effects

District heating enables utilization of positive grid effects not possible on local level, because heat consumption is distributed across various consumers simultaneously – for example transfer of waste heat from one building as a useful heat for another building in the system. District heating could also increase potential for production in CHP by accumulation of produced heat energy in heat storage

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[11] EUROSTAT, 2015: *Combined Heat and Power data*, Energy Data, http://ec.europa.eu/eurostat/web/energy/data

tanks for later use. District heating could also provide for stabilization of electrical grid by utilizing of excess electricity from renewables by transforming it into heat energy and delivery as a useful heat to consumers. Interconnection also enables to optimize installed thermal capacity.

7.1.3 Utilization of low quality fuels

The major advantage district heating offers is the possibility to use low quality fuels that cannot be used in other plants due to environmental or technological reasons/limits. This means in particular incineration of domestic coal and lignite, heavy fuel oil, municipal waste, raw biomass (biomass from wood mining), utilization of excess/waste heat and waste gases from industrial processes, etc. District heating thus significantly accounts for the Czech Republic's low energy dependency compared to the EU-28 average.

Table 6. Energy dependence in EU 28 (Eurostat, 2016)

Member state	1990	2000	2005	2010	2014
EU-28	44.2	46.7	52.2	52.6	53.4
Belgium	75.1	78.1	80.1	77.9	80.1
Bulgaria	62.8	46	46.7	39.6	34.5
Czech Republic	15.4	22.9	28	25.6	30.4
Denmark	45.8	-35	-49.8	-15.7	12.8
Germany	46.5	59.4	60.4	60.1	61.4
Estonia	44.2	32.2	26.1	13.6	8.9
Ireland	68.6	84.8	89.6	86.6	85.3
Greece	62	69.5	68.6	69.2	66.2
Spain	63.1	76.6	81.4	76.7	72.9
France	52.4	51.5	51.6	49.1	46.1
Croatia	39.8	48.4	52.5	46.6	43.8
Italy	84.7	86.5	83.4	82.6	75.9
Cyprus	98.3	98.6	100.7	100.8	93.4
Latvia	88.9	61	63.9	45.5	40.6
Lithuania	71.7	59.4	56.8	81.8	77.9
Luxembourg	99.5	99.6	97.4	97.1	96.6
Hungary	49	55.2	63.1	57.3	61.1
Malta	100	100.3	100	99	97.7
Netherlands	22.1	38.2	38	30.4	33.8
Austria	68.5	65.4	71.6	62.8	65.9
Poland	0.8	9.9	17.2	31.3	28.6
Portugal	84.1	85.1	88.6	75.1	71.6
Romania	34.3	21.8	27.6	21.9	17
Slovenia	45.7	52.8	52.5	48.6	44.6
Slovakia	77.5	65.5	65.3	63.1	60.9
Finland	61.2	55.1	54.2	47.8	48.8
Sweden	38.2	40.7	36.8	36.6	32
United Kingdom	2.4	-16.9	13.4	28.4	45.5

7.1.4 Diversification of energy resources

The next advantage is energy source diversification within one district heating system (for example lignite and natural gas etc.), which is something local heat generation cannot provide. Fuel mix diversity strengthens energy security and absorbs price shocks in the absence of primary fuels.

7.1.5 Lowering emission intensity

District heating allows for removing emissions from problematic areas (especially from city centres) and ensures better emission dispersion thanks to the stack height (pollutants in flue gasses have higher kinetic energy and is transported away from the installation area). The technology is beneficial to the environment and improves air quality in urban areas at the acceptable societal cost.

7.1.6 Better monitoring and measurement

District heating facilitates emission measurement and best available techniques ("BAT") application. In local heat plants, BAT for pollution control usually cannot be used due to economic and technological reasons. Compared to local heat generation, district heating helps reduce the environmental impact of heat supply. District heating facilities also enables continuous monitoring of pollutants.

7.1.7 Investment costs

The main disadvantage of district heating is permanent connection to a single-purpose transport line – the district heating network – which constitutes connection between the heat plant and heat consumers. District heating has only very limited possibility to adapt in cases of a significant drop in heat demand and is dependent on preferably stable heat sales.

- Lower heat sales (for example due to disconnection of several consumers) bring about lower heat supplies and thus lower variable costs.
- Reduction in heat sales does not mean reduction in fixed costs[12].

Lower heat sales increase the fixed cost share in the heat price and thus increase the heat price for customers. This causes new disconnections, thus escalating the price increase, so in the end the process could cause the whole district heating network to collapse.

On the other hand, higher heat sales improve the economy of the district heating system and bring the heat price down. This is, however, seldom the case as new customers mostly stabilize heat sales. Gradual decrease in heat sales is caused mainly by thermal insulation of the buildings connected. Other factors impacting heat price will be addressed in the following chapters.

7.2 Calculation of district heating effects

Calculation of district heating effects is dependent on type of production facility and used fuels or energy. Broadly used convention on calculation based on primary energy factors[13] could be used for describing effectiveness of certain solution for covering energy needs. Concept of primary energy factors (PEF) is used within assessing of energy performance of buildings. Calculation of district

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[12] List of common variable and fixed costs is in the Annex.

[13] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, Common general framework for the calculation of energy performance of buildings

heating effects is based on production facility and overall distribution system level. In theory, heat energy could be produced in single or multiple-output generation systems.

7.2.1 Primary energy factor concept

Concept of primary energy factors (PEF or weighting factors f_P) is established in core EU standard EN 15603[14]. Total primary energy factor is defined as follows

$$PEF_{tot} = PEF_{nren} + PEF_{ren} \tag{2}$$

Where:

PEF_{tot}	weighting factor of the district energy system;
PEF_{nren}	non-renewable primary energy factor
PEF_{ren}	renewable primary energy factor

Non-renewable primary energy factor for a given energy carrier is defined as the non-renewable primary energy, including the delivered energy and the considered energy overheads of delivery to the points of use, divided by the delivered energy. Renewable primary energy factor for a given energy carrier is defined as the renewable primary energy, including the delivered energy and the considered energy overheads of delivery to the points of use, divided by the delivered energy.

Conventions on overheads calculated within PEF calculation is shown in following table.

Table 7. Overheads included in the primary energy factors EN 15603 (CEN option[15])

		Primary energy factors
Included overheads	Energy to extract the primary energy carrier	YES
	Energy to transport the primary energy carrier	YES
	Energy used for any other operations necessary for the delivery to the building (e.g. storage)	YES
	Energy to build, operate and dismantle the transformation units	NO
	Energy to build , operate and dismantle the transportation system	NO
	Energy to clean up or dispose the wastes	NO
	Energy embedded in materials	NO
Applicable for ratings based on		Net calorific value net calorific value

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[14] CEN/TC 371/WG 1, 2015: *Energy performance of buildings — Overarching EPB assessment – Part 1: General framework and procedures*

[15] CEN option stands for recommendation of CEN for correct PEF application and thus represents first best option, however each Member State could you its own approach (so called National Annex) if all CEN rules is fulfilled.

Table 8. Weighting factors based on net calorific value EN 15603 (CEN option)

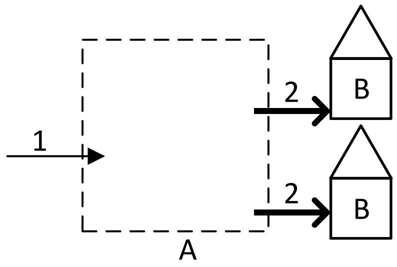
Energy carrier		PEF_{nren} f_{Pnren}	PEF_{ren} f_{Pren}	PEF_{tot} f_{Ptot}
Fossil fuels	Solid	1.1	0	1.1
	Liquid	1.1	0	1.1
	Gaseous	1.1	0	1.1
Bio fuels	Solid	0.2	1	1.2
	Liquid	0.5	1	1.5
	Gaseous	0.4	1	1.4
Electricity		2.3	0.2	2.5
District heating(1)		1.3	0	1.3
Solar		0	1	1
Wind		0	1	1
Geo-, Aero-, Hydrothermal		0	1	1

Note

(1) Default value based on a natural gas boiler. Specific values are calculated according to specific district energy standard.

7.2.2 Single output generation system

Single output generation system using input fuels or energy and transform it into one type of useful energy (in most cases useful heating energy). This type of generation system could be for simplification regarded as black-box and according to CEN standard EN 15316-4-5[16] could be described as follows:



Key

A	system boundary	1	energy input to system	E_{in}
B	energy consumer	2	energy delivered from the system	E_{del}

Figure 12. Single output generation system

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[16] CEN/TC 228/WG 4, 2015: *Heating systems and water based cooling systems in buildings — Method for calculation of system energy requirements and system efficiencies — Part 4-5: District heating and cooling*

$$f_{\mathrm{we}} = \frac{\sum_{cr} E_{\mathrm{in};cr} \cdot f_{\mathrm{we};cr}}{\sum E_{\mathrm{del}}} \tag{3}$$

where

f_{we}	weighting factor of the district energy system;
$E_{\mathrm{in};cr}$	energy content of input to the system of energy carrier *cr*;
$f_{\mathrm{we};cr}$	weighting factor of energy carrier *cr*;
E_{del}	delivered energy;

This type of generation system is usually used in households (conventional boilers), but could be also effectively used in district heating systems. Key performance booster enabled by district heating is possibility to use special fuels or energy types such as

- waste (eg. household waste, industrial waste, polluted materials from waste sorting or waste recycling etc.)
- residual fuel – could be derived from waste or could be produced from waste materials from industrial processes
- sewage sludge
- land fill gas
- mine gas
- industrial gasses – eg. low calorific gases from coke ovens in the iron and steel industry etc.
- excess energy from industrial processes – such as energy from chemical industry

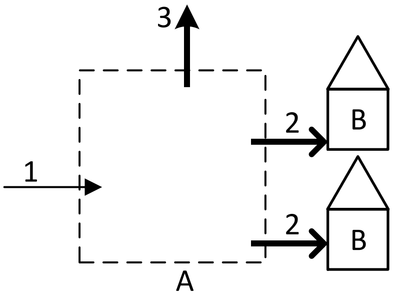
These types of fuels/energies could be utilized in heat generator and distributed via district heating as an useful heat energy to customers with exceptional high efficiency.

Table 9. Weighting factors of special fuels based on net calorific value EN 15316-4-5 (CEN option)

Energy carrier		f_{Pnren}	f_{Pren}	f_{Ptot}
Fuels from multi-output systems	waste	0	0	0
	residual fuel	0.2	0	0.2
	sewage sludge	0	0	0
	land fill gas	0	0	0
	mine gas, coke oven gas	0	0	0

7.2.3 Multi output generation system

Multi-output generation systems transform input fuel or energy into more than one energy carrier. Common example is district heating system using CHP technology for production of heat and power simultaneously. System could be described as follows (EN 15316-4-5 definition):



Key

A	system boundary	1	energy input to system	E_{in}
B	energy consumer	2	energy delivered from the system	E_{del}
		3	exported energy	E_{exp}

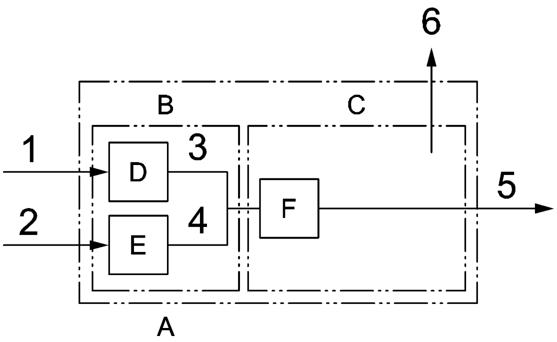
Figure 13. Multi output generation system (EN 15316-4-5)

$$f_{we} = \frac{\sum_{cr} E_{in;cr} \cdot f_{we;cr} - E_{exp} \cdot f_{we;exp}}{\sum E_{del}} \qquad (4)$$

where

f_{we}	weighting factor of the district energy system;
$E_{in;cr}$	energy content of input to the system of energy carrier *cr*;
$f_{we;cr}$	weighting factor of energy carrier *cr*;
E_{del}	delivered energy;
E_{exp}	energy exported to an external system or area;
$f_{we;exp}$	weighting factor of the exported energy;

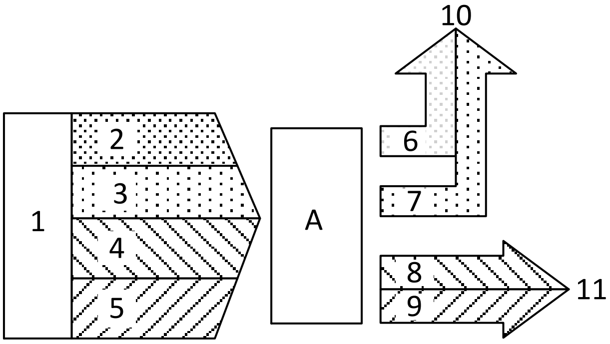
For this type of system additional information about the district energy system is required, system cannot be regarded as black-box.



Key

A	system boundary district heating system	1	energy input generator 1	$E_{in;gen1}$
B	system boundary generation part	2	energy input generator 2	$E_{in;gen2}$
C	system boundary distribution part	3	energy output generator 1	$E_{out;gen1}$
D	generation device 1	4	energy output generator 2	$E_{out;gen2}$
E	generation device 2	5	delivered energy	E_{del}
F	network pump or compressor	6	distribution related loss	$E_{dis;ls}$

Figure 14. Multi output generation system detailed information (EN 15316-4-5)



Key

A	CHP unit		6	electricity from non-cogeneration mode	$E_{el;ncm}$
1	fuel input	E_{in}	7	electricity from cogeneration mode	$E_{el;cm}$
2	electricity-related fuel for non-cogeneration mode	$E_{in;el;ncm}$	8	heat from cogeneration mode	Q_{cm}
3	electricity-related fuel for cogeneration mode	$E_{in;el;cm}$	9	heat from non-cogeneration mode	Q_{ncm}
4	heat-related fuel for cogeneration mode	$E_{in;th;cm}$	10	electricity produced by cogeneration unit	$E_{el;pr}$
5	heat-related fuel for non-cogeneration mode	$E_{in;th;ncm}$	11	heat produced by cogeneration unit	Q_{pr}

Figure 15. Example of energy flows in CHP unit (EN 15316-4-5)

CHP generation units can operate in different modes - in full cogeneration mode, in non-cogeneration mode or in mix/hybrid mode. This needs to be reflected in the calculation procedure and energy flows can thus include heat from non-cogeneration mode as well as electricity from non-cogeneration mode. Electricity and heat produced in non-cogeneration mode should not be taken into account while defining performance of produced heat in CHP process.

7.2.3.1 Weighting factors for heat produced in CHP mode

There are number of methods to calculate the weighting factors of a district heating system that includes a CHP unit. The heat-related CHP fuel $E_{in;th}$ cannot be measured directly, thus considering method selection criteria calculation procedure needs to use one of the following methods[17] (EN 15316-4-5 and TR 15316-6-8).

- *Power bonus method*

This method is universal and applicable to all cogeneration units.

- *Power loss simple method*

The power loss simple method can only be applied if the heat is extracted from a condensation turbine. It is the only method to calculate performance indicators for heat from nuclear power plants because the method does not require E_{in} as input data.

- *Power loss method*

The power loss method is applicable if the heat is extracted from a condensation turbine. It is the only method that facilitates the determination of the real expenditure of heat production in a cogeneration unit without any external reference systems. It is based on specific data of the cogeneration unit and thus reflects the efficiencies of its technical components. It is well known and accepted among power plant operators and scientists as thermodynamically correct. It is based on the idea that the amount of fuel that is related to the lost electricity production due to heat extraction shall be allocated to the heat. The power loss method does not require the exclusion of the electricity-related part of the non-cogeneration mode.

- *Carnot method*

The Carnot method is a simplified version of the exergy method. It requires temperatures as additional input data. These are easy to measure. It is recommended to use the outdoor temperature at the plant site. For systems with modulating supply temperatures it is recommended to use a monthly calculation interval. Systems with a constant supply temperature can be calculated on an annual basis. The mean temperature of the CHP-heat can easily be calculated from the supply and return temperatures at the outlet of the plant site or at the outlet of the CHP unit if available. If the return temperature is not available $\Delta T = 20$ K can be assumed. In case of a steam supply system the steam temperature is used. Data from external reference systems is not required. The carnot method does not require the exclusion of the electricity-related part of the non-cogeneration mode. It can be applied to all cogeneration units. The basic idea is related to the power loss method but it is more based on the physical concept of exergy. It determines the exergy content of the heat and compares it with the produced electricity to allocate the fuel.

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[17] More details about CHP allocation methods could be found in EN 15316-4-5 and TR 15316-6-8

- *Alternative production method*

The alternative production method requires two external reference systems and the exclusion of both the electricity-related and heat-related energy flows of the non-cogeneration mode. The method allocates much more fuel to the heat than the other methods. This results in rather low electricity factors. Especially CHP units with rather low electric efficiency are misinterpreted as CHP units with rather high electric efficiency. So the method seems to violate the second law of thermodynamics. However it is described in the standard because there are already cases of application and it is applicable for statistical purposes where only aggregated data is available.

- *Residual heat method*

This method follows the same idea as the power bonus method but facilitates the determination of electricity factors.

- *Power loss ref method*

This method follows the same idea as the power loss simple method but facilitates the determination of electricity factors.

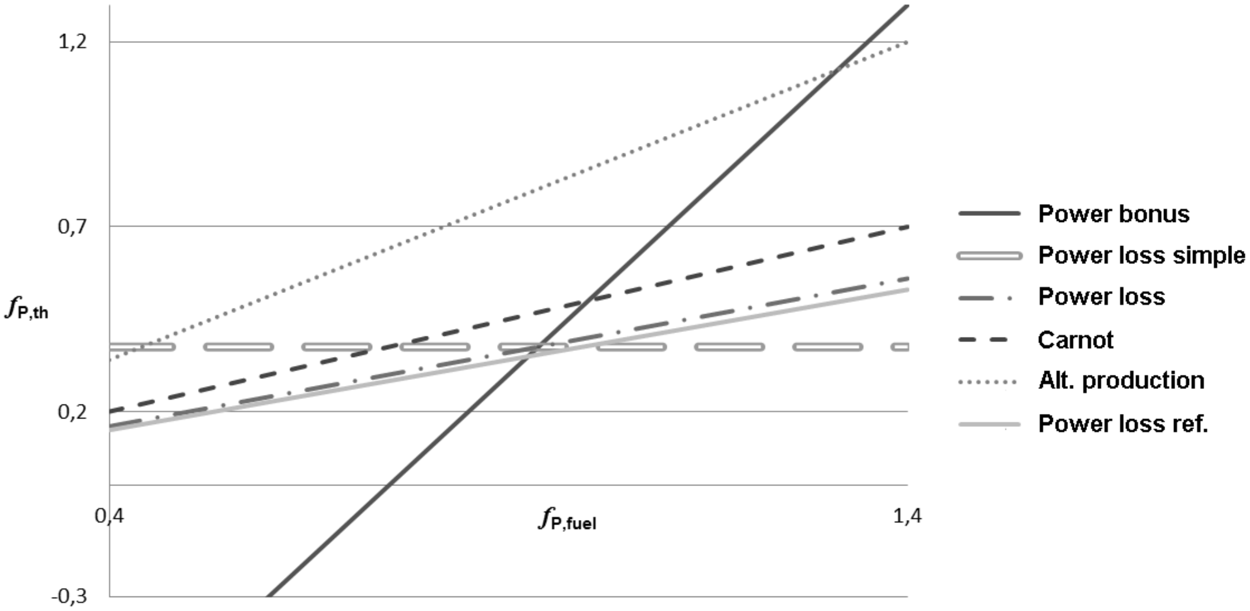

Figure 16. Primary energy factors for heat calculated with different allocation methods[18]

Each of the method has its role but only Power Bonus Method is generally applicable to all cogeneration installations. All primary energy savings achieved in CHP process have to be logically applied to heat and not to electricity because it is heat demand which brings about those savings. Increasing heat demand increases primary energy savings achieved, increasing electricity demand creates no savings at all. This approach is fully recognized in related standard EN 15316-4-5, which recommends PEF for electricity from CHP as follows:

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[18] CEN TC 228/WG 4, 2015: *TR 15316-6-8, Technical Report to FprEN 15316-4-5:2015 "District Heating and Cooling" — M3-8-5, M4-8-5, M8-8-5, M11-8-5*

Table 10. Weighting factors of electricity based on net calorific value EN 15316-4-5 (CEN option)

Energy carrier		f_{Pnren}	f_{Pren}	f_{Ptot}
electricity	delivered from the grid	2.3	0.2	2.5
	exported from CHP	2.5	0	2.5
	from PV, wind, water	0	1	1

Calculation of PEF for heat distributed via district heating systems includes also downstream losses.

Table 11. Default values for distribution systems EN 15316-4-5 (CEN option)

Distribution system		Value	unit
district heating	heat loss of new networks	250	kWh/m per pipe route and year
	heat loss of existing networks	13	% of heat input
	electricity consumption of network pumps	1	% of heat input

Final PEF for heat delivered through district heating systems (including system losses) based on Power Bonus Method is listed in following table.

Table 12. Default PEF for heat delivered via district heating systems EN 15316-4-5 (CEN option)

Energy carrier			f_{Pnren}	f_{Pren}	f_{Ptot}
heat from boilers		solid fossil fuel	1.7	0	1.7
		liquid fossil fuel	1.6	0	1.6
		gaseous fossil fuel	1.5	0	1.5
		solid bio fuel	0.4	1.4	1.8
		liquid bio fuel	0.7	1.4	2.1
		gaseous bio fuel	0.6	1.4	2.0
heat from CHP$^{(1)}$		solid fossil fuel	0.8	0	0.8
		liquid fossil fuel	0.7	0	0.7
		gaseous fossil fuel	0.7	0	0.7
		solid bio fuel	0	2.0	1.8
		liquid bio fuel	0	2.4	1.7
		gaseous bio fuel	0	2.4	1.4
		nuclear power plant	0.6	0	0.6
waste heat from	industrial process	process-related component	0	0	0
		district heating component + process-related component	0.4	0	0.4
	waste-to-energy	incl. CHP	0.1	0	0.1
		without CHP	0.2	0	0.2
environmental heat (geo-, aero- and hydrothermal)			0	1	1

Note

$^{(1)}$ Values are "conservative" and calculated including losses of a distribution system.

7.3 *Comparing efficiency of heating solution*

Based on calculation procedures described in previous Chapter it is possible to compare efficiency of various heating solution for the purposes of defined partial target of doctoral thesis.

7.3.1 Energy efficiency of district heating compared to other heating solutions

Standard EPBD approach uses as a main indicator consumption of non-renewable primary energy within the building (f_{Pnren}).

I can use described calculation based on primary energy factors for declaring district heating with combined heat and power as one of the most efficient solution for covering heat needs comparable with local heat pump even when using fossil fuels. In terms of non-renewable energy consumption district heating installations based on waste-to-energy technology could provide efficiency comparable to biomass installations. However district heating with heat-only boilers using fossil fuels are presented as ineffective solution and should be avoided in this respect. The real district heating network could consist of several installations with different production regimes, thus the correct value needs to be calculated.

Table 13. Comparing heating solutions based on EPBD non-renewable primary energy consumption according to EN 15603 and EN 15316-4-5 (CEN option)

	f_{Pnren}
Heat only installation (local)	
Coal/Lignite	1.1
Natural gas	1.1
Biomass	0.2
Electricity	2.3
Heat pump$^{(1)}$	0.8
District heating$^{(2)}$	
Coal/Lignite without CHP	1.7
Natural gas without CHP	1.5
Biomass without CHP	0.4
Coal/Lignite with CHP	0.8
Natural gas with CHP	0.7
Biomass with CHP	0
Waste with CHP	0.1
Waste without CHP	0.2

Note

(1) Value calculated based on seasonal coefficient of performance (COP) = 3 and PEF_{nren} for electricity = 2.3. No direct use of electricity for heating.

(2) Values are “conservative” and calculated including losses of a distribution system.

7.3.2 Emission efficiency of district heating compared to other heating solutions

Emission efficiency could be described as potential for production of particulate matter fraction below 2.5 µm ($EPS_{2.5}$), which is commonly used characteristics for evaluation of projects according to State Environmental Fund[19]. Parameter could be defined as follows:

$$EPS_{2.5} = EmPM_{2.5} + EmSO_2 \cdot 0.298 + EmNO_X \cdot 0.067 + EmNH_3 \cdot 0.194 + EmVOC \cdot 0.009 \quad (5)$$

Where:

$EPS_{2.5}$	emission efficiency parameter;
$EmPM_{2.5}$	emissions of $PM_{2.5}$ (particulate matter fraction below 2.5 µm)[20];
$EmSO_2$	emissions of SO_2 (sulphur dioxide);
$EmNO_x$	emissions of NO_X, the sum of nitrogen monoxide (NO) and nitrogen dioxide (NO_2), expressed as NO_X;
$EmNH_3$	emissions of NH_3 (ammonia);
$EmVOC$	emissions of VOC (volatile organic compound);

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[19] The system of evaluation of projects in the Operational programme Environment of the Ministry of Environment of the Czech Republic uses for standard pollutants and indicators of the emissions of $PM_{2.5}$ and its precursors (EPS = $_{prim}PM_{2.5}$ + precursors $_{sek}PM_{2.5}$).

[20] For calculating the emissions of primary $PM_{2.5}$ emissions is used the conversion from dust emission levels according to Annex no. 2 Methodical instruction of Air Protection Department of the Ministry of Environment for the preparation of dispersion studies according to § 32 Art. 1 point. e) of the Act no. 201/2012 Coll., on air protection

Table 14. Emission efficiency – example calculation for block of flats building for various types of heating solutions

Indicator	**Unit**	**Lignite DH with CHP**	**Natural gas DH with CHP**	**Natural gas Local CHP**	**Natural gas Local boiler**	**Biomass Local boiler**	**Electric heating Local**	**Heat pump Local**
Heat needs	GJ	1,200	1,200	1,200	1,200	1,200	1,200	1,200
Heat needs including distribution losses	GJ	1,364	1,364	1,200	1,200	1,200	1,200	1,200
Electrical efficiency	-	0.3	0.35	0.4	0	-	-	-
Heat efficiency	-	0.5	0.5	0.5	0.9	0.85	1	-
Total efficiency	-	0.8	0.85	0.9	0.9	0.85	1	3
Efficiency of distribution	-	0.88	0.88	1	1	1	1	1
Total fuel input	GJ	2,727	2,727	2,400	1,333	1,412	1,200	400
Heat production	GJ	1,364	1,364	1,200	1,200	1,200	1,200	1,200
Power production	GJ	818	955	960	0	0	0	0
NO_X Emissions	g/GJ	70.93	37.65	60.61	25.10	106.39	-	-
SO_2 Emissions	g/GJ	84.49	0	0	0	0	-	-
Dust Emissions	g/GJ	4.05	0	0	0	80.92	-	-
Factor NO_X to $PM_{2.5}$	-	0.067	0.067	0.067	0.067	0.067	0.067	0.067
Factor SO_2 to $PM_{2.5}$	-	0.289	0.289	0.289	0.289	0.289	0.289	0.289
Factor dust to $PM_{2.5}$	-	0.6	0.6	0.6	0.6	0.6	0.6	0.6
$EPS_{2.5}$ (1)	g/GJ	31.60	2.52	4.06	1.68	55.68	84.23	84.23
Total $EPS_{2.5}$ production	kg	86.18	6.88	9.75	2.24	78.61	101.08	33.69
Coefficients of significance[21]	-	5	8	26	26	26	5	5
Total impact of energy production	**kg**	**430.88**	**55.04**	**253.38**	**58.30**	**2,043.76**	**505.38**	**168.46**

Note

own calculations

(1) $EPS_{2.5}$ for consumed electricity is according to data of Ministry of Environment 0.30323 kg/MWh[22]

For case of CHP installations there is a need for allocation of emissions to electricity and heat production. If the same logic as for primary energy factors is used (power bonus method for emissions) final impacts of energy production would be as presented in Table 15.

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[21] Coefficients of significance for the calculation of compensation measures depending on the height of the chimney, according to Annex no. 16 Regulation no. 415/2012 Coll. on the permitted level of pollution and its ascertainment, value 26, 8 resp. 5 stands for chimney height 20.5-23 m, 135-150 m resp. 185-206 m

[22] Data presented in revision of Decree no. 480/2012 Coll. on the energy audits and energy assessment, version after interdepartmental comment procedure, July 2016

Table 15. Emission efficiency – example calculation for block of flats building for various types of heating solutions with allocations of emissions to electricity production

Indicator	**Unit**	**Lignite DH with CHP**	**Natural gas DH with CHP**	**Natural gas Local CHP**	**Natural gas Local boiler**	**Biomass Local boiler**	**Electric heating Local**	**Heat pump Local**
$EPS_{2.5}$ for consumed electricity	kg/MWh	0.30323	0.30323	0.30323	0	0	0	0
Emissions from electricity production	kg	68.92	80.40	80.86	0	0	0	0
Coefficients of significance for avoided production	-	5	5	5	-	-	-	-
Allocated emissions to electricity production	kg	344.58	402.01	404.31	0	0	0	0
Total impact of energy production	**kg**	**86.30**	**-346.97**	**-150.93**	**58.30**	**2,043.76**	**505.38**	**168.46**

Note
own calculations

Allocation of emissions to electricity shows avoided emissions thanks to the application of CHP technology. District heating systems based on coal/lignite could be considered as comparable even with local natural gas heat only solutions in cases when CHP technology is used. Natural gas fired CHP district heating or local installation could provide even positive overall impacts on emission efficiency (negative effects on production of particulate matter) thanks to the fact that $EPS_{2.5}$ for consumed/produced electricity, which is allocated towards energy production, is based on lignite/coal power plant facilities according to data of Ministry of Environment.

7.3.3 Efficiency of district heating systems

Comparison of emissions and energy efficiency of district heating systems described in previous sub-chapters assessed district heating systems with employed combined heat and power technology as one of the most efficient way how to cover heat needs while maintaining a high degree of flexibility, low overall energy consumption and limit environmental impacts of production of heat and power.

8 Legislation and other factors on the heat market

8.1 Defining the effects on the heat market

I focused this chapter on assessing factors and drivers of heat market and described related position of district heating. Relevant hypothesis within this Chapter is: "New environmental legislation focuses on key environmental issues and all stakeholders on the heat market are covered in non-discriminatory way and its effects are not differentiated by the scale of emitter ("Polluter-pays-principle" is ensured)"

8.2 Legislation effects on the heat market

Major factors influencing all actors on the heat market are legislative requirements and other regulations.

8.2.1 Promotion of cogeneration

8.2.1.1 EU Directive on energy efficiency

Directive 2012/27/EU on the energy efficiency[23] was adopted in October 2012 and replaces previous Directive 2004/8/EC on promotion of cogeneration. Directive aims at increase in energy efficiency through establishing a support scheme for development of highly efficient cogeneration. The Directive defines in particular the following:

- cogeneration itself as simultaneous generation of heat and electricity and/or mechanical energy in a single process,
- economically justifiable heat demand as a demand not exceeding the needs which would otherwise be satisfied at market conditions without cogeneration,
- useful heat as heat produced in a cogeneration process to satisfy an economically justifiable demand,
- reference values for separate heat and power production as efficiency of alternative separate heat and power production that the cogeneration process is intended to substitute.

Calculation of primary energy savings

Primary energy savings from cogeneration can be calculated using the formula mentioned in Chapter 7.1.1.

Highly efficient cogeneration shall provide at least 10 % primary energy savings compared to the reference values for separate heat and electricity production. The aforementioned Directive, however, lacks binding targets for member states. There is Commission decision related to the Directive 2012/27/EU focused on determination of reference values for separate production of electricity and heat, which is regularly updated each 5 years. Last updated version is EU regulation no. 2015/2402[24]. These updates ensure that CHP installations are compared to most efficient installations for separate production of electricity and heat.

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[23] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency

[24] Commission delegated regulation (EU) 2015/2402 of 12 October 2015 reviewing harmonised efficiency reference values for separate production of electricity and heat in application of Directive 2012/27/EU of the European Parliament and of the Council

Harmonised efficiency reference values for separate production of electricity and heat are listed in Annex IV.

8.2.1.2 Czech Act on promoted energy sources

Provisions about support for cogeneration of Directive 2012/27/EU on the energy efficiency were transposed into Czech legislation system to Act on promoted energy sources[25]. This Act merges all supported energy sources for electricity and heat production (renewables, secondary energy sources, combined heat and power) into one single act of law as the reaction to facilitate sustainable growth and management of supported energy sources. Act uses so called "National Action Plan for energy from renewable sources"[26], which describes planned development of renewable energy installations and their support in order to attain EU targets. The act stipulates the financial support for electricity and heat production from renewable and secondary energy sources

Basic principles on renewable electricity of the Act are:

- the financial support for the renewable electricity is set by the Energy Regulatory Office
- the renewable electricity producers can choose from 2 support systems: selling the electricity at the prices set by the Energy Regulatory Office as a "feed-in" tariff or the "green bonus" system.

Support for CHP electricity is based on "green bonus" system and is annually set by Energy Regulatory Office within Price Decisions. Actual Price Decision[27] set support for electricity from high-efficient combined heat and power production, detailed information about Annual Green Bonuses for installations based on the size and production regime could be found in Annex V.

CHP installations with electrical output below 5 MW need to reach Primary energy savings above 0 % in order to claim support for high-efficiency CHP.

Total support for electricity produced in cogeneration is then calculated as follows:

$$SupportCHP = E_{CHP} \cdot \left(GB_{standard} + GB_{supplement} \right) \tag{6}$$

Where:

$SupportCHP$	Total support for electricity produced in CHP
E_{CHP}	Electricity produced in CHP
$GB_{standard}$	Green bonus standard rate
$GB_{supplement}$	Green bonus supplemental rate

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[25] Act no. 165/2012 Coll., on promoted energy sources

[26] According to Commission Decision 2009/548/EC of 30 June 2009 defining a template for the National Action Plan for energy from renewable sources in compliance with the Directive of the European Parliament and of the Council 2009/28/EC.

[27] Price Decision of the Energy Regulatory Office no. 9/2015 of 29 December 2015 laying down support for the promoted energy sources

Act on promoted energy sources has in total 14 related Decrees. The fundamental one for the district heating sector is the Decree on high efficient cogeneration[28], dealing with details of methods for calculating electricity from highly efficient combined heat and power production based on the demand for useful heat, and calculating electricity from secondary energy sources, and regulates assessment and accounting for electricity from combined heat and power production and from secondary energy sources. The Decree is based on Directive 2012/27/EU and defines conditions for the production of highly efficient cogenerated electricity.

8.2.1.3 Czech Energy Legislation

The Act no. 458/2000 Coll., on Business Conditions and Public Administration in the Energy Sectors and on Amendment to Other Laws (the "Energy Act")[29] is the cornerstone of the Czech energy legislation. This Act provides for the conditions applicable to business activity, the exercise of public administration, and non-discriminatory regulation in the energy sectors, including the electricity, natural gas and district heating sector, as well as for the rights and obligations of individuals and related entities. Beside other issues, the Energy Act defines conditions for electricity and heat production and distribution. This Act also clearly stipulates that district heating systems are established and operated in the public interest.

There are 29 Decrees in total related to the Energy Act.

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[28] Decree no. 37/2016 Coll. on electricity from high efficient combined heat and power production and electricity from secondary sources

[29] Act no. 458/2000 Coll., on Business Conditions and Public Administration in the Energy Sectors and on Amendment to Other Laws

8.2.2 Integrated prevention and air protection

8.2.2.1 EU Large Combustion Plants Directive (“LCP Directive”)

The Directive 2001/80/EC on the Limitation of Emissions of Certain Pollutants into the Air from Large Combustion Plants[30] was adopted in October 2001. The LCP Directive sets out emission limits applicable to large combustion plants (above 50 MW rated thermal input) as follows:

Table 16. Emission limit values for combustion plants in the LCP Directive

Pollutant	**Fuel type**	**Emission limit values in mg/Nm^3**			
		50 - 100 MW	**> 100 - 300 MW**	**> 300 - 500 MW**	**> 500 MW**
SO_2	**Solid**	2,000	2,000 to 400 (linear scale)		400
	Liquid	1,700		1,700 to 400 (linear scale)	400
	Gaseous	35 in general			
		5 for liquefied gas			
		800 for coke oven gas & blast furnace gas			
NO_x	**Solid**	600			500/200(1)
	Liquid	450			400
	Gaseous	300			200
dust	**Solid**	100			50
	Liquid	50			
	Gaseous	5 in general			
		10 for blast furnace gas			
		50 for steel industry gases that can be used elsewhere			

Note
(1) From 1 January 2016 onwards

The LCP Directive was replaced by the Industrial Emissions Directive in the end of 2010.

8.2.2.2 EU Industrial Emissions Directive (“IED”)

The Industrial Emissions Directive 2010/75/EU31 was adopted following lengthy negotiations in December 2010 as a recast of the previous Directive on Integrated Pollution Prevention and Control (referred to as “IPPC”). This new Directive merges 6 Directives in the field of pollution control and in effect integrates environmental management. The purpose of Integrated Prevention is to focus on the impact of industrial installations on all aspects of the environment – including soil and ground water.

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[30] Directive 2001/80/EC of the European Parliament and of the Council of 23 October 2001 on the Limitation of Emissions of Certain Pollutants into the Air from Large Combustion Plants

[31] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on Industrial Emissions (integrated pollution prevention and control)

Compared to the previous LCP Directive, the IED introduces new ambitious emission limit values for combustion plants (as listed in Table 17). These new limits developed from BAT levels for each technology. These limits apply when there are no approved BAT conclusions for given installation.

Table 17. Emission limit values for combustion plants according to the IED (so called "safety net")

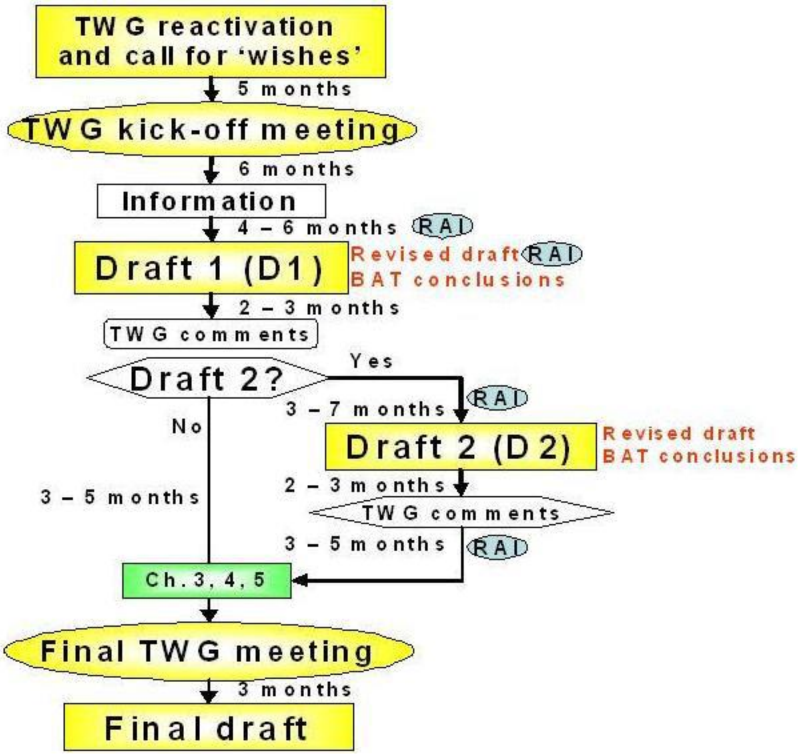
	Fuel		**Hard coal or lignite**	**Liquid fuels**	**Biomass**	**Gaseous fuels**
Emission limit values in mg/Nm^3	**50 – 100 MW**	**SO_2**	**400**	**350**	**200**	**35**
		NO_x	**300/450**	**450**	**300**	**100**
		Dust	**30**			**5**
	101 – 300 MW	**SO_2**	**250**		**200**	**35**
		NO_x	**200**		**250**	**100**
		Dust	**25**		**20**	**5**
	> 300 MW	**SO_2**	**200**			**35**
		NO_x	**200**	**150**	**200**	**100**
		Dust	**20**			**5**

Member States can opt for various possibilities to derogate from these emission limit values:

- "Transitional national plans" ("TNP") for large combustion plants which were put in operation before 2002; these can apply individual emission limits until 30 June 2020. TNP sets an emission ceiling for each pollutant it covers (one or more of the following pollutants: nitrogen oxides, sulphur dioxide and dust). Emission ceilings decrease linearly until 30 June 2020, when the emission limit values should be applicable.
- Exception for district heating plants (installations with up to 200 MW thermal capacity) where at least 50 % of the useful heat produced by the plant - as a rolling average over a period of 5 years – is delivered in the form of steam or hot water to a district heating system; the exception expires on 31 December 2022,
- Limited lifetime derogation for plants which will remain in operation for no more than 17,500 operating hours from 1 January 2016 to 31 December 2023.

IED has built in procedure for reassessment of emission limits each 8 year period based on the deriving of so called BREF revision process where BREF documents (BAT reference documents) are to be derived. Each BREF has dedicated part called BAT Conclusions which should serve as reference for setting emission limits. Once BAT conclusions are derived it is mandatory for operators to use them.

8.2.2.3 EU Large combustion plants BREF revision



Note
RAI = Request for additional information

Figure 17. Final draft of BREF development – time scheme (EC decision 2012/119/EU[32])

LCP BREF revision started in February 2011 by reactivation of LCP Technical working group ("TWG"). Members of the TWG are representatives of EU Member States, environmental NGOs and industrial NGOs. TWG was asked to send its comments and suggestions to the current LCP BREF (version of 2006). EU IPPC Bureau ("EIPPCB") gathered these comments and created "wishlist" – in total 2000 comments to previous LCP BREF text. In October 2011 Kick-off meeting took place, where stakeholders agreed on the future shape, structure and the scope of the BREF and determined the type and form of the required information for deriving sound BREF and the method of acquisition and exchange of this information. Information were gathered via complex questionnaires in first half of 2012, in total EIPPCB worked with a total of 482 questionnaires from operators and another 64 questionnaires were completed by EIPPCB itself.

After assessment of these questionnaires EIPPCB sent in June 2013 first draft of LCP BREF ("D1 LCP BREF") to TWG for comments. In total 8512 comments were raised. This significant number of comments motivated EIPPCB for organizing informal working group meeting in June 2014. In April 2015 EIPPCB forwarded Background document (assessment of the D1 LCP BREF comments) as well as proposal for BAT conclusions for LCP BREF. In June 2015 Final meeting of LCP BREF TWG took place

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[32] Commission Implementing Decision 2012/119/EU of 10 February 2012 laying down rules concerning guidance on the collection of data and on the drawing up of BAT reference documents and on their quality assurance referred to in Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions

followed by one webinar. Although meeting was scheduled for 7 full days plus 1 day of webinar meeting there was not enough time to discuss all the issues. The rest was subject to written consultation process.

In February 2016 EIPPCB sent to TWG prefinal draft of LCP BREF (intermediate step to Final draft). According to the latest information Final draft should be ready by July 2016.

After issuing Final draft of LCP BREF, this will go to IED Article 13 Forum (IPPC Forum), there will be another exchange of views from broader perspective on the meeting currently planned in Autumn 2016. After Forum meeting only BAT Conclusions will go to the IED Article 75 meeting, where Member States' representatives will vote about accepting or declining of BAT Conclusions text. After this final vote BAT Conclusions will be sent to Official Journal of the European Union. From this date 4 year period to include all provisions of BAT Conclusions will start. According to the latest information publication in EU Journal could be expected in the beginning of 2017. This means that LCP operators will have to follow requirements of LCP BREF from 2021. Thus LCP BREF revision process is not finalized yet and related emission limits and requirements are subject to possible change later in the negotiation process.

Table 18. LCP BREF – BAT Conclusions Yearly average Emission Limit Values in mg/Nm^3 (upper limit) for existing plants (version of February 2016)

	Fuel		Hard coal or lignite	Liquid fuels	Biomass	Natural Gas
Emission limits values in mg/Nm^3	**50 - 100 MW**	**SO_2**	**360**	**175**	**100**	**-**
		NO_x	**270**	**270**	**225**	**100**
		Dust	**18**	**20**	**15**	**-**
		HCl/HF Hg	**10/6 0.009/0.01**	**-**	**15/1.5 0.005**	**-**
	101 - 300 MW	**SO_2**	**200**	**175**	**70**	**-**
		NO_x	**180**	**100**	**180**	**100**
		Dust	**14**	**20**	**12**	**-**
		HCl/HF Hg	**5/3 0.009/0.01**	**-**	**9/1 0.005**	**-**
	> 300 MW	**SO_2**	**130/180***	**110**	**50**	**-**
		NO_x	**150**	**100**	**150**	**100**
		Dust	**10/8****	**10**	**10**	**-**
		HCl/HF Hg	**5/3 0.004/0.007**	**-**	**5/1 0.005**	**-**

Note

All listed values in dry flue gasses, reference conditions, for solid fuels 6% O_2, for gaseous and liquid fuels 3% O_2

new plant = A combustion plant first permitted at the installation level following the publication of these BAT conclusions or a complete replacement of a combustion plant on the existing foundations of the installation

existing plant = A combustion plant which is not a new plant

Table 19. LCP BREF – BAT Conclusions Emission limits in mg/Nm^3 for plants firing solid fossil fuels (version of February 2016)

	Size	**Pollutant**		
		NO$_X$	**SO$_2$**	**Dust**
New Plants	**50 - 100 MW$_{th}$**	(Y) 100-150 (D) 155-200	(Y) 150-200 (D) 170-220	(Y) 2-5 (D) 4-16
	>100 MW$_{th}$	(Y) 50-100 (D) 80-130	(Y) 80-150 (D) 135-200	(Y) 2-5 (D) 3-15
	>300 MW$_{th}$	FBC boiler combusting coal and/or lignite and lignite-fired PC boiler: (Y) 50-85 (D) 80-125 coal-fired PC boiler: (Y) 65-85 (D) 85-125	PC boiler: (Y) 10-75 (D) 25-110 Fluidised bed boiler: (Y) 10-75 (D) 25-110	(Y) 2-5 (D) 3-10
Existing Plants	**50 - 100 MW$_{th}$**	(Y) 100-270 (D) 165-330	(Y) 150-360 (D) 170-400	(Y) 2-18 (D) 4-22
	>100 MW$_{th}$	(Y) 100-180 (D) 155-210	(Y) 95-200 (D) 135-220	(Y) 2-14 (D) 4-22
	>300 MW$_{th}$	FBC boiler combusting coal and/or lignite and lignite-fired PC boiler: (Y) 50-175 (D) 140-220 coal-fired PC boiler: (Y) 65-150 (D) 85-165	PC boiler: (Y) 10-130 (D) 25-165 Fluidised bed boiler: (Y) 20-180 (D) 50-220	(Y) 2-10 (D) 3-11 above 1000 MW$_{th}$: (Y) 2-8 (D) 3-11

Note

All listed values in dry flue gasses, reference conditions, 6% O_2

(Y) = yearly average

(D) = daily average

new plant = A combustion plant first permitted at the installation level following the publication of these BAT conclusions or a complete replacement of a combustion plant on the existing foundations of the installation

existing plant = A combustion plant which is not a new plant

8.2.2.4 Comparison of EU LCP legislation

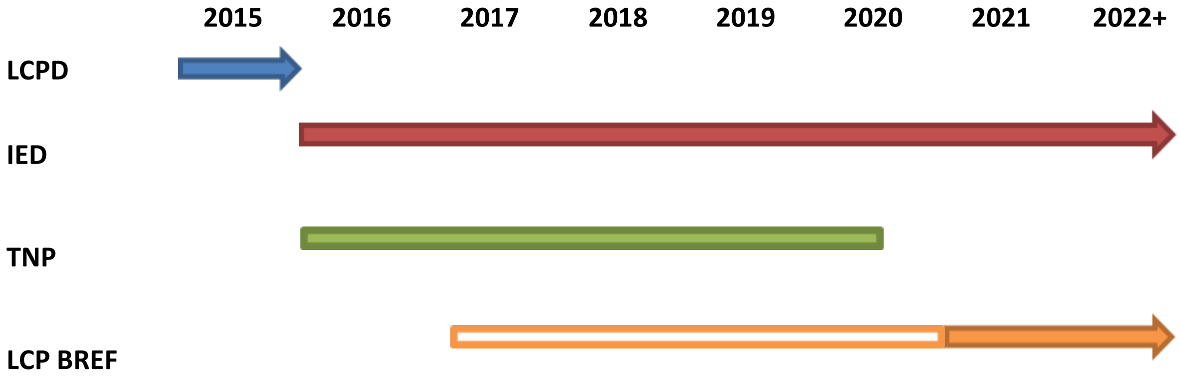

Figure 18. EU legislation air pollution measures for LCP – time scheme of application

Up to the 2015 LCPD applied to all LCP installations (above 50 MW thermal installed input). From 2016 onwards IED applies with its own derogation regimes such as TNP from 1st January 2016 to 30th June 2020. After expiration of TNP, IED values will apply as long as there will be no approved BAT conclusions. BAT conclusion requirements are subjects to transposition period of 4 years, it is valid after 4 years from official publication in EU Journal.

Comparison of development of EU Air protection legislation for lignite fired installations above 50 MW thermal input is described in following tables.

Table 20. Example of lignite fired installation above 50 MW$_{th}$ and development of SO_2 emission limit values for large combustion plants according to the EU legislation on air protection

LCP Directive 2001/80/EC		**IED Directive 2010/75/EC - from 2016 existing/new**		**LCP BREF – from 2021 existing/new (upper limits)**		
Thermal input [MW$_{th}$]	**Monthly average [mg/Nm^3]**	**Thermal input [MW$_{th}$]**	**Monthly average [mg/Nm^3]**	**Thermal input [MW$_{th}$]**	**Daily average [mg/Nm^3]**	**Yearly average [mg/Nm^3]**
50-100	**2000**	50-100	**400**	<100	**400/220**	**360/200**
‹100;500)	**2,000-400** (linear decrease)	100-300	**250/200**	100-300	**(250)220/200**	**200/150**
≥500	**400**	>300	**200/150**	>300	**PC: 165/110** **FBC: 220/110** **(E-NGO: 75/60)(1)**	**PC: 130/75** **FBC: 180/75** **(E-NGO: 40/20)(1)**

Note

All listed values in dry flue gasses, reference conditions, 6% O_2

In brackets listed requirements for installations put into operation before 7th January 2014

(1) Requirements of Environmental NGOs

Table 21. Example of lignite fired installation above 50 MW_{th} and development of NO_X emission limit values for large combustion plants according to the EU legislation on air protection

LCP Directive 2001/80/EC		**IED Directive 2010/75/EC - from 2016 existing/new**		**LCP BREF – from 2021 existing/new (upper limits)**		
Thermal input [MW_{th}]	**Monthly average [mg/Nm^3]**	**Thermal input [MW_{th}]**	**Thermal input [MW_{th}]**	**Monthly average [mg/Nm^3]**	**Thermal input [MW_{th}]**	**Thermal input [MW_{th}]**
50-500	**600**	50-100	**450/400**	50-100	**330/200**	**270/150**
		>100	**200**	100-300	**210/130**	**180/100**
>500	**500 (200 from 2016)**			>300 lignite	**PC: 220/125** **FBC: (200)165/125** **(E-NGO: 160/~)(1)**	**PC: 175/85** **FBC: 150/85** **(E-NGO: 100/~)(1)**

Note

All listed values in dry flue gasses, reference conditions, 6% O_2

In brackets listed requirements for installations put into operation before 7th January 2014

(1) Requirements of Environmental NGOs

Table 22. Example of lignite fired installation above 50 MW_{th} and development of Dust emission limit values for large combustion plants according to the EU legislation on air protection

IED Directive 2010/75/EC - from 2016 existing/new		**LCP BREF – from 2021 existing/new (upper limits)**		
Thermal input [MW_{th}]	**Thermal input [MW_{th}]**	**Thermal input [MW_{th}]**	**Thermal input [MW_{th}]**	**Thermal input [MW_{th}]**
50-100	**30/20**	50-100	**(28)22/16**	**18/5**
100-300	**25/20**	100-300	**(25)22/15**	**14/5**
300-1000	**20/10**	>300	**(20)11/10**	**(12)10/5**
>1000	**20/10**	>1000	**(14)11/10**	**8/5**

Note

All listed values in dry flue gasses, reference conditions, 6% O_2

In brackets listed requirements for installations put into operation before 7th January 2014

8.2.2.5 EU Medium Combustion Plants Directive ("MCP Directive")

Medium combustion Plant Directive[33] is setting requirements for combustion plants from 1 MW to 50 MW of installed thermal input. MCPD uses definitions of "existing plants" as plants put into operation no later than 3 years from the publication of MCPD in the Official EU Journal and "new plants" as plants put into operation later. MCPD provisions affect these two groups differently. Existing plants have not to be aggregated and emission limit requirements is applicable from 1st January 2025 for plants above 5 MW thermal input and from 1st January 2030 for plants 1-5 MW thermal input. Existing plants could also be subjects of transitional regimes:

- for "district heating installation" – If at least 50 % of the useful heat production of the plant, as a rolling average over a period of five years, is delivered in the form of steam or hot water to a public network for district heating the application of emission limits will be postponed to 1st January 2030. Within the regime the emission limit values set by the competent authority shall not exceed 1,100 mg/Nm^3 for SO_2 and 150 mg/Nm^3 for dust.
- for "biomass installation" – Installations firing solid biomass as the main fuel, which are situated in zones where, according to assessments under Directive 2008/50/EC, conformity with the limit values of that Directive is ensured could postpone application of emission limits to 1st January 2030 from compliance with the emission limit values for dust set out in Annex II to this Directive. Within the regime the emission limit values set by the competent authority shall not exceed 150 mg/Nm^3 for dust.

New plants cannot use transitional regimes and hate to be aggregated if flue gasses are discharged through common stack or by taking into account both technical and economic factors could be discharged through a common stack. Emission limit for new plants are applicable immediately, this mean from 20th December 2018 (after 3 year since MCPD entered into force).

There is also special treatment of peak load plants:

- to existing plants in operation less than 500 hours per year (rolling five year average) emission limits not apply, in case of exceptionally cold weather events this amount could be increased to 1,000 hours per year. Within the regime the dust emission limit of 200 mg/Nm^3 applies.
- to new plants in operation less than 500 hours per year (rolling three year average) emission limits not apply. Within the regime the dust emission limit of 100 mg/Nm^3 applies.

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[33] Directive 2015/2193 of the European Parliament and of the Council of 25 November 2015 on the limitation of emissions of certain pollutants into the air from medium combustion plants

Table 23. Emission limit values for medium combustion plants 1 – 5 MW thermal input according to the Medium Combustion Plants Directive (existing/new plants)

Pollutant	**Solid biomass**	**Other solid fuels**	**Natural gas**	**Other gaseous fuels**	**Gas oil**	**Other liquid fuels**
SO_2	**200**/200	**1,100**/400	-	**200**/35	-	**350**/350
NO_x	**650**/500	**650**/500	**250**/100	**250**/200	**200**/200	**650**/300
Dust	**50** /50	**50**/50	-	-	-	**50**/50

Note

All listed values in dry flue gasses, reference conditions, for solid fuels 6% O_2, for gaseous and liquid fuels 3% O_2

Table 24. Emission limit values for medium combustion plants 5 – 50 MW thermal input according to the Medium Combustion Plants Directive (existing/new plants)

Pollutant	**Solid biomass**	**Other solid fuels**	**Natural gas**	**Other gaseous fuels**	**Gas oil**	**Other liquid fuels**
SO_2	**200**/200	**400(1)**/400	**-**	**35**/35	**-**	**350**/350
NO_x	**650**/300	**650**/300	**200**/100	**250**/200	**200**/200	**650**/300
Dust	**30(2)**/20(3)	**30(2)**/20(3)	-	-	-	**30**/20

Note

All listed values in dry flue gasses, reference conditions, for solid fuels 6% O_2, for gaseous and liquid fuels 3% O_2

(1) Plants below 20 MW thermal input 1100 mg/Nm^3

(2) Plants below 20 MW thermal input 50 mg/Nm^3

(3) Plants below 20 MW thermal input 30 mg/Nm^3

Table 25. Emission limit values for engines and turbines 1 – 50 MW thermal input according to the Medium Combustion Plants Directive (existing/new plants)

Pollutant	Type of medium combustion plant	Gas oil	Other liquid fuels	Natural gas	Other gaseous fuels
SO_2	Engines and turbines	-	**120**/120	-	**15**/15
NO_X	Engines	**190**/190	**190**/190	**190**(1) 95(2)	**190**/190
	Turbines	**200**/75	**200**/75	**150**/50	**200**/75
Dust	Engines and turbines	-	**10**/10	-	-

Note

All listed values in dry flue gasses, reference conditions, 15% O_2

(1) For dual fuel engines in gas mode 380 mg/Nm^3

(2) For dual fuel engines in gas mode 190 mg/Nm^3

8.2.2.6 *European Commission implementing decisions to Directive 2009/125/EC with regard to ecodesign requirements for solid fuel boilers*

During the year 2013[34] and 2015[35], European Commission laid down ecodesign requirements for placing on the market and putting into service new solid, gas and liquid fuel boilers and heaters with a rated heat output of 500 kilowatt ('kW') or less. These new requirements are in general applicable from 1st January 2020 for new installations.

8.2.2.7 *Czech Act on Integrated Prevention*

This Act[36] lays down the obligations of plant operators and establishes the procedure for granting integrated permits. The Integrated permit reflects all the relevant information about the plant and represents a decision laying down conditions for the plant operation, including performance of activities directly connected with the operation and consents issued pursuant to special regulations in the area of the environment and public health protection.

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[34] Commission Regulation (EU) No 813/2013 of 2 August 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for space heaters and combination heaters

[35] Commission Regulation (EU) 2015/1189 of 28 April 2015 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for solid fuel boilers

[36] Act No. 76/ 2002 Coll. on Integrated Pollution Prevention and Control, on the Integrated Pollution Register and on Amendment to Some Laws (the Act on Integrated Prevention)

8.2.2.8 Czech Air Protection Act

The Czech Republic has put in 2012 a recast of Air Protection Act[37], where new increased rates for air pollution fees for all installations with total fees above 50,000 CZK/year. In the context of the IED framework (with strict emission limits on BAT levels revised regularly through BREF revision process) they bring no additional economic incentive for producers to aim for even lower emissions. The definition of BAT itself means there is no (or but a very narrow) technological possibility to go further. Consequently, pollution fees only become a new pollution tax.

Table 26. Pollution fees based on Air Protection Act in CZK/t

Pollutant	Dust	SO_2	NO_X	VOC
2016	4,200	1,350	1,100	2,700
2017	6,300	2,100	1,700	4,200
2018	8,400	2,800	2,200	5,600
2019	10,500	3,500	2,800	7,000
2020	12,600	4,200	3,300	8,400
2021 onwards	14,700	4,900	3,900	9,800

8.2.2.9 Czech Water Act

Installations using water for certain purposes have to pay for amount of water drained, released and for pollution in released water (according to emission limits in weight and concentration) based on Czech legislation[38]. There is substantial revision of Czech Water Act[39] in place, which will change fees and emission limits. Only installations with discharges above 50,000 cubic meters are subject to fees for water discharges.

Table 27. Fees for water discharges in CZK per cubic meter (Water Act)

	Proposed by MoE	Possible compromise
Current	0.1	0.1
2017	0.5	0.2
2018	0.7	0.2
2019 and further	1	0.2

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[37] Act no. 201/2012 Coll., on Air Protection and Amending Certain Laws (the Air Protection Act)

[38] Act no. 254/2001 Coll. on Water (The Water Act)

[39] Act no. 254/2001 Coll. on Water (The Water Act), revision proposed by Ministry of Environment in November 2015

Table 28. Fees for pollution discharged to receiving water-body (Water Act)

Pollutant	Current [CZK/kg]	Proposed [CZK/kg]	Fees applicable above	
			Amount [kg/year]	Concentration [mg/l]
Chemical oxygen demand	8	8	10,000	40
Dissolved inorganic salts	0.5	0.5	20,000	1,200
Total Suspended Solids	2	2	10,000	30
P	70	300	100	0.2
N ammoniac	40	100	100	1
AOX	300	500	250	2
Hg	20,000	20,000	15	0.06
Cd	4,000	4,000	0.4	0.002

Note

Pollution fees are applicable only if installation meets both amount and concentration limits.

8.2.3 Emission trading related to district heating

8.2.3.1 EU Emission Trading Scheme Directive (EU ETS Directive)

The EU ETS Directive[40] was adopted in October 2003 and introduced a brand new comprehensive EU emission trading system ("EU ETS") – system of allowance trading. Each European allowance represents the right to emit one tonne of CO_2 (or 1 tonne of CO_2 equivalent in case of other greenhouse gasses ("GHG")) from an installation covered by the EU ETS. This EU ETS Directive was amended by the Directive 2004/101/EC, which added the opportunity to use external emission credits to the limited scope and by the Directive 2009/29/EC, which created provisions for trading period 2013-2020.

Each EU member state must develop a National Allocation Plan (NAP) approved by the European Commission. This sets an overall cap on the total emissions allowed from all the installations covered by the system. This is subsequently converted into allowances (one allowance equals one tonne of CO_2), which are then distributed by EU member states to installations covered by the system.

At the end of each year, installations are required to surrender allowances to account for their actual emissions. They may use all or part of their allocation. Installations can emit more than their allocation by buying allowances from the market. Similarly, an installation that emits less than its allocation can sell its surplus allowances. The environmental outcome is not affected because the amount of allocated allowances is fixed.

The EU ETS covers electricity and heat generation and the main energy-intensive industries – power stations, refineries and offshore, iron and steel, cement and lime, paper, food and drink, glass, ceramics, engineering and the manufacture of vehicles. Thresholds for inclusion in the EU ETS are set quite high so only large installations are covered by the system (for example threshold for

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[40] Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community

combustion plants is 20 MW rated thermal input). Combined, these account for around 60% of the Czech Republic's CO_2 emissions. The EU-28 average, however, is around 45%.

Table 29. Total GHGs emissions in EU-28 compared to emissions in EU ETS (UNFCCC statistics and EC statistics)

	EU-28 [th. t GHGs]	**EU-28 change comp. to baseyear [%]**	**EU ETS [th. t GHGs]**	**EU ETS change comp. to 2005 [%]**	**Share of EU ETS on EU-28 total [%]**
1990 (Base Year)	5,403	---	---	---	---
2005	4,891	-9.5%	2,377	---	48.6%
2006	4,862	-10.0%	2,383	0.3%	49.0%
2007	4,844	-10.3%	2,400	1.0%	49.6%
2008	4,697	-13.1%	2,259	-5.0%	48.1%
2009	4,337	-19.7%	2,004	-15.7%	46.2%
2010	4,461	-17.4%	2,052	-13.7%	46.0%
2011	4,304	-20.3%	2,010	-15.4%	46.7%
2012	4,242	-21.5%	1,969	-17.2%	46.4%
2013	4,148	-23.2%	1,908	-19.7%	46.0%
2014	3,976	-26.4%	1,814	-23.7%	45.6%
2015	NA	NA	1,800	-24.3%	---

8.2.3.2 Czech emission trading legislation

The EU ETS Directive is implemented into the Czech legislation through the EU ETS Act[41]. There is a related Commission Regulation No. 601/2012[42], which defines the process of monitoring, reporting and verification of greenhouse gas emission quantities.

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[41] Act No. 383/2012 Coll., on the Conditions of Greenhouse Gas Emission Allowance Trading and Amending Certain Laws

8.2.3.3 EU Climate-Energy Package

The Climate-Energy Package (Package) was adopted in June 2009. It consists of 4 parts. The main part is the Directive 2009/29/EC[43], amending the existing EU ETS Directive. The new Directive 2009/29/EC includes inter alia EU greenhouse gas targets to decrease GHGs emissions by 20% by 2020. The final text was adopted after lengthy debates and contained many terms that were further defined by the relevant authorities. This task falls to what is called the "Climate Change Committee" (CCC), which was established by Directive 2003/87/EC. The CCC acts as the implementing body for all EU ETS Directives (2003/87/EC, 2004/101/EC and 2009/29/EC).

The most important aspect of Directive 2009/29/EC for all installations in the EU ETS is the new allocation tool – auctioning of allowances, which serves as a universal approach for distribution of European allowances (EUA) from 2013 onwards. Auctioning means that all EUAs will not be distributed to producers free of charge (as was the case in period 2005-2007 and 2008-2012) but producers have to purchase them in open auctions. There are several exceptions to this rule

- Free allocation is given to sectors endangered by what is referred to as "carbon leakage" – meaning sectors like steel or lime production, which could be moved to countries outside the EU because of higher costs. This rule is not applicable to district heating.
- Free allocation is given to the district heating sector and also to high efficiency cogeneration, as defined by Directive 2012/27/EU on Energy Efficiency, for economically justifiable demand, in respect of heating or cooling – allocation according to Article 10a of Directive 2003/87/EC
- Transitional free allocation is given for the modernization of electricity generation – fulfilling at least one of the three criteria determined by Directive 2009/29/EC, a Member State can ask for a partial free EUA allocation for electricity producers. The market value of free EUAs has to be used for retrofitting and upgrading the infrastructure and clean technologies – allocation according to Article 10c of Directive 2003/87/EC

8.2.3.4 Division of emissions in CHP

Division of emissions in the combined heat and power process is defined within the EC Guidance document no. 6, Cross-boundary heat flows[44] and should be made according to following formulas:

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[42] Commission Regulation (EU) No. 601/2012 of 21 June 2012 on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council

[43] Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community

[44] European Commission, Guidance Document no. 6 on the harmonized free allocation methodology for the EU-ETS post 2012 Cross-Boundary Heat Flows Final version issued on 14 April 2011

$$Em_{total,el} = Em_{CHP} \cdot \frac{\frac{\eta_{el}}{\eta_{ref,el}}}{\frac{\eta_{el}}{\eta_{ref,el}} + \frac{\eta_{heat}}{\eta_{ref,heat}}} \qquad Em_{total,heat} = Em_{CHP} \cdot \frac{\frac{\eta_{heat}}{\eta_{ref,heat}}}{\frac{\eta_{el}}{\eta_{ref,el}} + \frac{\eta_{heat}}{\eta_{ref,heat}}} \tag{7}$$

where

η_{el}	Efficiency of electricity production – actual
$\eta_{ref,el}$	Efficiency of electricity production – reference
η_{heat}	Efficiency of heat production – actual
$\eta_{ref,heat}$	Efficiency of heat production - reference

Reference efficiencies are presented in Commission Delegated Regulation (EU) 2015/2402.

Em_{CHP}	Total emissions of CHP installation
$Em_{total,el}$	Emissions attributable to production of electricity in CHP
$Em_{total,heat}$	Emissions attributable to production of heat in CHP

8.2.3.5 Free allocation according to Article 10a

In December 2010, Commission Decision on determining transitional Union-wide rules for the harmonised free allocation of emission allowances according to Article 10a Directive 2003/87/EC (Decision 10a)[45] was adopted within the CCC body. This Decision introduces new rules for adjusting the allocation of free allowances in respect of heat delivered to private households. There are also several Guidance documents focusing on different allocation aspects related to Decision 10a. For district heating plants, the most important document is the Guidance Document No. 6 – Cross-boundary heat flows dealing with issues concerning free allocation for district heating systems.

8.2.3.5.1 Benchmarks

According to the text of Decision 10a to Directive 2009/29/EC, allocation of free allowances is determined by what is called “benchmarks”. A benchmark is a fixed ratio between GHG emissions and a unit of production (in case of the district heating sector it is 1 GJ of heat). Benchmarks are used for free EUA allocation as follows (according to current Directive 2003/87/EC)

- In 2013, there is free EUA allocation of 80% of the benchmark value, with a linear decrease down to 30% in 2020.
- In 2027, there should be no free EUA allocation.

Decision 10a based the benchmark on 10% of the best installations with natural gas as a fuel and 90% boiler efficiency. The final value of what is called heat benchmark is 62.3 kg CO_2/GJ of the heat produced.

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[45] Commission Decision C(2011) 2772 on determining transitional Union-wide rules for the harmonised free allocation of emission allowances pursuant to Article 10a of Directive 2003/87/EC

8.2.3.5.2 Free allocation for heat to private households

Free allocation for heat delivered to private households is a tool introduced by Decision 10a and is referred to as the household rule. It increases free allocation for district heating systems based on their emissions associated with the production of heat for private households over the period from 1 January 2005 to 31 December 2008 (or alternatively from 1 January 2009 to 31 December 2010). This means that the free allocation applicable to heat for private households is adjusted by the difference between historical emissions associated with heat for households and allocation according to the benchmark. However, application of historical emissions is lowered by 10 % each year, starting from 90% in 2014. Heat for other customers is allocated exclusively in line with the benchmark (as described above). Detailed rules applicable to this tool were set by the Guidance Document No. 6.

8.2.3.6 Free allocation according to Article 10c

In March 2011, Commission Decision on guidance on the methodology to transitionally allocate free emission allowances to installations in respect of electricity production pursuant to Article 10c of Directive 2003/87/EC (Decision 10c)[46] was adopted within the CCC body. This Decision is relatively short and provides for basic free allocation rules. More detailed rules were presented in the Guidance Document issued by the European Commission[47].

8.2.3.6.1 Total quantity of free allocation according to Article 10c

In order to determine the total quantity of free allocation, Member States had to use formulas determined by Decision 10c. The total quantity of free allowances which the Czech Republic will be able to allocate for electricity generation has been determined in accordance with Article 10c(2) of Directive 2003/87/EC and the Guidance Document issued by the European Commission.

The total quantity of free allowances for electricity generation for the Czech Republic has been calculated using the following formula:

$$TQFA_{13} = \left(\frac{GFNC}{TGEP}\right) \cdot AAQE^{EG}_{05-07} \cdot 0.7 \qquad (8)$$

where:

TQFA13	Total quantity of free allowances for the year 2013,
GFNC	Gross final national consumption of electricity,
TGEP	Total gross electricity production,
AAQEEG05-07	Annual average quantity of emissions from eligible installations resulting from electricity generation in the years 2005-7,
0.7	Linear reduction factor corresponding to the progressive reduction of free allowances - in 2013 the maximum level for allocation of free allowances

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[46] Commission Decision C(2011) 1983 of 29.3.2011 on guidance on the methodology to transitionally allocate free emission allowances to installations in respect of electricity production pursuant to Article 10c(3) of Directive 2003/87/EC

[47] Communication from the Commission (2011/C 99/03): Guidance document on the optional application of Article 10c of Directive 2003/87/EC

amounts to 70 % and thereafter decreases linearly to 0 % in 2020 (thus, the factor for the year 2014 is 0.6, etc.).

Since there is no officially registered figure for GFNC in the EUROSTAT statistics, the following formula, prescribed by the European Commission, was used:

$$GFNC = FEC - MNET + \frac{FEC - MNET}{TGEP + MNET} \cdot TDL + \frac{FEC - MNET}{TGEP} \cdot CEG \qquad (9)$$

where:

FEC	final electricity consumption (Eurostat code 101700),
MNET	net electricity imports (Eurostat code 100600),
TGEP	total gross electricity generation (Eurostat code 107000),
TDL	transmission and distribution losses (Eurostat code 101400),
CEG	in-house consumption during electricity generation (Eurostat code 101301).

The total quantities of free allowances for electricity generation broken down according to the gradual growth of the auctions (with the reduction factors for each year in the period 2013-20) are shown in the following table:

Table 30. Free allowances for electricity production in the Czech Republic for 3rd Trading period[48]

	Linear factor	Quantity of free allowances
2013	0.7	26,916,667
2014	0.6	23,071,429
2015	0.5	19,226,191
2016	0.4	15,380,953
2017	0.3	11,535,714
2018	0.2	7,690,476
2019	0.1	3,845,238
2020	0	0
Total	**-**	**107,666,668**

8.2.3.6.2 Eligible investments

As was said before, the market value of free EUAs allocated under Article 10c has to be used for retrofitting and upgrading the infrastructure and clean technologies. The Guidance Document sets out basic requirements for investments to be included into the National investment plan and

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[48] Ministry of Environment, 2012: Application of the Czech Republic for allocation of free allowances for investments in retrofitting and upgrading of the infrastructure and clean technologies and national investment plan, Approved version, Methodology report, June 2012

accounted against necessary investments. The main investment principles could be described as follows:

- The national plan should identify investments, which, directly or indirectly (investments in networks and ancillary services), help decrease greenhouse gas emissions in a cost effective manner.
- The investments should be mutually compatible and also compatible with other applicable European legislation. They must neither reinforce dominant positions nor unduly distort competition and trade in the internal market.
- The investments identified in the national plan should be additional to investments Member States must make in order to comply with other objectives or legal requirements accruing from the EU legislation. They should also not include investments which would be required to match increasing electricity supply and demand.
- The investments identified in the national plan should contribute to diversification and reduction in carbon intensity of the electricity mix and the sources of energy supply for electricity production.
- Investments should be economically viable in the absence of the free EUA allocation under Article 10c of Directive 2003/87/EC, once this comes to an end.

Investments in heat distribution networks

For the district heating sector it was very important to include investments in heat distribution networks into the National Investment Plan as eligible investments. The European Commission does not automatically exclude investments in other energy sectors, on condition that they benefit from strong justification on the basis of Article 10c. Installations employing high efficiency cogeneration (meeting the conditions of Directive 2012/27/EU) are identified as electricity generators under the European Commission's Guidance Paper to Identify Electricity Generators and the Communication of the Ministry of Environment of the Czech Republic, and can therefore be allocated free allowances in accordance with Article 10c of the Directive.

The European Commission's Guidance leaves it to the Member States to decide on the definition of installations. In the Czech Republic, an installation is defined in the ETS Act as "a stationary technical unit where one or more of the activities listed in Annex I to this Act are carried out, and any other directly associated activities which have a technical connection with the activities carried out on that site and which could have an effect on emissions; installations shall not include stationary technical units used for research, development and testing of new products and processes. Where one operator of an installation carries out at a single installation or on the same site several activities falling under the same heading in the list given in Annex I to this Act, the capacities of such activities are to be added together."

The arguments for including investments in heat distribution networks into the "national plan" in the case of installations employing high efficiency cogeneration of heat and power (CHP) according to Directive 2012/27/EU are as follows:

- The physical principle employed in CHP indicates that the expansion of useful heat supply is the sole possible means for expanding clean electricity production in cogeneration. If Article 10c were not to support the expansion of heat supplies, this would mean surrendering a source of motivation for the expansion of clean electricity production technology capable of reducing primary energy consumption, and at the same time giving up the opportunity to reduce greenhouse gas emissions by the order of tens of percent. Such reduction cannot be achieved by any other known method of electricity generation upgrade which would be usable on a mass scale.

- The very definition of high efficiency CHP (Directive 2012/27/EC) and the wording of Article 10a(4) of the Directive require that useful heat supplies be carried out using heat distribution networks connecting the heat producer and the consumer (customer). Electricity generation in high efficiency CHP is therefore clearly tied to the production and supply of useful heat even from the perspective of legislation. Without development of heat distribution networks, it will not be possible to increase the share of CHP in the total electricity generation.
- In addition to the opportunity for wider usage of CHP, investments in heat distribution networks will also reduce energy losses during transmission, thereby resulting in reduction of greenhouse gas emissions (the fundamental objective of the EU ETS).
- If the investments under the national plan are partially focused on heat distribution networks, this will simultaneously minimise the risk of distortion of competition on the electricity market (a requirement of Directive 2009/29/EC). In the context of the assessment of support for investments into CHP and heat distribution networks, DG Competition has already issued a precedent decision to the effect that direct support for high efficiency CHP and heat supply does not violate the rules on the provision of public support – e.g. in March 2010 for project N 295/2008 Investment aid for a heat plant in Mellach with a grant of 16 million EUR[49].

8.2.3.7 EU ETS revision for the 4th trading period (2021-2030)

Substantial revision process is taking place since July 2015, when European Commission presented revisions[50] aiming at EU's target to reduce greenhouse gas emissions by at least 40% domestically by 2030 in line with the 2030 climate and energy policy framework and as part of its contribution to the Paris Agreement. To achieve the at least 40% EU target, the sectors covered by the ETS have to reduce their emissions by 43% compared to 2005. The overall number of emission allowances need to decline at an annual rate of 2.2% from 2021 onwards, compared to 1.74% currently. This linear annual decrease is called linear reduction factor ("LRF") and affects all covered sectors by reducing total amount of EUAs in the system. District heating is directly influenced because the fact that free allocation for heat from CHP is subject to annual decrease by LRF according to the provisions of Article 10a(4) Directive 2003/87/EC. EC proposes to keep the same percentage for free allocation for heat from district heating as for year 2020. Thus free allocation for heat from district heating should

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[49] State aid, Austria, N 295/2008 – Austria Investment Aid for co-generation of electricity and heat (CHP) – Mellach of Verbund Austrian Thermal Power GmbH and Co KG, http://ec.europa.eu/competition/elojade/isef/case_details.cfm?proc_code=3_N295_2008

[50] European Commission, Proposal for Directive of the European Parliament and of the Council amending Directive 2003/87/EC to enhance cost-effective emission reductions and lowcarbon investments, COM(2015) 337 final, 2015/148 (COD), Brussels, 15.7.2015

not end by 2027 as it is in current Directive 2003/87/EC, but should be kept at 30% through 4th trading period. This EC proposal takes into account Council Conclusions of October 2014[51] clearly stipulating that fee allocation to non-carbon leakage sectors should not expire. It needs to be noted that even though district heating is not subject to carbon leakage as defined by the Directive 2003/87/EC it is exposed to competition of local gas boilers which are outside of EU ETS. Expiration of free allocation to district heating would lead to risk of serious distortion of competition and subsequently possible decay of DH schemes which would shift GHG emissions from EU ETS to sectors not covered.

EC also proposes to lower the benchmark values by flat linear reductions (so called "flat-rates") in the three levels 0.5, 1 or 1.5% calculated from 2008, which translates into reduction of 7.5% between 2021 and 2025, and 10% between 2026 and 2030 (based on 0.5% improvement per year from 2008) or 15% and 20% (based on 1% improvement per year from 2008) or 22.5% and 30% (based on 1.5% improvement per year from 2008). European Council is asking for background data for these reductions, so there is a possibility that benchmark values will be completely reassessed.

Table 31. Application of „flat-rates" according to European Commission's proposal for EU ETS revision for 4th Trading period

3rd Trading period (2013-2020)							
Heat benchmark value	**EUA/TJ**	**62.3**					
4th Trading period		**2021-2025**			**2026-2030**		
Flat-rate level	-	0.5%	1%	1.5%	0.5%	1%	1.5%
Flat rate reduction	-	7.5%	15%	22.5%	10%	20%	30%
Heat benchmark value	**EUA/TJ**	**57.6**	**53**	**48.3**	**56.1**	**49.8**	**43.6**

Concerning transitional free allocation for modernization of energy production there is a proposal to continue with this tool for 4th Trading period with maximal amount of allowances up to 40% of the respective Member State's amount for auction. This is in line with the text of European Council Conclusions from October 2014, but detailed modalities do not exist. There is a possibility that current tool for free allocation according to Article 10c will continue with just redefined amounts of total free allocation. As the proposal stands now, final decision will be on Member States eligible to use this tool.

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[51] European Council (23 and 24 October 2014) – Conclusions

8.2.3.8 *EU ETS overview*

	2005-2007 (1st phase)	**2008-2012 (2nd phase)**	**2013-2020 (3rd phase)**	**2021-2030 (4th phase)**
Base allocation method	Grandfathering (based on historical emissions)	Grandfathering (based on historical emissions)	Auctioning + Benchmarking	Auctioning + Benchmarking
Free allowances	For all sectors	For all sectors	For certain sectors (carbon leakage, DH)	For certain sectors (carbon leakage, DH)
Banking	No	Yes	Yes	Yes
External credits	No	Yes (up to 10% of 2008-2012 allocation)	Yes (up to 11% of 2008-2012 allocation), only from participating states	Yes (up to 11% of 2008-2012 allocation), only from participating states

Figure 19. EU ETS Overview, comparing certain system aspects across EU ETS Phase 1 - 4

8.2.4 Energy taxation

8.2.4.1 *Czech Energy tax*

There is defined rate 8.5 per GJ of gross calorific value of fuel for energy tax in existing Act on Public Budgets Stabilization[52]. This energy tax, considered as “Ecology” tax, is paid for all heat-only generation installation except for local gas fired installations which is non-systemically exempted. Introduction of taxation based tool should be also accompanied by cancellation of this exception.

CHP installations are not subject to “ecology tax” if heat is delivered to households.

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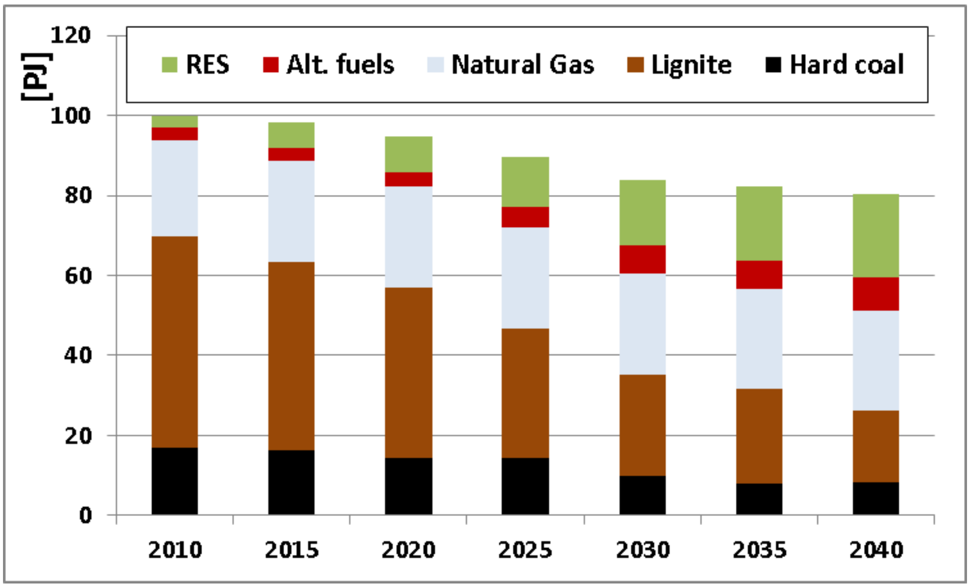
[52] Act. no. 261/2007 Coll. on Public Budgets Stabilization

8.3 *Other effects on the heat market*

8.3.1 State Energy Policy

Objectives for development of DH sector are defined in Update of state energy policy of the Czech Republic[53] ("SEP"). According to SEP there will be a significant shift to low-carbon solutions such as biomass and waste-to-energy technologies as source for future heat supply. However DH sector in the Czech Republic will still be in 2040 dependent by more than a 60% on fossil fuels (coal, lignite and natural gas).



Note

"Alt. fuels" represents Alternative fuels such as waste, industrial gasses etc.

Figure 20. Development and structure of heat supply from District heating systems according to State Energy Policy

8.3.2 Potential for CHP in the Czech Republic

Assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling according to Article 14 of Directive 2012/27/EU on energy efficiency[54] ("CHP potential") was concluded by Ministry of Industry as reporting obligation under the Directive 2012/27/EU on energy efficiency. Heat consumption for heating, hot water and for technological purposes (excluding process heat) reached in 2013 the value of 445 PJ. Assessment of heat demand mentioned in this report reflects, on the one hand, the expected economic growth in the Czech Republic in the sectors of services and industry, growth in the number of households and on the other hand, the continuing trend of energy savings, which should offset the upward pressure on the heat demand. The result is the relative stagnation of forecasts due to

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[53] Ministry of Industry and Trade of the Czech Republic, 2015: *Update of state energy policy of the Czech Republic*, Prague, May 2015

[54] Ministry of Industry and Trade, 2015: *Assessment of the potential for the application of high-efficiency cogeneration and efficient district heating and cooling according to Article 14 of Directive 2012/27/EU on energy efficiency*, December 2015

a combination of economic development, esp. the number of households and energy savings in all these sectors.

In production terms 2/3 of the heat is produced on the individual (local) level and the rest is produced centrally. In the case of central (district) heating production approximately ¾ apply production of heat in combined heat and power generation and only ¼ of heat is produced in heat-only installations. The dominant fuel in individual production of heat and heat-only production is natural gas. On the contrary, the dominant fuel in combined heat and power represents coal and lignite mainly of domestic origin. About 11 to 12 TWh is currently produced in the CHP – 53% with awarded support for high-efficiency cogeneration.

The current situation in the Czech Republic in terms of scale of the use of CHP is considered as favourable. Installations with employed cogeneration have a long tradition in the Czech Republic. There are the availability of appropriate technology, sufficient operating experience and know-how for the preparation and implementation of new high-efficiency cogeneration projects.

Potential for development of high-efficiency cogeneration has been identified by CHP potential in particular in installations of smaller scale with electric capacity about several MW. CHP potential identifies possible CHP development in the increasing number of micro-cogeneration[55] and small-scale cogeneration[56] units and medium sized CHP installations firing natural gas. CHP development is also envisaged in the use of biomass, biogas (including the utilization of recycled heat from existing installations) and the deployment of Waste-to-Energy, however maintaining stable economic incentives for investors and installations' operators need to be secured.

8.3.3 EU Heating and Cooling Strategy

In February 2016, the Commission proposed an EU heating and cooling strategy[57]. Commission stated within this Strategy that to achieve EU decarbonisation objectives, buildings must be decarbonized. This entails renovating the existing building stock, along with intensified efforts in energy efficiency and renewable energy, supported by decarbonized electricity and district heating. District heating should be considered in the analyses how to deliver on the Energy Union objectives.

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[55] According to Directive 2012/27/EU unit with electrical capacity below 50 kW

[56] According to Directive 2012/27/EU unit with electrical capacity below 1 MW

[57] European Commission, 2016: *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, An EU Strategy on Heating and Cooling*, Brussels, 16.2.2016 COM(2016) 51 final

8.4 Comparison of situation of heating actors on the heat market

District heating installations face different legislation requirements compared to similar heating solutions based on the size of installations. Each of the requirement/impact factor has different effect, which I describes in next chapter.

I summarized application of different legislation tools on installations in the following table.

Table 32. Application of legislative tools based on the size of installation concerned

Legislative tool	**Rated thermal input of the installation**			
	below 1 MW_{th}	**1 - 20 MW_{th}**	**20 - 50 MW_{th}**	**above 50 MW_{th}**
Promotion of CHP	YES	YES	YES	YES
Emission limits	NO(1)	YES	YES	YES
Air Pollution fees	NO	NO(2)	YES	YES
Water Pollution fees	NO	NO(3)	YES	YES
CO_2 price	NO	NO	YES	YES
Energy taxation	YES	YES	YES	YES

Note

Legislative tools such as air and water pollution fees are defined based on pollution discharged to environment and not related to the actual installation size. Thus application limit for these tools is defined based on expert estimation.

(1) Below 0.3 MW_{th} only for new installations.

(2) Air pollution fees are relevant only for certain fuels and energy production capable of exceed legislation limit of 50,000 CZK/year total sum of fees.

(3) Water pollution fees are relevant only for certain fuels and energy production capable of exceed legislation limit of 50,000 m^3/year total sum of water discharges.

Table 33. Application of legislation requirements to direct competitors – example of natural gas fired boilers

	District heating 1 x 100 MW_{th} input	**Local heating 1000 x 100 kW_{th} input**
Stack height	130 m	20 m
Emission limits	YES	YES
Emission monitoring	YES	NO
Ecology tax (Act no. 261/2007 Coll.)	YES	NO
Emission fees (Act no. 201/2012 Coll.)	YES	NO
Water fees (Act no. 254/2001 Coll.)	YES	NO
EU Allowances (Act no. 383/2012 Coll.)	YES	NO

8.4.1 Hypothesis about application of environmental legislation

In this Chapter I described legislation instruments applicable to heat market actors. Comparison of applicable instruments identified district heating installations as affected by all relevant environmental legislation. However installations with thermal input below 20 MW are not affected by all new legislation tools. Thus hypotheses “New environmental legislation focuses on key environmental issues and all stakeholders on the heat market are covered in non-discriminatory way and its effects are not differentiated by the scale of emitter (“Polluter-pays-principle” is ensured)” could be considered as not valid.

9 Modeling the risk factors on the heat market

9.1 *Modelling the effects on the heat market*

This chapter focusses on description of key risk factors influencing heat market. Relevant hypothesis within this Chapter is: "Risk factors influencing heat market could be modeled by optimization model of differential NPV comparing situation business-as-usual and new circumstances".

9.2 *Optimization model*

To assess positions and future behaviour of different players on heat market, it is essential to create uniform parameter which could be applied on each participant. This uniform parameter could be derived from basic economic modelling as variable responsible for change in price of heat based on risk factors caused by legislation and other effects (Vecka, 2016).

I assume that evaluation of future production from district heating plants is based on microeconomic approach to installation, which could be applied to various types of installations even across different sectors. I based the model on creation of future profit and loss statement in different scenarios. Main criterion is to keep constant profit margin and energy price increase is as variable. Identified risk factors could be divided into two categories: legislation-induced risk factors and other changes. As district heating installations always compete with local heat sources, the crucial is identification of legislation induced risk factors, which is usually borne by district heating installations only. Other changes in expenditures – prices of fuels, labour costs etc. are applied to both categories of installations.

In order to assess impact into heat price for modelled installation I evaluated incurred costs driven by effects on heat market described in Chapter 8. Key aspect for general evaluation of investments is creation of excess financial resources (profit) for investors. These excess resources are generated based on overall balance of cash flow as follows (during period T):

$$CF_T = \left(R_T - C_{ofT} - C_{ovT} - D_{tT} - I_{lT} \pm I_{itT}\right) \cdot \left(1 - r_t\right) + D_{tT} - A_{lT} \pm S_{cT} - C_{iT} + B_{aT} \qquad (10)$$

where:

R_T	revenues [EUR]
C_{ofT}	fixed operational costs [EUR]
C_{ovT}	variable operational costs [EUR]
D_{tT}	tax depreciation [EUR]
I_{lT}	interests on loans [EUR]
I_{itT}	items changing base for income tax [EUR]
r_t	income tax rate [EUR]
A_{lT}	amortization of loans [EUR]
S_{cT}	change in stocks [EUR]
C_{iT}	investment costs [EUR]
B_{aT}	bonds/obligation/loans acquired [EUR]

These excess resources could be also defined as overall economic efficiency (Net Present Value) as follows:

$$NPV = DCF_L = \sum_{i=0}^{L} \frac{CF_i}{(1+r)^i} \qquad (11)$$

where:

L	lifetime of the project
DCF_L	discounted cash-flow during lifetime of the project [EUR]
CF_i	cash-flow in year i [EUR]
r	discount [-]

I suppose that final optimization criterion should enable selection of the optimal variant of system development from several variants of one strategy selected in preliminary optimization phase (Vecka, 2016). One of the conditions for comparability of variants is that they cover the same time period. However the economic life of assessed objects can be different, usually exceed optimization period and will normally be completed in different years. This has to be reflected in the design of options of system development and allow that options are comparable. Therefore, I need to establish term comparable period as the period of time for which an economic assessment of an investment is made.

In case of evaluation period E < lifetime L:

$$DCF_L = \sum_{i=0}^{E} CF_i \cdot (1+r)^{-i} + CF_{Te} \sum_{i=E+1}^{L} (1+r)^{-i} \qquad (12)$$

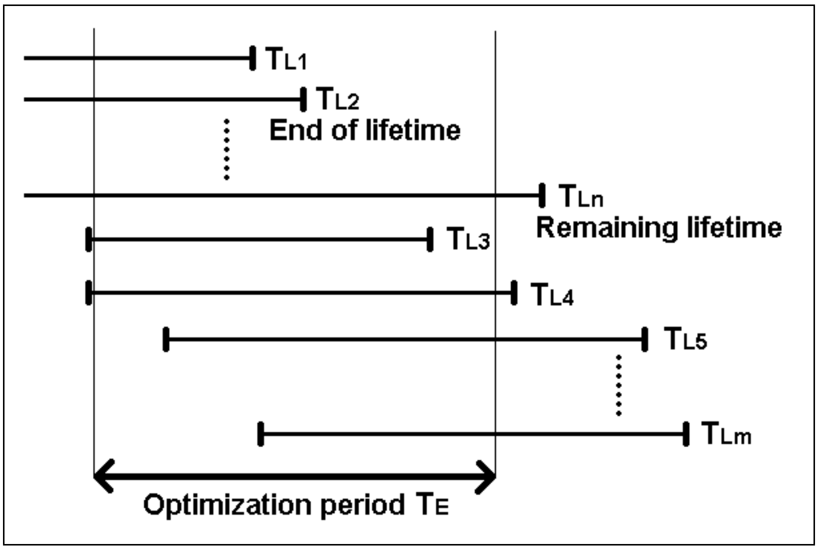

Figure 21. Time scheme development options for existing system

I assume that in decision making process project should be assessed by differential NPV. The difference stems from the fact that without new legislation instruments plant would continue in business-as-usual operation. In case study example plant has to adjust its operation according to new requirements.

$$NPV_{Diff} = NPV_{New} - NPV_{BAU} \quad (13)$$

where:

NPV_{new} NPV in new circumstances [EUR]
NPV_{BAU} NPV without new circumstances [EUR]

According to my assumptions the economic effectiveness in new legislation circumstances could then be derived from effectiveness in business-as-usual scenario as follows:

$$NPV_{New} = NPV_{BAU} + NPV_{Ex} \quad (14)$$

where:

NPV_{Ex} NPV of the new externalities [EUR]
NPV_{BAU} NPV without new circumstances [EUR]

I can calculate effectiveness of project under new circumstances caused by new legislation according to following formula using formulas (11) to (14):

$$NPV = \sum_{i=0}^{T_E} \frac{R_{Ex,i} - E_{Ex,i}}{(1+r)^i} \quad (15)$$

where:

$R_{Ex,i}$ plant revenues caused by legislation induced circumstances in period i [EUR]
$E_{Ex,i}$ plant expenditures caused by legislation induced circumstances in period i [EUR]

If the plant effectiveness should be maintained the effectiveness of the project has to be reflected in in its outputs (Vecka, 2016). I could consider price of electricity as exogenous variable, determined by market conditions outside the scope of micro-economic assessment (i.e. price comes from long-term contracts), and the same price could occur in business-as-usual operation. However I am assuming that incurred costs will be allocated to entire energy production.

9.3 Economic model

I can simplify optimization model to the economic one in order to properly assess future development of externalities for different actors on the heat market. Model should mirror impact of environmental instruments on economic situation of heat installation of all sizes and technology employed (e.g. combined heat and power technology). In case of district heating sector, I assume that DH systems are already developed in the area where economical and technical opportunities were fulfilled. I suppose system development to be carried out by operator of the installation and current connected DH system. At the installation level, there are frequently several types of units/devices in terms of fuel mix, commissioning, operation time etc., which has to be also taken into account.

Legislation-induced impacts could be defined as risk factors influencing heat price as follows:

$$I_{Total} = I_{CO2} + I_{ENV} + I_{PF} + I_{WF} + \left(I_{TAX} + I_{VAT}\right) \qquad (16)$$

where:

I_{Total}	total impacts/risk factors influencing heat price [EUR]
I_{CO2}	impact/risk factor caused by CO_2 price - emission trading scheme [EUR]
I_{ENV}	impact/risk factor caused by new environmental performance levels [EUR]
I_{PF}	impact/risk factor caused by pollution fees [EUR]
I_{WF}	impact/risk factor caused by water fees [EUR]
I_{TAX}	impact/risk factor caused by energy taxation [EUR]
I_{VAT}	impact/risk factor caused by value added tax [EUR]

Impact factors I_{CO2}, I_{ENV}, I_{PF}, I_{WF} are generally applicable. Impact factors I_{TAX} and I_{VAT} are driven by circumstances of heat delivery and are applicable only in certain scenarios.

9.3.1 Risk factor CO_2 price

Risk factor is based on provisions given by European legislation establishing European Emission trading scheme. Only heat producers above 20 MW rated thermal input are included in European emission trading scheme, which means that installations have to cover their CO_2 emissions by carbon rights (allowances). Allowances can be obtained on open auction starting from 2013, with certain diminishing portion of allowances allocated free of charge (described in Chapter 8.2.3.5 and 8.2.3.6).

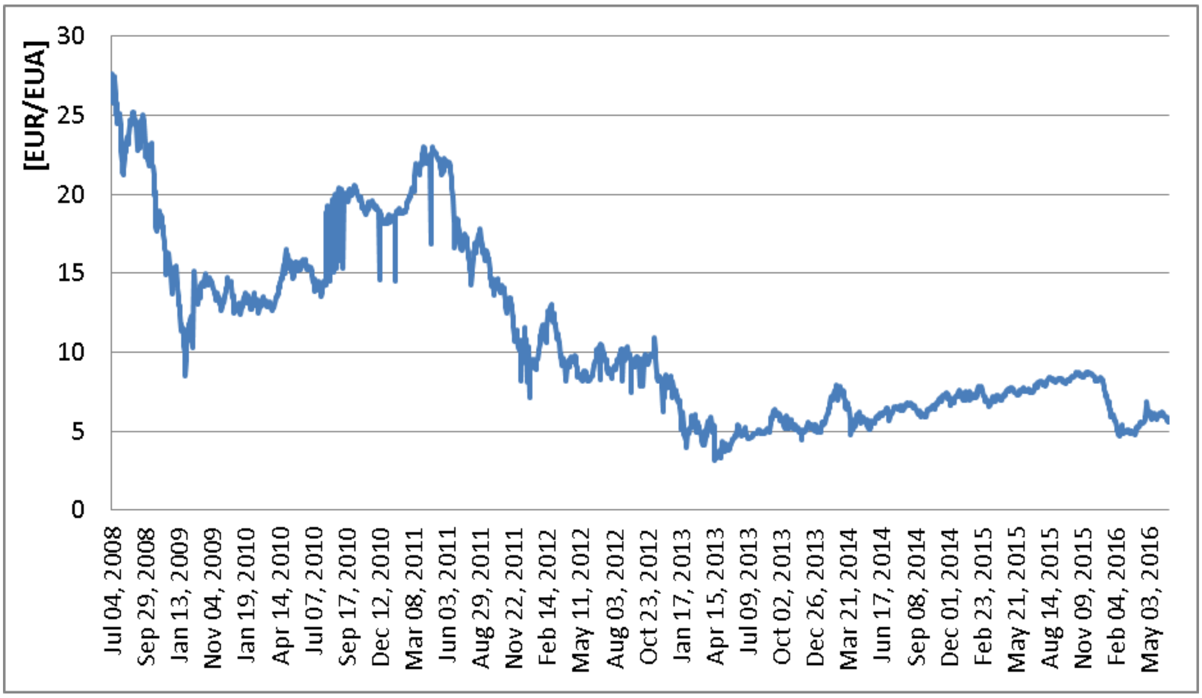

Figure 22. Development of Carbon price on EEX[58]

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[58] European Energy Exchange (EEX), EU Emission Allowances, spot market

CO_2 costs are driven by fuels used for heat production. Emission factors of CO_2 per net calorific value of fuels are presented in Decree of Ministry of environment to energy audits[59]. Estimation of CO_2 price impacts based on fuel input shows following table.

Table 34. Example Impacts of CO_2 costs to heat prices for installations covered by CO_2 regulation (installations above 20 MW thermal input in general)

	Unit	**Fuel**					
		Lignite	**Hard coal**	**Heavy fuel oil**	**Gas Oil**	**Natural Gas**	**Biomass**
Emission factor(1)	tCO_2/MWh NCV	0.36	0.33	0.27	0.26	0.20	0.00
Efficiency of energy production(2)	%	80	80	82	85	90	80
Current EUA price							
Price of CO_2(3)	EUR/tCO_2	6.0	6.0	6.0	6.0	6.0	6.0
Impact on heat price	EUR/GJ	0.75	0.69	0.55	0.51	0.37	0.00
Future EUA price							
Price of CO_2(4)	EUR/tCO_2	10.0	10.0	10.0	10.0	10.0	10.0
Impact on heat price	EUR/GJ	1.25	1.15	0.91	0.85	0.62	0.00

Note

own calculations

(1) Values from Decree no. 480/2012 Coll.

(2) Expert estimation

(3) Estimated price of EUA based on EUA prices on EEX market, clearing prices from 1st January 2016

(4) Estimated price of EUA as an example based on future emerging EU ETS measures

Logically, according to presented figures only fossil fuels face CO_2 price impacts, highest in case of lignite and coal fired installations. Biomass is considered as CO_2 free fuel, thus without CO_2 costs. However installations below 20 MW thermal input firing fossil fuels are outside of the scope of CO_2 pricing.

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[59] Ministry of Industry and Trade, Decree n. 480/2012 Coll. on the energy audits and energy assessment

9.3.2 *Risk factor New environmental performance levels*

Factor is based on requirements of new environmental legislation such as Industrial emissions directive (installations above 50 MW_{th}) or Medium combustion plants Directive (installations 1-50 MW_{th}). New emission levels are derived from best available techniques in given area. This leads to certain necessary investments in abatement equipment.

Impacts are driven by technology employed to reach required emission levels. Based on new emission levels presented in Chapter 8.2.2.3, for LCP installations needed techniques are:

- Lignite/Hard coal installation
    - desulphurization techniques - Boiler sorbent injection, Circulating fluidised bed (CFB), Spray-dry absorber (SDA), Wet flue-gas desulphurisation (Wet FGD)
    - deNOx techniques - Low-NO_X burners, Selective catalytic reduction (SCR), Selective non-catalytic reduction (SNCR)
    - dust reduction techniques – bag filters, electrostatic precipitator

    New LCP BREF pollutants (HCl, HF, Hg) are reduced to emission limits by dedicated abatement techniques if necessary[60].
- Liquid fuel installation
    - desulphurization techniques - fuel choice and similar to techniques for Lignite/coal installation
    - DeNOx techniques similar to techniques for Lignite/coal installation
    - dust/solid residues requirements are met by quality management of used fuel (high quality gas oil)
- Gaseous fuel installation
    - desulphurization and dust techniques are not applicable (with exception of waste gasses and other industrial gasses)
    - DeNOx technology – low-NO_X burners
- Biomass installations
    - desulphurization techniques – not applicable
    - deNOx techniques - Low-NO_X burners, Selective catalytic reduction (SCR), Selective non-catalytic reduction (SNCR)
    - dust reduction techniques – bag filters, electrostatic precipitator

    New LCP BREF pollutants (HCl, HF) are reduced to emission limits by dedicated abatement techniques if necessary.

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[60] Dedicated technique listed in LCP BREF is for example Activated (halogenated) carbon injection. However increase in efficiency of desulphurization, dust measures and also fuel choice could lead to sufficient performance levels.

For MCP installations needed techniques are:

- Lignite/Hard coal installation
  - desulphurization techniques – fuel choice or dry to semi wet desulphurization technique
  - deNOx techniques – only primary techniques, combustion optimization
  - dust reduction techniques – bag filters, electrostatic precipitator
- Liquid fuel installation
  - desulphurization techniques – fuel choice
  - DeNOx techniques similar to techniques for Lignite/coal installation
  - dust/solid residues requirements are met by quality management of used fuel (high quality gas oil)
- Gaseous fuel installation
  - desulphurization and dust techniques are not applicable (with exception of waste gasses and other industrial gasses)
  - DeNOx technology – low-NO_X burners
- Biomass installations
  - desulphurization techniques – not applicable
  - deNOx techniques - similar to techniques for Lignite/coal installation
  - dust reduction techniques – bag filters, electrostatic precipitator

Table 35. Example of impacts of costs for meeting new environmental performance levels to heat prices for medium sized heat installations with CHP heat and heat-only production

Indicator		Unit	Lignite/Hard Coal	Liquid fuels	Natural Gas	Biomass
Desulphurization	**Investment costs**	mil. EUR	6	0	0	0
	Operational costs	mil. EUR/year	0.2	0	0	0
DeNOx	**Investment costs**	mil. EUR	6	3	2	6
	Operational costs	mil. EUR/year	0.2	0.1	0.1	0.2
Dust measures	**Investment costs**	mil. EUR	1	0	0	1
	Operational costs	mil. EUR/year	0.03	0	0	0.03
Other measures	**Investment costs**	mil. EUR	0	0	0	0
	Operational costs	mil. EUR/year	0	0	0	0
Total	**Investment costs**	mil. EUR	13	3	2	7
	Operational costs	mil. EUR/year	0.43	0.09	0.1	0.23
Efficiency of energy production		%	80	85	90	80
Energy production		TJ/year	1 417	1 526	1 800	1 417
Impact on heat price(1)		EUR/GJ	0.92	0.19	0.13	0.49

Note

(1) Increase of costs per produced GJ of heat produced, optimization period 15 years, costs allocated to entire energy production.

According to presented figures major impacts are assumed for solid fuels based installation (lignite/coal and biomass). Limited impacts are on the liquid and gas fired installations. Only installations above 1 MW thermal input are subject of increased requirements. In the case of CHP installations additional costs cannot be in reality allocated towards electricity production, because installations are selling electricity on the open market and cannot influence its price.

9.3.3 Risk factor Pollution fees

This risk factor is based on provisions given by Czech national Air protection legislation. Installations of certain emission volumes of pollutants – dust, SO_2 and NO_X have to pay fees for these emissions. Installations must still comply with emission limits based on BAT.

9.3.4 Risk factor Water fees

This risk factor is based on provisions given by Czech Water Act. Installations releasing certain volumes of water have to pay the fees (according to emission limits in weight and concentration) and for discharged water.

9.3.5 Risk factor Energy taxation

In Czech national legislation local boiler houses and smaller installations fuelled by natural gas are completely exempt from energy taxation, other heat-only installations are taxed at rate 8.5 GJ/GCV of fuel. CHP installations delivering heat to households is not subject to the taxation. This risk factor is applicable only in situations where delivery to households or to smaller consumers is considered.

9.3.6 Risk factor Value Added Tax

This factor is based on difference in Value added tax ("VAT") placed on heat production from district heating installations. Factor is relevant for only for heat consumers considered as VAT payers, for example private households. If there is no difference or change in VAT tax in this respect, risk factor is 0. However in the Czech Republic VAT rates were subject to several changes since year 2000.

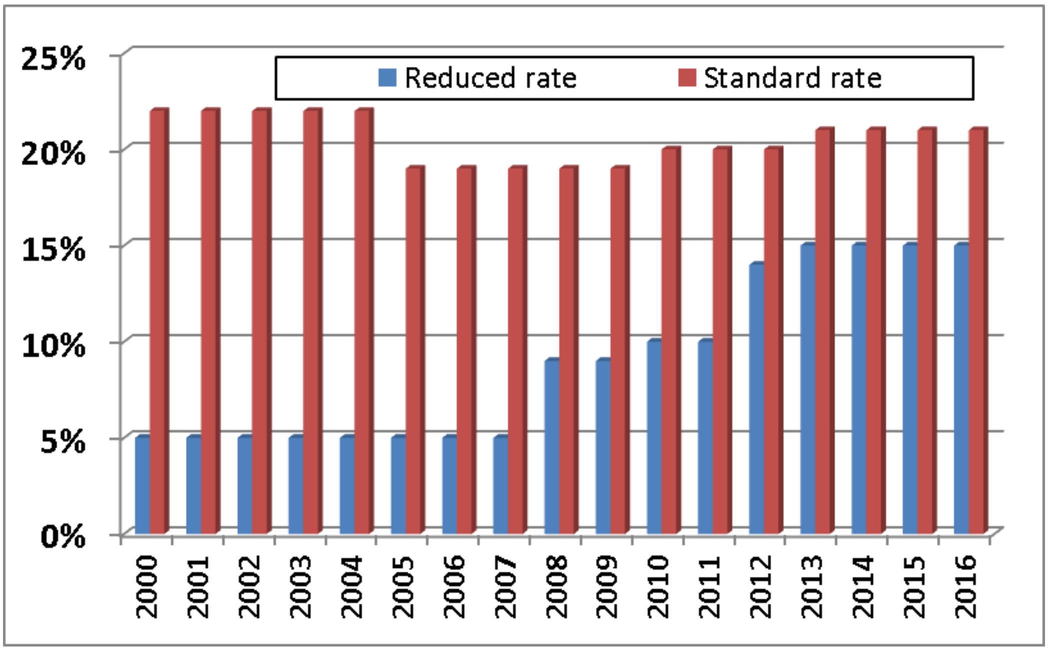

Figure 23. Development of VAT rates in the Czech Republic in period 2000 - 2016

District heating is subject to reduced VAT rate and standard fuels (like natural gas) are subject to standard rate. Thus there is a VAT difference 6% which creates positive effects towards consumption of heat as a service (from district heating systems). This risk factor is applicable only in situations where delivery to households or to smaller consumers is considered.

9.3.7 Structure of the model

Structure of my model could be summarized as input-output economic model as presented in Figure 24.

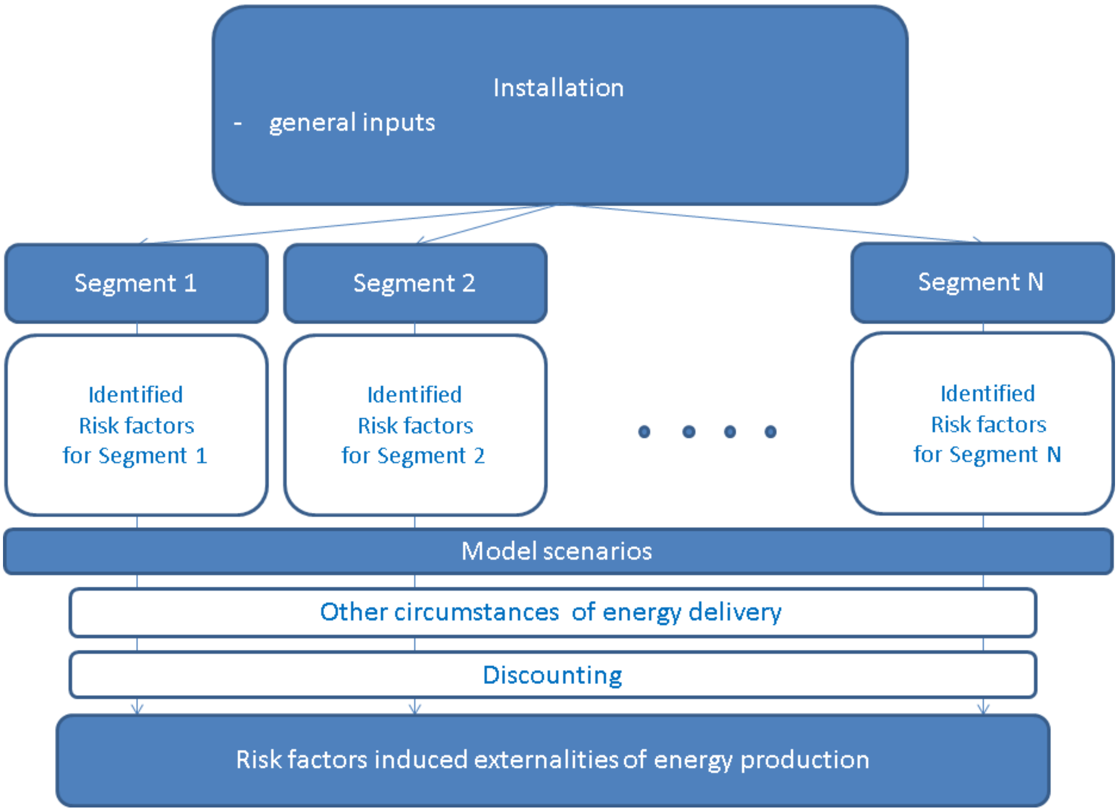

Figure 24. General structure of the model

Model uses installation general input to identify relevant model segment for calculation of induced externalities of energy production. There is a need for proper assessment of influencing risk factor for each reference case to correctly define segments and model scenarios.

I used this general structure to model the reference case of heat market of the Czech Republic, where structure inputs refer to installation parameters

- installation size,
- employed production technology,
- fuel input,
- energy parameters
    - efficiency of electricity and heat production,
    - water consumption,
- emission parameters,
- costs for reaching new emission parameters (based on legislation-induced requirements).

Model for reference case consist of 4 segments differentiated by size of respective installation

- for installations below 1 MW thermal input,
- for installations from 1 to 20 MW thermal input,
- for installations from 20 to 50 MW thermal input,
- and for installations above 50 MW thermal input.

I identified these segments in the Chapter 8.4. Each of the segments reflects identified risk-factors in different way, based on relevant legislation provisions.

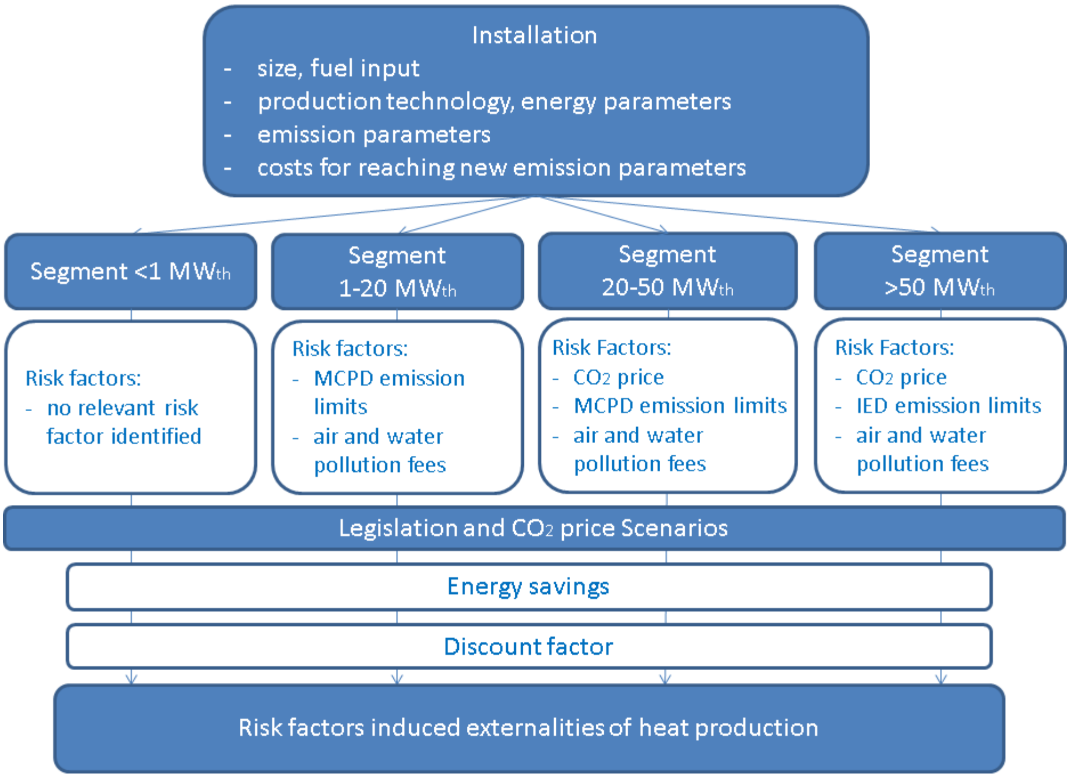

Figure 25. Structure of the model for reference case

There is a possibility to create different scenarios of legislation application and CO_2 price development based on various approaches. I defined 2 legislation scenarios and 3 CO_2 price scenarios for reference case.

Model of reference case calculates 4 basic legislation-induced impacts:

- impact caused by CO_2 price - emission trading scheme [EUR]
- impact caused by new environmental performance levels [EUR]
- impact caused by pollution fees [EUR]
- impact caused by water fees [EUR]

These impacts are subsequently confronted with energy efficiency measures defined within State energy policy and reflecting of change in energy production.

In order to reflect NPV calculation modelled impacts are also subject to discounting.

9.4 Model summary – reference case

I used abovementioned economic model for calculating the implementation of the new EU and Czech environmental legislation in reference case of the situation in the Czech Republic and calculated legislation-induced influence on future heat prices could be summarized as follows:

- Model calculates the influence caused by CO_2 price, new emission levels, air pollution fees and water fees.
- Model can be applied to heat installations of whole range
  - since there are discrepancies in application of environmental legislation (as described in previous chapter) I used 4 different model-segments
    - for installations from 1 to 20 MW thermal input
    - for installations from 20 to 50 MW thermal input
    - and for installations above 50 MW thermal input
    - since there is no relevant legislation induced externalities for existing heat installations below 1 MW thermal input, result of the modelling for the purposes of comparison (see Chapter 10.6.4.1) could be simplified to no legislation induced externalities in basic scenarios (Legislation and CO_2 price).
- Model is applicable to combined heat and power generation and heat-only production as well. Basic scenarios (Legislation and CO_2 price) assume CHP technology.
- Model is applicable to solid (lignite/coal/biomass), liquid and gas fired installations.
- Certain inputs were set by using ADH CR internal database and expert estimation (e.g. efficiency of heat production, efficiency of electricity production etc.)
- A basic presumption is that heat and electricity production for the period 2015-2030 will be the same (or without significant changes) as average production during the period 2005-2008, which is the basic period for historical data according to relevant legislation.
- Model calculates the impacts on the energy produced (1 GJ of energy produced) for the whole Czech Republic based on fuels used in two basic legislation scenarios. The real impact

on heat prices has to take into account the fuel mix used for heat generation in real CHP plant.

- Model uses uniform Discount factor for all model-segments to ensure comparability of outcomes

9.4.1 General inputs

Table 36. Net calorific values

Indicator	Unit	Fuel				
		Lignite	**Hard Coal**	**Fuel Oil**	**Natural Gas**	**Biomass** (1)
Net calorific value	GJ/t or GJ/th.m^3	14.5	23	40.61	34.08	16,5/12

Note

(1) Values based on data from Ministry of Industry and Trade[61]. Higher value for local installations below 1 MW_{th} firing biomass pellets.

Table 37. CO_2 emission factors

Fuel	Emission factor(1)	
	t CO_2/MWh of fuel calorific value	**t CO_2/GJ of fuel calorific value**
Lignite	0.360	0.100
Hard Coal	0.330	0.092
Fuel Oil	0.260	0.072
Natural Gas	0.200	0.056
Biomass	0	0

Note

(1) Values based on data from Ministry of Industry and Trade, Decree no. 480/2012 Coll. on the energy audits

Table 38. Heat demand development

Indicator	Unit	Fuel					
		2015	**2020**	**2025**	**2030**	**2035**	**2040**
Heat demand	%	100	96	91	85	84	82

Note

Values based on data from Update of state energy policy of the Czech Republic

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[61] Ministry of Industry and Trade, 2014: Briquettes and pellets in 2013. Statistical results, December 2014; https://www.mpo-efekt.cz/cz/ekis/informacni-listy/8948

Table 39. Discount factor

Indicator	Unit	Model segment			
		below 1 MW_{th}	1 to 20 MW_{th}	20 to 50 MW_{th}	above 50 MW_{th}
Discount factor	%	5	5	5	5

I set discount factors at uniform level to ensure comparability of results. I derived the value itself from assumption that cost of capital for municipal investors and smaller energy utilities (operating medium sized installations) is around 3 %[62] and for large energy utilities around 8 %[63]. I chose value which should reflect "average" value across the model segments.

9.4.2 Energy production parameters

Listed values present typical values for reference case and is based on ADH CR database.

Table 40. Energy production – main indicators for model-segment below 1 MW_{th}

Indicator	Unit	Fuel		
		Lignite	Natural Gas	Biomass
Efficiency of electricity production	%	0	0	0
Efficiency of heat production	%	80	90	85
Total efficiency	%	80	90	85
Heat Production	GJ	1,000	1,000	1,000
Electricity Production	MWh	0	0	0
Total production of energy	GJ	1,000	1,000	1,000
Primary energy in fuel	GJ	1,250	1,111	1,176
Fuel consumption	t or th.m^3	74	33	71

Note

In the segment below 1 MW thermal input only lignite, natural gas and biomass installations are relevant.

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[62] According to the Czech National Bank, Time series database - ARAD, Long-term interest rates for assessing convergence (%) in July 2016 was 0.37% (IND1 10-year maturity Treasury bond yield (Maastricht criterion)). This value could be considered as Risk-free Rate. Taking into account Risk premium for the business risk of the enterprise estimated by MIT, Benchmarking diagnostic system of financial indicators (INFA) for NACE-35 Electricity, gas, steam and air conditioning supply at 2.21%, total discount factor for smaller and municipal energy utilities could be extrapolated at 2.58% (disregarding debt).

[63] According to "The principles of price regulation for the period 2016-2018 for the electricity and gas sector", ERO uses value of 7.951% for electricity distribution sector and 7.940% for gas distribution sector as the rate of return on the regulatory asset base nominal value of the WACC for the IV. regulatory period 2016-2018.

Table 41. Energy production – main indicators for model-segment 1 to 20 MW_{th}

Indicator	Unit	Fuel				
		Lignite	Hard Coal	Fuel Oil	Natural Gas	Biomass
Efficiency of electricity production	%	20	22	30	40	20
Efficiency of heat production	%	60	60	57	50	60
Total efficiency	%	80	82	87	90	80
Heat Production	GJ	100,000	100,000	100,000	100,000	100,000
Electricity Production	MWh	9,259	10,185	14,620	22,222	9,259
Total production of energy	GJ	133,333	136,667	152,632	180,000	133,333
Primary energy in fuel	GJ	166,667	166,667	175,439	200,000	166,667
Fuel consumption	t or th.m^3	11,494	7,246	4,320	5,869	9,259

Table 42. Energy production – main indicators for model-segment 20 to 50 MW_{th}

Indicator	Unit	Fuel				
		Lignite	Hard Coal	Fuel Oil	Natural Gas	Biomass
Efficiency of electricity production	%	20	22	30	40	20
Efficiency of heat production	%	60	60	57	50	60
Total efficiency	%	80	82	87	90	80
Heat Production	GJ	500,000	500,000	500,000	500,000	500,000
Electricity Production	MWh	46,296	50,926	73,099	111,111	46,296
Total production of energy	GJ	666,667	683,333	763,158	900,000	666,667
Primary energy in fuel	GJ	833,333	833,333	877,193	1,000,000	833,333
Fuel consumption	t or th.m^3	57,471	36,232	21,600	29,343	55,556

Table 43. Energy production – main indicators for model-segment above 50 MW_{th}

Indicator	Unit	Fuel				
		Lignite	Hard Coal	Fuel Oil	Natural Gas	Biomass
Efficiency of electricity production	%	25	27	30	40	25
Efficiency of heat production	%	60	60	57	50	60
Total efficiency	%	85	87	87	90	85
Heat Production	GJ	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
Electricity Production	MWh	115,741	125,000	146,199	222,222	115,741
Total production of energy	GJ	1,416,667	1,450,000	1,526,316	1,800 000	1,416,667
Primary energy in fuel	GJ	1,666,667	1,666,667	1,754,386	2,000,000	1,666,667
Fuel consumption	t or th.m^3	114,943	72,464	43,201	58,685	138,889

9.4.3 Emission parameters

Listed values present typical values for reference case and is based on ADH CR database.

There is no new regulation of emission parameters for existing installations for model segment below 1 MW thermal input.

Table 44. Emission parameters for model-segment 1 to 20 MW_{th}

Indicator	Unit	Fuel				
		Lignite	Hard Coal	Fuel Oil	Natural Gas	Biomass
Before retrofitting						
SO_2 emissions total	t/year	100	100	60	0	0
NO_X emissions total	t/year	100	100	100	60	100
Dust emissions total	t/year	3.75	3.75	1.50	0.00	3.75
SO_2 emissions in flue gases	mg/Nm^3	1,500	1,500	1,500	20	0
NO_X emissions in flue gases	mg/Nm^3	550	550	550	200	550
Dust emissions in flue gases	mg/Nm^3	50	50	50	5	50
After retrofitting						
SO_2 emissions total	t/year	73	73	14	0	0
NO_X emissions total	t/year	91	91	36	30	91
Dust emissions total	t/year	3.75	3.75	3	0	3.75
SO_2 emissions in flue gases	mg/Nm^3	1,100	1,100	350	20	0
NO_X emissions in flue gases	mg/Nm^3	550	550	550	200	550
Dust emissions in flue gases	mg/Nm^3	50	50	50	5	50

Table 45. Emission parameters for model-segment 20 to 50 MW_{th}

Indicator	Unit	Fuel				
		Lignite	**Hard Coal**	**Fuel Oil**	**Natural Gas**	**Biomass**
Before retrofitting						
SO_2 emissions total	t/year	200	120	0	0	0
NO_X emissions total	t/year	200	200	120	200	100
Dust emissions total	t/year	8	3	0	8	3.75
SO_2 emissions in flue gases	mg/Nm^3	1,500	1,500	20	0	0
NO_X emissions in flue gases	mg/Nm^3	550	550	200	550	550
Dust emissions in flue gases	mg/Nm^3	20	10	5	20	50
After retrofitting						
SO_2 emissions total	t/year	53	28	0	0	0
NO_X emissions total	t/year	73	73	54	73	91
Dust emissions total	t/year	8	3	0	8	3.75
SO_2 emissions in flue gases	mg/Nm^3	400	350	20	0	0
NO_X emissions in flue gases	mg/Nm^3	200	200	90	200	550
Dust emissions in flue gases	mg/Nm^3	20	10	5	20	50

Table 46. Emission parameters for model-segment above 50 MW_{th}

Indicator	Unit	Fuel				
		Lignite	**Hard Coal**	**Fuel Oil**	**Natural Gas**	**Biomass**
Before retrofitting						
SO_2 emissions total	t/year	500	500	300	0	0
NO_X emissions total	t/year	500	500	500	300	500
Dust emissions total	t/year	19	19	10	0	19
SO_2 emissions in flue gases	mg/Nm^3	500	500	1,500	20	0
NO_X emissions in flue gases	mg/Nm^3	550	550	550	200	550
Dust emissions in flue gases	mg/Nm^3	20	20	10	0	20
After retrofitting						
SO_2 emissions total	t/year	130	130	22	0	0
NO_X emissions total	t/year	159	159	91	150	136
Dust emissions total	t/year	9.5	9.5	3	0	9.5
SO_2 emissions in flue gases	mg/Nm^3	130	130	110	0	0
NO_X emissions in flue gases	mg/Nm^3	175	175	100	100	150
Dust emissions in flue gases	mg/Nm^3	10	10	10	0	10

9.4.4 Investment and operational costs

Listed values present typical values for reference case and is based on ADH CR database.

There is no new regulation of emission parameters for existing installations for model segment below 1 MW thermal input, so there are no investments or operational costs driven by legislation induced risk factors.

Table 47. Investment and operational costs for reaching new emission parameters for model segment 1 to 20 MW_{th}

Indicator		**Unit**	**Lignite/Hard Coal**	**Liquid fuels**	**Natural Gas**	**Biomass**
Desulphurization	**Investment costs**	mil. EUR	0.6	0	0	0
	Operational costs	mil. EUR/year	0.018	0	0	0
DeNOx	**Investment costs**	mil. EUR	0.6	0.3	0.2	0.6
	Operational costs	mil. EUR/year	0.02	0.01	0.01	0.02
Dust measures	**Investment costs**	mil. EUR	0.1	0	0	0.1
	Operational costs	mil. EUR/year	0.003	0	0	0.003
Total	**Investment costs**	mil. EUR	1.3	0.3	0.2	0.7
	Operational costs	mil. EUR/year	0.039	0.009	0.006	0.021

Table 48. Investment and operational costs for reaching new emission parameters for model segment 20 to 50 MW_{th}

Indicator		**Unit**	**Lignite/Hard Coal**	**Liquid fuels**	**Natural Gas**	**Biomass**
Desulphurization	**Investment costs**	mil. EUR	3	0	0	0
	Operational costs	mil. EUR/year	0.1	0	0	0
DeNOx	**Investment costs**	mil. EUR	3	2	2	3
	Operational costs	mil. EUR/year	0.1	0.05	0.05	0.1
Dust measures	**Investment costs**	mil. EUR	0.5	0	0	0.5
	Operational costs	mil. EUR/year	0.015	0	0	0.015
Total	**Investment costs**	mil. EUR	6.5	1.5	1.5	3.5
	Operational costs	mil. EUR/year	0.215	0.05	0.05	0.115

Table 49. Investment and operational costs for reaching new emission parameters for model segment above 50 MW_{th}

Indicator		**Unit**	**Lignite/Hard Coal**	**Liquid fuels**	**Natural Gas**	**Biomass**
Desulphurization	**Investment costs**	mil. EUR	6	0	0	0
	Operational costs	mil. EUR/year	0.2	0	0	0
DeNOx	**Investment costs**	mil. EUR	6	3	2	6
	Operational costs	mil. EUR/year	0.2	0.1	0.1	0.2
Dust measures	**Investment costs**	mil. EUR	1	0	0	1
	Operational costs	mil. EUR/year	0.03	0	0	0.03
Total	**Investment costs**	mil. EUR	13	3	2	7
	Operational costs	mil. EUR/year	0.43	0.09	0.1	0.23

9.4.5 Water consumption

Listed values present typical values for reference case and is based on ADH CR database.

Table 50. Waste water discharged during operation Investment costs for reaching new emission parameters for model segment above 50 MW_{th}

Installation size	Unit	Fuel			
		Lignite/Hard Coal	Liquid fuels	Natural Gas	Biomass
above 50 MW_{th}	th. m^3/year	400	200	100	200
20 to 50 MW_{th}	th. m^3/year	200	100	50	100
1 to 20 MW_{th}	th. m^3/year	40	20	10	20
below 1 MW_{th}	th. m^3/year	0.4	-	0.1	0.2

9.4.6 Hypothesis about modelling the effects on the heat market

Optimization model is taking into account the complexity of energy systems (different position and age of installations) as well as other circumstances. Thus hypotheses ""Risk factors influencing heat market could be modeled by optimization model of differential NPV comparing situation business-as-usual and new circumstances" could be considered as valid.

10 Model outcomes

10.1 Key effect on the heat market

This chapter focusses on model outcomes. Relevant hypothesis within this Chapter is: "Among environmental measures CO_2 costs are main driver for future development and refurbishment of district heating industry, other environmental legislation has limited impacts."

10.2 Materials and methods

I discussed basic approaches to the problem of assessment of energy systems development in Chapter 6.5.

For the purposes of heat market modelling, I found as optimal scenario-based approach, which offers enough variability and could be defined even with limited micro-level data. In order to assess non-symmetrical impacts, model focuses on model heat installation with relevant size for each respected risk factor (see Chapter 9) and necessary investment/operational costs incurred by environmental instruments. I see triggered investments as excessive costs for installation producing heat, which needs to be reflected in its outputs (Vecka, 2016). This reflection creates distortions on heat market as installations below environmental instruments' thresholds suffer from no incurred costs.

10.3 Scenarios of legislation development

I constructed two legislation scenarios to picture the impacts of possible implementation scenarios of the described environmental legislation.

- Legislation Scenario 1 – Strictest implementation
  - Emission trading – no household rule, no derogation for electricity producers, after 2020 benchmark lowered at maximum;
  - IED – full application from 1 June 2020 (after expiration of IED Transitional national plan derogation), new LCP BREF applies without derogation from 1 July 2020 (approval process as fast as possible);
  - waste water fees at maximum.
- Legislation Scenario 2 – Pragmatic implementation
  - Emission trading – household rule, no benchmark reduction up to 2030, derogation for electricity producers up to 2030 at maximum according to benchmark;
  - IED – after Transitional national plan derogation 3 years of IED emission limits and full application of LCP BREF from 1 January 2023 (delay in approval process);
  - waste water fees at compromise level.

10.4 Scenarios of CO_2 price development

Since I identified CO_2 price as most important parameter (see Model sensitivity analysis below), I constructed three carbon price scenarios

- CO_2 price Scenario 1 – Conservative increase in price of CO_2 (represented by EUA price) according to Climate protection policy[64] (with linear extrapolation in period 2031-2040) as follows:

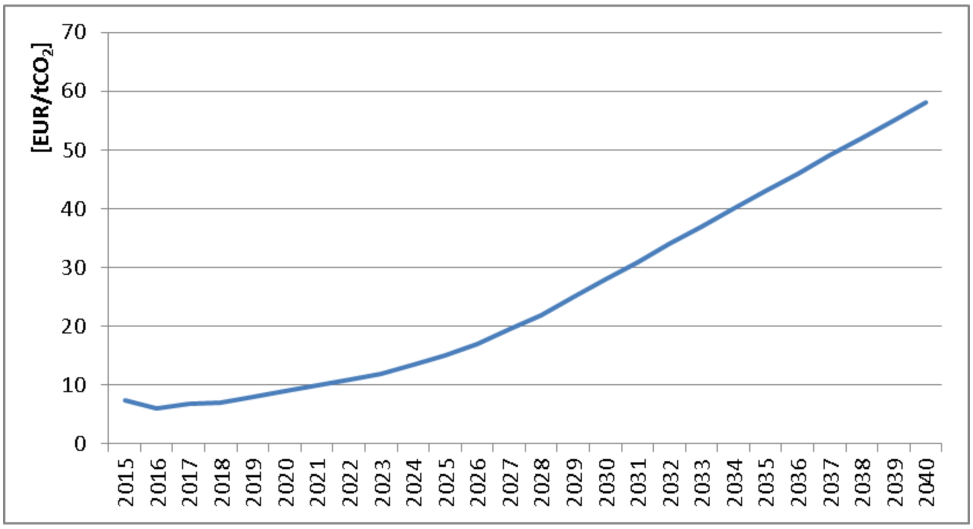

Figure 26. CO_2 price development according to MoE: Climate protection policy

- CO_2 price Scenario 2 – Conservative increase in price of CO_2 by European Investment Bank[65] in central scenario as follows:

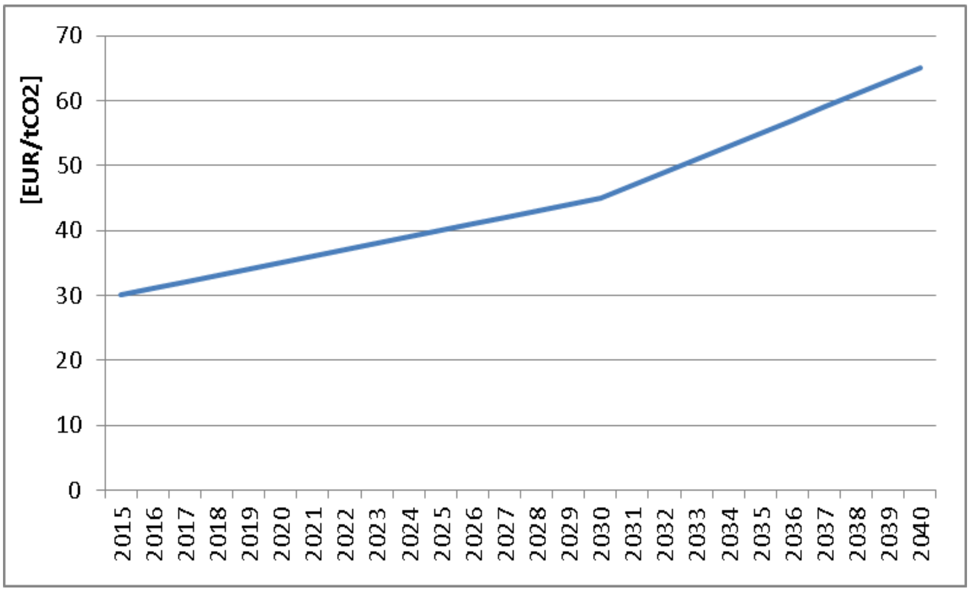

Figure 27. CO_2 price development according to EIB: Climate strategy

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[64] Ministry of Environment, 2016: Climate Protection Policy of the Czech Republic, June 2016 version

[65] European Investment Bank, 2013: The Economic Appraisal of Investment Projects at the EIB and 2016: EIB Climate Strategy Mobilising finance for the transition to a low-carbon and climate-resilient economy, Annex II, June 2016

- CO_2 price Scenario 3 – Conservative development in CO_2 price based on market data (EUA spot price) from Third trading period of EU ETS (from 1st January 2013) as follows:

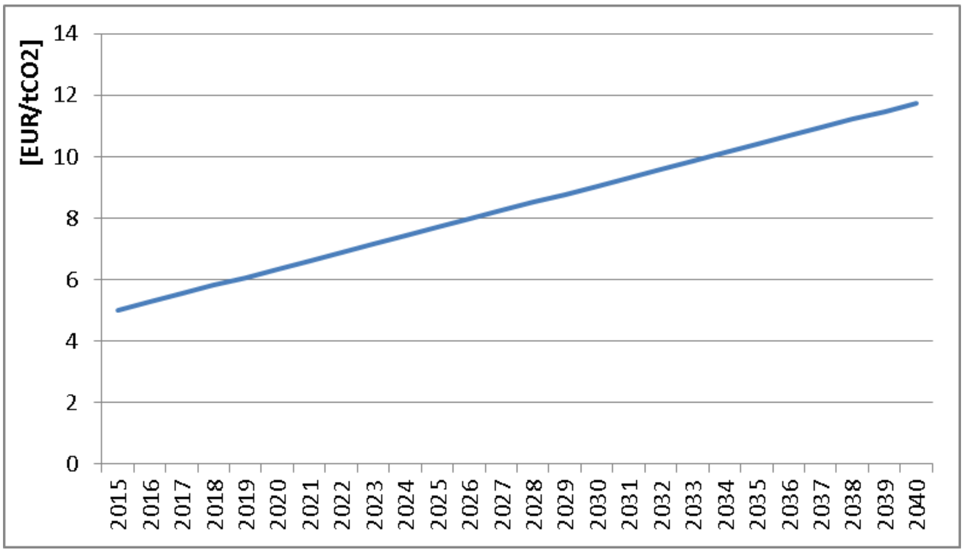

Figure 28. CO_2 price development – linear extrapolation of CO_2 price from 3rd trading period

10.5 Fuel switching

It is possible to define „fuel switching“ relation for plants, where different fuels could be used simultaneously. This dependency reflects externalities development in situations, when installation changes fuel for part or entire energy production. I constructed two basic scenarios for „fuel switching“ as follows

- lignite/coal to biomass – this scenario is quite common and is dependent only on price difference between lignite/coal and biomass. Biomass could be co-fired with lignite/coal up to 20 % fuel input without major additional measures[66] or up even to 100% with certain sophisticated pretreatment techniques applied[67]. Co-firing of biomass is also depends on boiler type (fluidized-bed boilers are in general capable of higher co-firing rates). Using biomass instead of lignite/coal is beneficial in terms of CO_2 costs savings and could be driven by subsidies as well. Based on current approach of Energy Regulatory Office, there are no subsidies operational or investment calculated towards this fuel switching scenario.
- fuel oil to natural gas – this scenario already happens in the Czech Republic as is shown in Chapter 6.4.1. Price difference between fuel oil and natural gas is positive towards natural gas consumption, thus fuel oil is relevant only in situations where it is not possible to use natural gas, for example due to limits in gas distributions infrastructure. Fuel oil installations usually use natural gas for start-up and shut-down operation periods and could easily increase its share in fuel input.

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[66] BAXTER, Larry, 2005: *Biomass-coal co-combustion: opportunity for affordable renewable energy*, Elsevier, Fuel 84 (2005) 1295–1302.

[67] BERGMAN, P.C.A., BOERSMA, A.R., ZWART, R.W.R., KIEL, J.H.A., 2005: *Torrefaction for biomass co-firing in existing coal-fired power stations "BIOCOAL"*, DEN programme of SenterNovem, project number 2020-02-12-14-001, July 2005.

- it is possible to derive other scenarios (such as lignite to natural gas etc.), but these are subject to other criteria as well (investment into plant infrastructure or complete retrofit of boilers etc.)

10.6 Modelled scenarios – outcomes for reference case

The listed figures reflect impact on heat price after the implementation of all new environmental legislation. Only model segment above 50 MW thermal input is presented here as a major representative, outcomes for other segments could be found in Annex VI.

10.6.1 Model segment above 50 MW_{th}

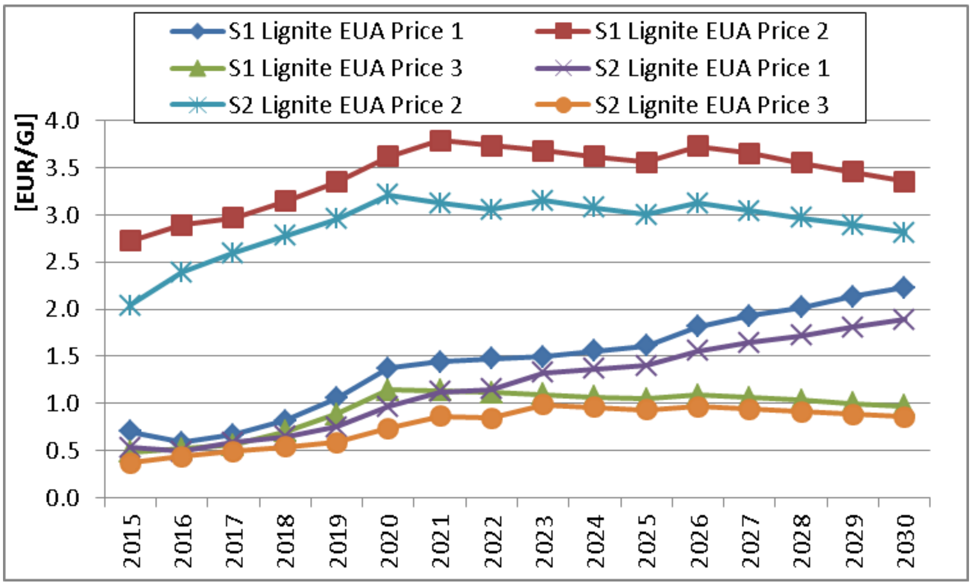

Figure 29. Model segment above 50 MW_{th} – development of externalities for lignite fired installation, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

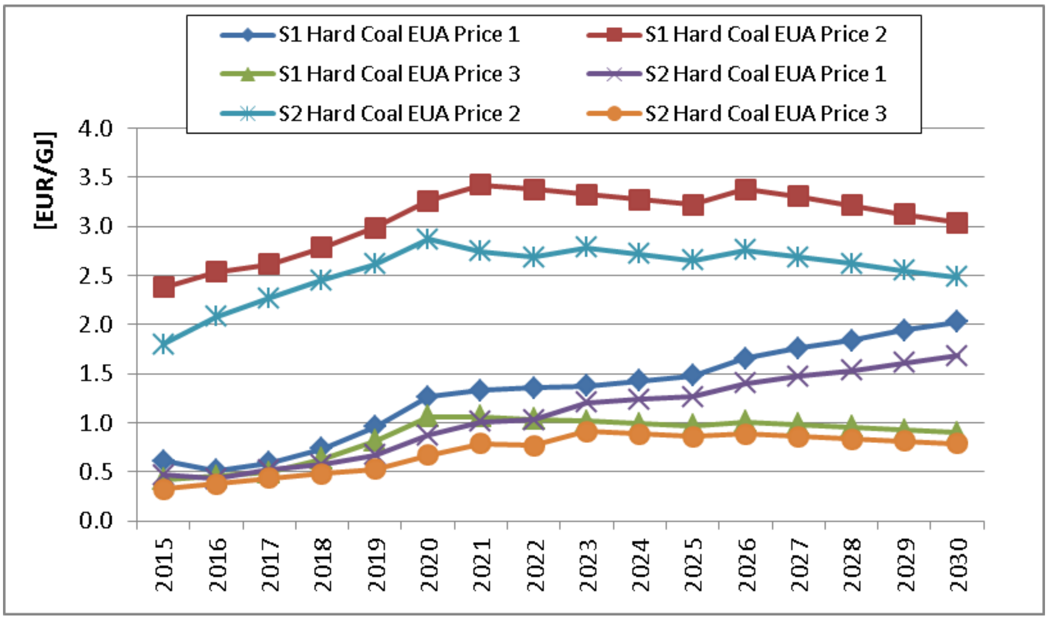

Figure 30. Model segment above 50 MW_{th} – development of externalities for hard coal fired installation, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

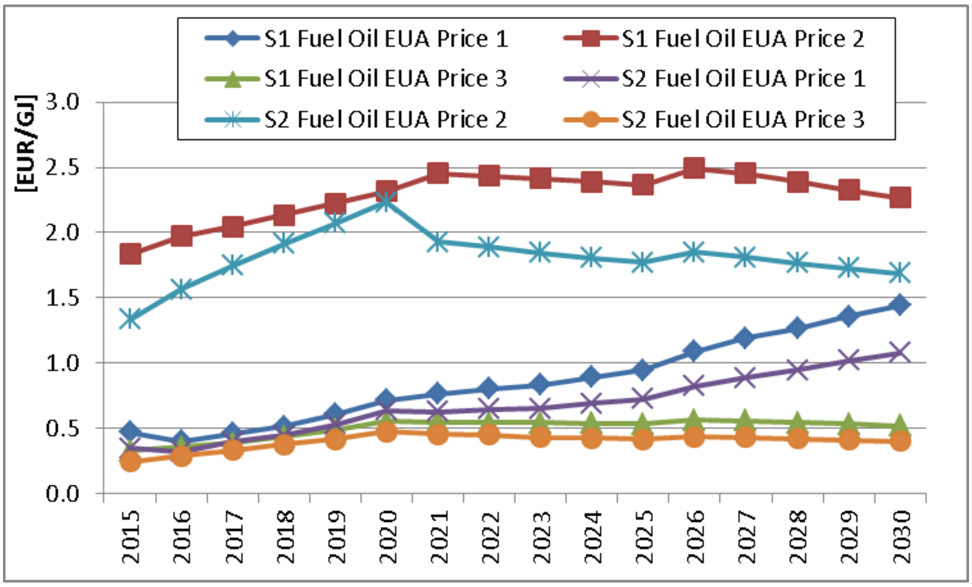

Figure 31. Model segment above 50 MW_{th} – development of externalities for fuel oil fired installation, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

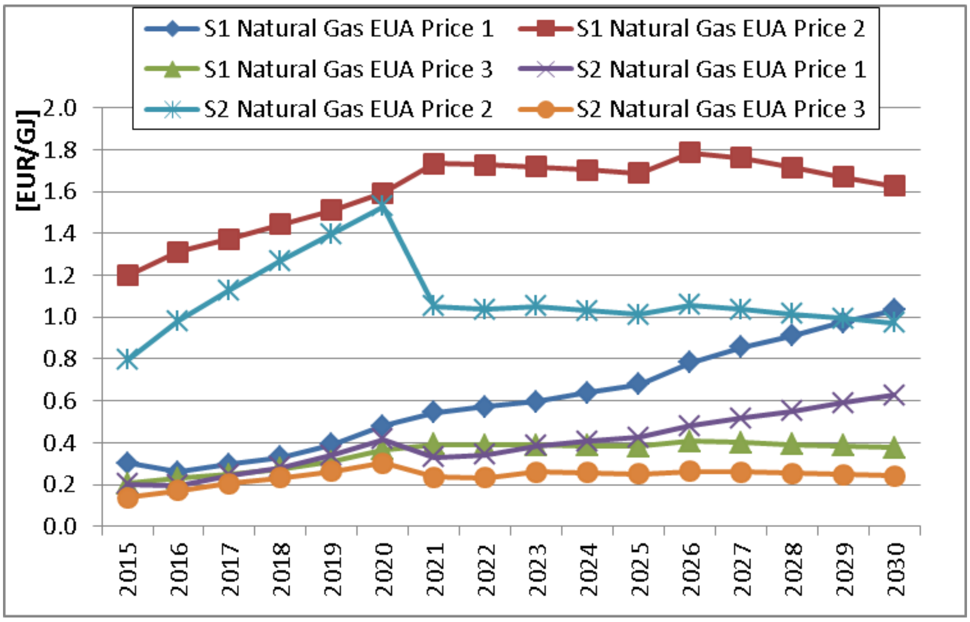

Figure 32. Model segment above 50 MW_{th} – development of externalities for natural gas fired installation, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

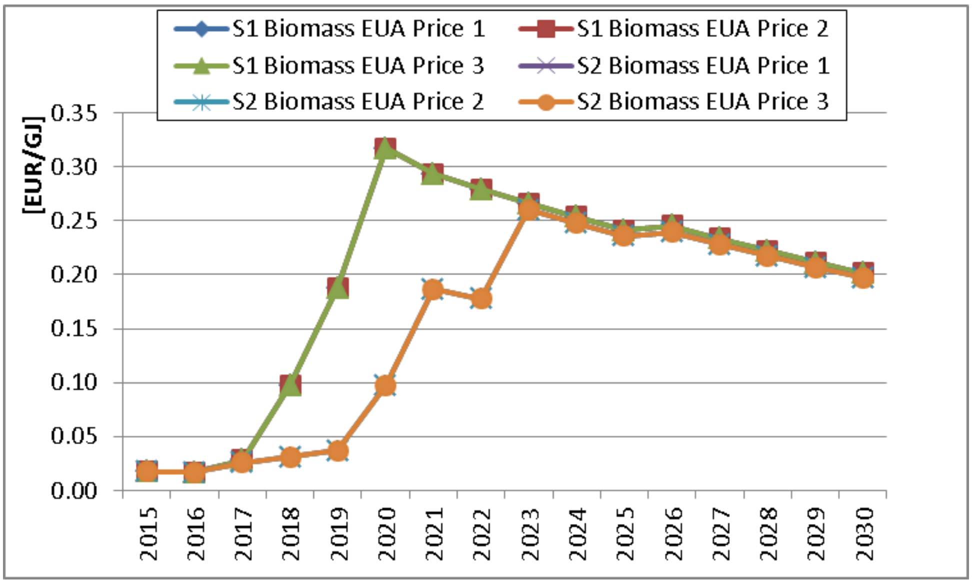

Figure 33. Model segment above 50 MW_{th} – development of externalities for biomass fired installation, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

I identified CO_2 cost as main driver for model segment above 50 MW_{th}. According to model outcomes major impacts are pictured for lignite fired installations with highes CO_2 emissions per produced energy output. Biomass installation are not influenced by CO_2 costs thus suffer only from other externalities. I made thorought comparison of identified externalities in Chapter 10.6.2.1.

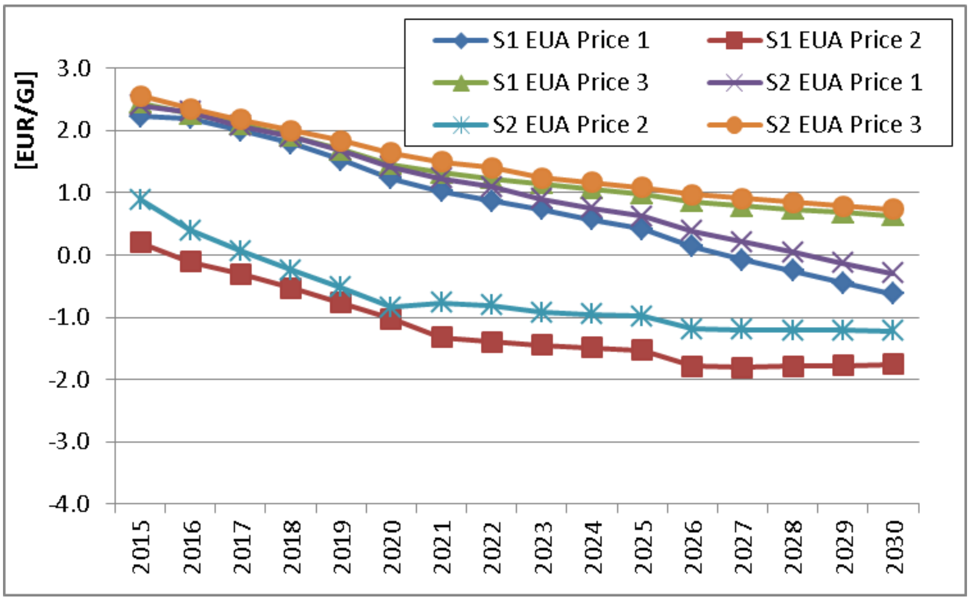

Figure 34. Model segment above 50 MW_{th} – fuel switching from lignite to biomass, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

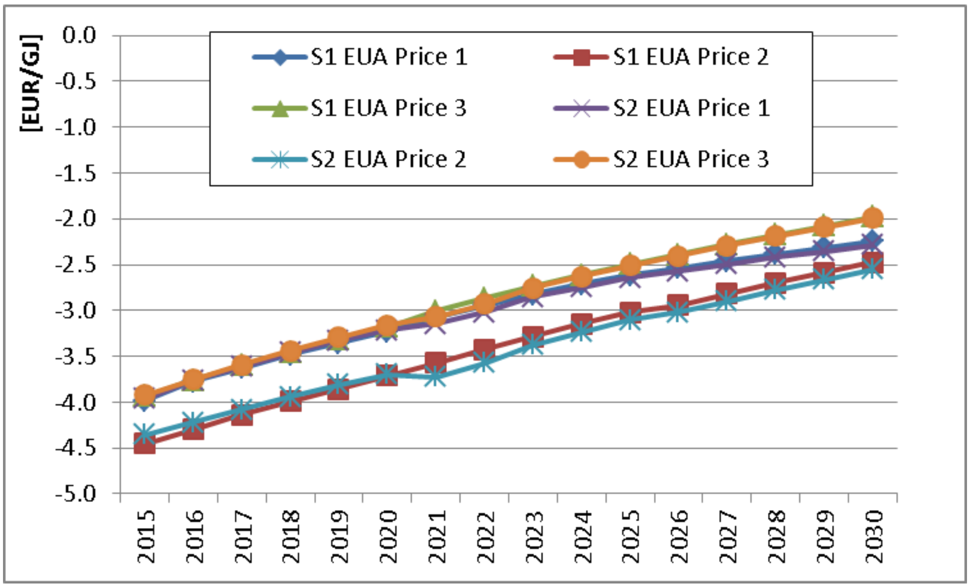

Figure 35. Model segment above 50 MW_{th} – fuel switching from fuel oil to natural gas, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

Similarly to other model segments fuel switch from fuel oil to natural gas is highly possitive, thus already happening as I showed in Chapter 6.4.1. Fuel switch from coal/lignite to biomass is dependat on CO_2 costs scenarios.

10.6.2 Model outcomes for reference case

Result of the model represent reference case of the situation in the Czech Republic concerning legislation-induced risk factors on the heat market participants. Given that heat is the main product of district heating plants, I focused the model on describing externalities reflected in heat price. All the legislative aspects referred to hereinbefore will impact heat prices in the Czech Republic substantially.

In respect of emission trading, model uses potential of legislation tool for free allocation of allowances for the district heating sector according to Article 10a, which is crucial for the economic model. According to the text of Directive 2009/29/EC, there should be free allocation for heat producers. The rules of this free allocation are presented in Decision 10a (as mentioned above), and the detailed modalities are shown in the Guidance Document No. 6. The benchmark value, which is the ratio between GHG emissions and heat production, was set at levels for a natural-gas-fired plant with 90% heat production efficiency – this gives 62.3 allowances per TJ of heat delivered to consumers. However rules and procedures after 2020 are subject to EU legislation process and still not very clear.

In terms of the IED, it is necessary to implement all possible derogation tools for local installations. New emission limits were correctly set at BAT levels, which are nowadays subject to another revision. Regulators, however, should bear in mind also local circumstances – local fuel sources, the huge air quality improvement over the last two decades and the energy security of the Czech Republic.

In terms of pollution fees, the national authority should take into account that going below BAT is not economically and technically possible and therefore pollution fees will become a “tax”. There is no necessity to introduce a “pollution tax”. The IED forms a comprehensive and sufficiently demanding framework for cleaner energy production.

The presented graphs show the outcomes from the economic model. Major influence could be attributed to CO_2 costs as a main driver for future legislation induced development of energy prices in model segments above 20 MW installed thermal input.

In all models segments major difference between the two scenarios is in the first years, where Scenario 1 models a severe price increase. Scenario 2 offers much more flexibility for producers through a gradual increase in heat prices. CO_2 costs are main driver for future increase in heat costs, if not properly reflected in costs for competitors (namely natural gas fired boilers below 20 MW_{th} input), could increase rate of disconnection from DH grids and further scale up heat prices.

10.6.2.1 Comparison of risk factors for reference case

I present comparison of risk factors between different fuels, installations sizes and model segments for Legislation scenario 2, CO_2 price scenario 1 (identified as most probable combination of scenarios) in the following figures.

Comparison based on type of risk factor shows following results:

- Strong influence of CO_2 costs responsible for majority of increase in costs for installations covered by EU ETS legislation and creates major detrimental effects on the heat market since installation below 20 MW thermal input is not subject of these costs. Both in 2020 and 2030 share of CO_2 costs on overall increase for installations above 20 MW thermal input are above 80% in case of lignite and hard coal fired installation and above 90% in case of natural gas fired installations.
- New emission performance standards (emission limits) represent second strongest impacts especially for larger installations above 20 MW thermal input. Pollution fees is relevant mainly in the case of smaller installations firing lignite and/or hard coal, which can excess legislation threshold for fees applicability and represent for this segment higher costs than in the case of emission limits. This is especially true for situation in 2020 before retrofitting to new environmental performance standards but with application of higher fees according to Czech on air protection.
- Water fees have very limited impacts compared to other legislation induced risks.

Comparing the effects based on installation size displays:

- No relevant legislation-induced costs for the model segment below 1 MW thermal input.
- For model segment 1-20 MW thermal input, absolute value of risk factors is smaller compared to higher model segments subject to the fact that EU ETS (CO_2 price) is applicable above 20 MW thermal input. However emission limit costs are comparable to higher segments and pollution fees impacts are even highest among all the segments for the lignite or hard coal fired installations. This is caused by relatively higher emissions per produced energy inputs (e.g. lower overall energy efficiency compared to larger installations).
- Model segment 20-50 MW thermal input suffers from highest induced costs in absolute terms, caused by the relatively lower energy efficiency compared to segment above 50 MW thermal input. I identified this segment as most vulnerable to competition distortions, since this segment is exposed to the full range of risk factors.
- Segment above 50 MW thermal is exposed to second highest impacts in terms of legislation induced externalities. This segment is subject to provisions of all legislation instruments, but thanks to the relatively higher efficiency compared to lower segments can allocate induced costs to the higher production.

Comparison based on fuels presents following results: the effects based on installation size displays:

- I modelled highest induced costs for installations based on lignite and hard coal.
- Second highest would be facing installations firing liquid fuels (fuel oil) followed by natural gas fired installations. Biomass installations will suffer only from minor legislation induced externalities.

When I compare situation in 2020 with situation in 2030, legislation induced costs rise for all the relevant model segments, installation sizes and fuels. This is caused by increase in emission performance standards and especially by CO_2 price increase modelled in all available scenarios.

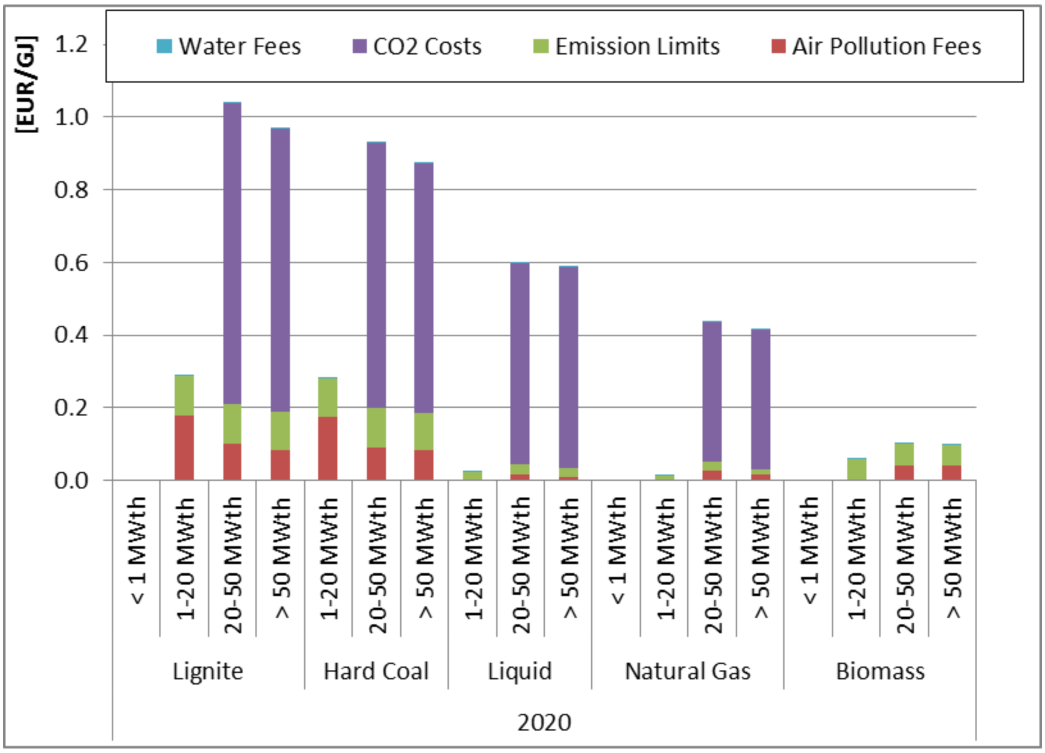

Figure 36. Comparison of risk factors in 2020 for Legislation Scenario 2 – Pragmatic implementation and CO_2 price Scenario 1, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

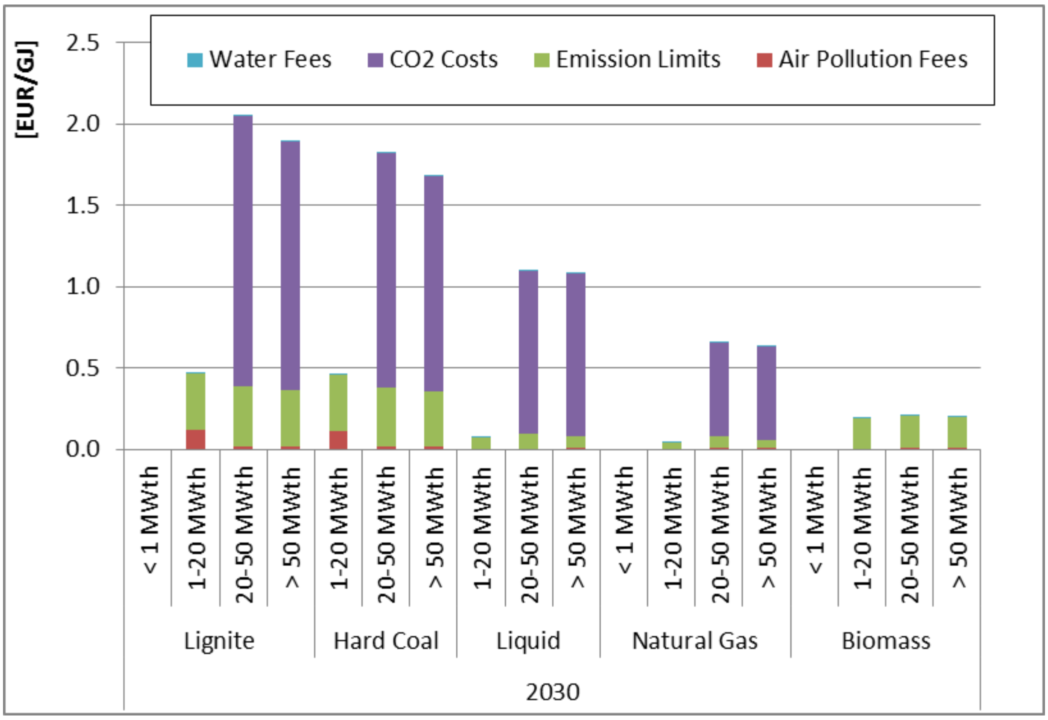

Figure 37. Comparison of risk factors in 2030 for Legislation Scenario 2 – Pragmatic implementation and CO_2 price Scenario 1, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

10.6.3 Model sensitivity analysis

Based on outcomes of the model, I identified as most important inputs the following:

- CO_2 costs
- discount factor
- potential for energy savings (heat demand reduction)

Model sensitivity is tested against Legislation Scenario 2 (Pragmatic implementation) and CO_2 price Scenario 1 (CO_2 price according to estimations of Ministry of Environment) as I identified this combination of scenarios as the most likely based on assessment of risk factors. Sensitivity could be best modelled on Lignite fired installations facing highest legislation induced impacts.

10.6.3.1 CO_2 costs sensitivity

Most sensitive input into the model represents CO_2 costs as main driver for increase in overall costs, three different CO_2 price developments scenarios according to projections given by Ministry of Environment, European Investment Bank and estimation based on market data from current trading period are already incorporated within model design as such (see Chapter 10.4).

10.6.3.2 Discount factor sensitivity

Second most important parameter in the model is discount factor. Sensitivity of model outcomes on discount factor is pictured in case of Legislation Scenario 2 and CO_2 price Scenario 1. Higher discount rates counters increase in overall costs driven by CO_2 price increase.

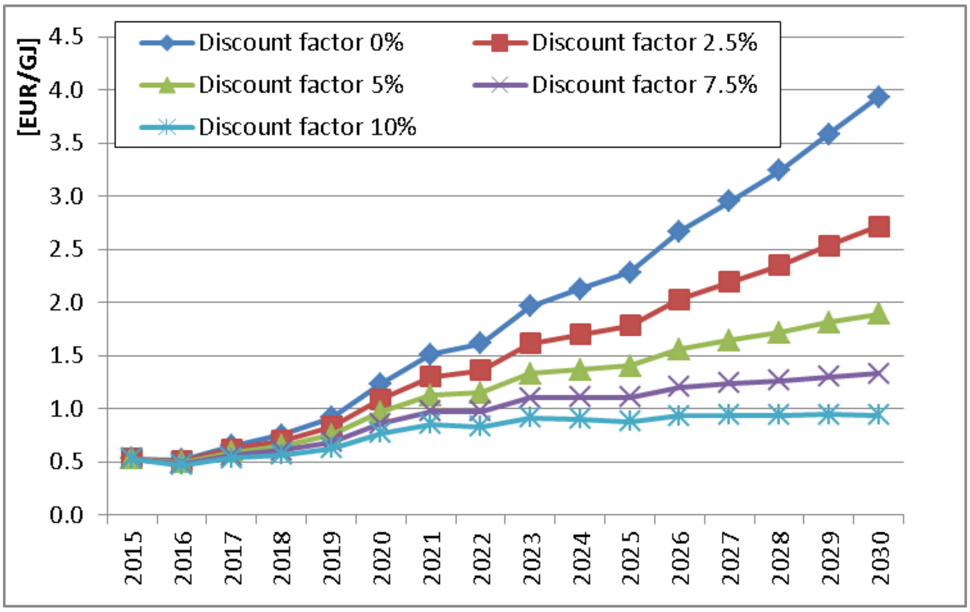

Figure 38. Model outcomes for lignite fired installation above 50 MW_{th} for different discount factor rates in Legislation Scenario 2 and CO_2 price Scenario 1, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

10.6.3.3 *Energy savings sensitivity*

Energy savings (heat demand reduction) could be considered as third most important parameter in the model. Higher savings means less heat production for allocation of additional costs caused by new legislation and increase in price of outputs. Basic scenario uses energy savings from Update of state energy policy of the Czech Republic ("SEP scenario"). Following figure shows impacts of energy savings higher or lower than SEP scenario.

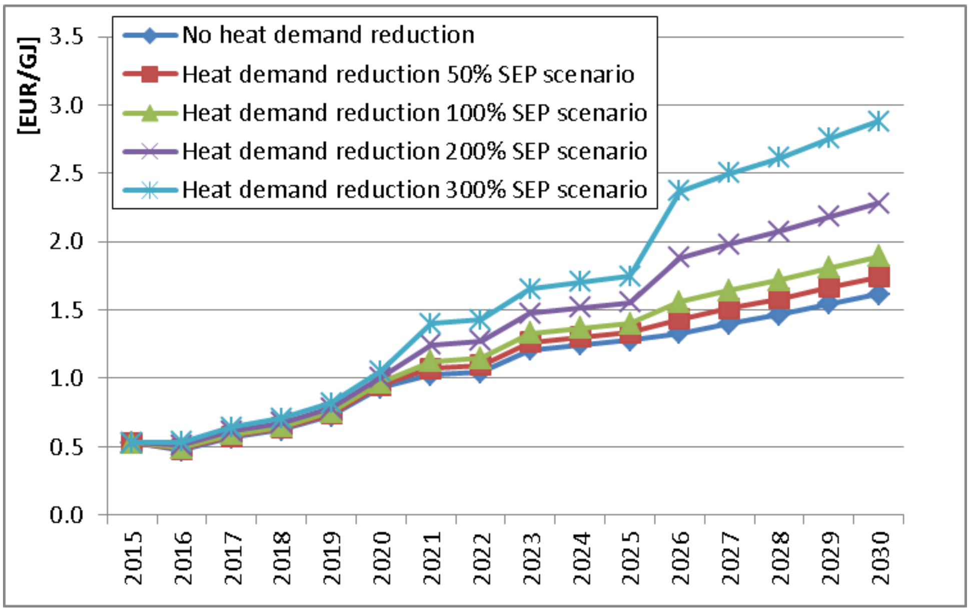

Figure 39. Model outcomes for lignite fired installation above 50 MW_{th} for different energy savings (heat demand reduction) scenarios in Legislation Scenario 2 and CO_2 price Scenario 1, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

10.7 *Hypothesis about key effect on the heat market*

Within this chapter I summarized main model outcomes, which represent clear results concerning dominance of CO_2 costs among other legislation factors. Thus hypotheses "Among environmental measures CO_2 costs are main driver for future development and refurbishment of district heating industry, other environmental legislation has limited impacts." could be considered as valid.

11 Discussion and designing of remedial tools

11.1 Solution for remedial tools on the heat market

Outcomes from the reference case model presented in Chapter 10 demonstrated legislation-induced increase in costs for certain actors on the heat market which could lead to competition distortions. In this chapter I am discussing possible new regulation tool to properly address solutions towards remedy of the heat market distortions caused by new environmental legislation.

Relevant hypothesis within this Chapter is: "Indirect carbon taxation offers effective tool to address heat market distortions caused by future environmental legislation."

11.2 Emission trading

Emission trading as a commonly used instrument within EU ETS could be seen as one of the possible solutions how to remedy the heat market distortions.

11.2.1 Perspective of emission trading

Adoption of the Clean Air Act in USA in 1990 could be considered the very beginning of the emission trading idea. This piece of legislation introduced a brand new market mechanism for SO_2 trading to help lower the costs of reaching environmental limits. Although quite slow in emerging, emission trading was seen an exciting example of the win-win environmental policy that will be copied around the world by the twenty first century and was predicted its use in United Nations as a potential for a global market in greenhouse gas reductions. However, it will take many years to manifest the full potential of these new market instruments in extension of the tools now commonplace in established financial and commodity markets (Walsh *et al.*, 1996).

There were several assessments of this new emission trading tool (Ramanathan, 1995, Rau and Adelmann, 1995, Burtraw and Szambelan, 2009). Operation of the system in emission constraints was described as a nonlinear constrained minimization problem, which could be applied in determining when allowances are to be sold or bought and in assigning the amount of allowances to be traded in accordance with requirements set by CAA at minimum cost (Rau and Adelmann, 1995).

However, this tool was designed for SO_2 emissions, which is a different type of pollutant than CO_2. The main difference is that CO_2 emissions cannot be reduced in relation to production other than by end-pipe Carbon Capture and Storage technology available at a high price; the only way of reducing CO_2 emissions at lower cost is to reduce output (Ellerman *et al.*, 2011).

11.2.2 Emission trading principles

The basic principles of emission trading could be demonstrated by using marginal abatement cost (MAC) curves as the main tool (Ellermann and Decaux, 1998). MAC curves are often used heuristically to demonstrate the advantages of emissions trading. Each reduction potential for a region (installation) represents a point on the MAC curve. Assuming that environmental goal for long-lived pollutant like CO_2, which is well-mixed globally, is not affected by the location of the emission reduction, if there is a difference in MAC between two regions (installations), the sum of costs of meeting the reduction targets will be less than a region with higher marginal costs can induce a region with lower marginal costs to abate on its behalf, (Ellermann and Decaux, 1998). By reducing more, the lower cost installation creates "right to emit" (permission rights), which can be traded to the higher cost installation. The difference in the marginal costs associated with each region's commitment in the absence of trade creates a potential gain to be shared in some manner between the two regions. The aggregate emission reduction will be achieved at least cost when the regions trade until their marginal abatement costs are equal at what will then be the market clearing price for the 'right to emit' carbon (Ellermann and Decaux, 1998).

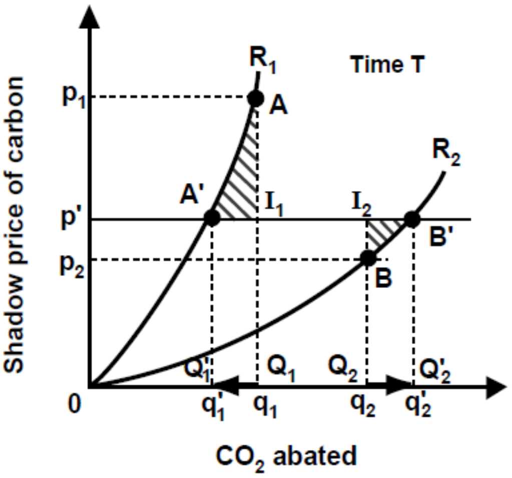

Figure 40. Marginal abatement cost curves (Ellermann and Decaux, 1998)

The gains from trading for two regions (installations), R1 and R2, are subject to the constraints: CO_2 abated = q1 for R1 and q2 for R2 (Ellermann and Decaux, 1998). Savings from trading are represented by the hatched area (AI1A') for region 1 and by the hatched area (BI2B´) for region 2.

Marginal abatement cost curves are affected by policies in other regions (they are not independent). MAC's stability differs through time regardless of what measures have been implemented in the past and rely on previous measures taken in the region. However, MACs are not closely related to marginal welfare cost curves and therefore should not been used to derive estimates of welfare change (Morris *et al.*, 2012).

11.2.3 Allocation of emission rights

In theory, emission trading should allow achieving emission reduction at the lowest costs for the economy. In ideal conditions, it does not matter how emission rights are allocated to installations within system boundaries. However, this is seldom the case and initial emission right allocations affect cost efficiency of emission trading systems (Stavins, 1995).

The debate about allocation options (Goulder, 1995, Cramton and Kerr, 2002, Requate, 2005) could be summarized into two basic models:

- grandfathering – regulator of the emission trading system freely allocates emission rights to each installation within system boundaries. This allocation could be based:
  - on historical emissions (possibly with some corrections or with emission reduction pathways)
  - on output or some other production data. This special case is called benchmarking.

  As the grandfathering approach is based on historical data, entities within the emission trading system are motivated to maintain historical emissions (production) to get larger share of free emission rights. This could even lead to a distortionary incentive to increase emissions (Böhringer and Lange, 2005, MacKenzie, 2008).

- auctioning – emission rights are allocated to each entity in the emission trading system based on monetary bid relative to every other entity (Cramton and Kerr, 2002). Emission rights are distributed to each entity independent of their historical emissions (or production), thus auctioning removes one of the main problems arising from the updated grandfathering scheme.

To facilitate international emission trading in greenhouse gases, there is also a necessity to put in place a universally acceptable standard for quantification and certification of CO_2 emission units, which is crucial for enabling them to be traded worldwide just like any other commodity (McConnach, 2002).

Cost-free allocation based on historical emission levels (or production) implies an increase in energy prices, which - in connection with base electricity price being constructed on the portfolio of coal-fired installations - leads to windfall profits for CO_2-free power generation (such as nuclear and renewable sources) as well as for CO_2-less intensive power generation (such as natural gas) (Wang and Yang, 2009). However, auctioning would not completely resolve this issue, because it could lead to massive fuel switch from coal to natural gas, with subsequent impact on energy dependency. Abrupt transition to a complete auctioning system may also endanger competitiveness of energy-intensive industries within the system, which could be the case for instance for primary aluminum production industry (Smale *et al.*, 2006).

11.2.4 Theory of Auctioning

Hahn (1984) theoretically shows that free allocations can cause inefficiencies, especially when a firm with market power receives more (or fewer) allowances than its cost effective allocation and finds that when the initial allocation deviates from the least cost allocation, a zero-revenue auction is less susceptible to market power than free distribution. High emitters may have bid more than the permit's value to increase the chance of winning that permit while expecting to pay a low price (i.e. the market-clearing price set by the marginal unit that transacts) since an increase in one's bid only changes the outcome if the bid becomes the marginal bid that determines the price, in which case bidding above one's value leads to a sure loss (Goeree *et al.*, 2010). Bidding above value is commonly observed in second-price auctions, where the high bidder wins and pays only the second-highest bid (Kagel and Levin, 1993).

Auction revenues are affected by the auction form as well. An ascending auction provides the bidders with information through the process of bidding and it may stimulate competition by creating a reliable process of price discovery and by reducing the winner's curse. Ex ante asymmetries and weak competition favor a sealed-bid design, in other cases, an ascending auction is likely to perform better in efficiency and revenue terms and can be tailored to limit collusion (Cramton, 1998).

Another comparison of uniform, sealed and ascending auction, with focus on the ability of entities to tacitly or explicitly collude in order to maximize profits, shows that the discriminatory and uniform price auctions produce greater revenues than the ascending auction. Ascending auction appears to be more subject to successful collusion because of its sequential structure and because it allows bidders to focus on one dimension of cooperation (quantity) rather than two (price and quantity) (Burtraw *et al.*, 2009).

In terms of auction of public resources auction design must be responsive to the institutional context, because each context will imply different information and different strategies available to participants; each economic environment requires auction design for its circumstances (Binmore and Klemperer, 2002). In general, increasing the competitiveness of an auction will be associated with better auction outcomes. The design of the institutional setting for the environmental asset auctions should emphasize features that increase competition among bidders (Burtraw *et al.*, 2009, Kretzmar and Whitford, 2011).

11.2.5 Perspective of EU ETS enlargement towards smaller installations

Installations are included into EU ETS conform to the requirements meeting certain size or production volumes that are defined within EU ETS directive. The limits are set at very ambitious levels, so major installations are compulsorily covered by the scheme. Basic facts of the system:

- operates in 31 countries (all 28 EU countries and Iceland, Liechtenstein and Norway)
- more than 11,000 heavy energy-using installations included
- covers around 45% of the EU's greenhouse gas emissions.

Installation in the EU ETS receiving allowances (part for free and part needs to be obtained on auctions) and may dispose of them freely. Based on installation's independently verified emissions must then surrender corresponding volume of allowances. For installations that do not fall under the EU ETS, it would be extremely difficult to participate in the system with the distribution of allowances, followed by trade (or buying) and verifying actual emissions.

Table 51. Number of entities in the Czech Republic covered by EU ETS by main activity type and verified emissions[68]

	Verified emissions					Total
	0 kt CO_2eq	0 - 25 kt CO_2eq	25 - 50 kt CO_2eq	50 - 500 kt CO_2eq	> 500 kt CO_2eq	
Aviation	0	3	0	2	0	5
Combustion of fuels	2	127	24	39	28	220
All industrial installations (excl. combustion)	0	64	22	33	8	127
All stationary installations	2	191	46	72	36	347

Note

Data for year 2015

In total 347 stationary installations are covered by EU ETS in the Czech Republic. However going below EU ETS threshold for thermal input means substantial increase in number of covered installations. Available data for installations from 1 to 20 MW_{th} shows additional 6,500 installations (Vojáček *et al.*, 2014), numbers of installations below 1 MW_{th} could be estimated in millions. Thus it is impossible to expand the scope of EU ETS with full range of sytem measures to installations below 20 MW_{th}. There is possibility to reduce the administrative burden, for example by inclusion of fuel distribution companies (gas distribution utilities, coal warehouses or other similar utilities) instead of fuel consumers but more progressive and effective approach would be to address this issue by introduction of tax based tool.

Table 52. Number of installations in the Czech Republic based on data from REZZO database[69]

	Thermal input			Total	
Fuel	1 to 4.9 MW	5 to 19.9 MW	20 to 50 MW	**Number of Installations**	Share
Sorted Lignite/Coal	245	30	6	**281**	4%
Pulverized Lignite/Coal	21	63	10	**94**	1%
Biomass	224	40	2	**266**	4%
Fuel Oil	469	93	2	**564**	8%
Natural Gas	4,479	739	96	**5,314**	79%
Biogas	182	7	2	**191**	3%
Total	**5,620**	**972**	**118**	**6,710**	**100%**

Note

Data presented by IREAS study (Vojáček *et al.*, 2014)

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[68] EU ETS data viewer

[69] Register of Emissions and Air Pollution of Ministry of Environment of the Czech Republic

Table 53. Number of occupied dwellings (flats) in the Czech Republic by heating solutions – outcome from Census 2011[70]

Flats		Total occupied	Flats		Number of inhabitants	
			In family houses	In block-of-flats houses	Total	In Family houses
Occupied flats in total		4,104,635	1,795,065	2,257,978	10,144,961	5,033,359
Central heating		3,301,760	1,520,260	1,749,183	8,326,696	4,393,887
Central heating with boiler room in the building	Solid fossil fuels	554,116	507,575	43,027	1,619,229	1,496,203
	Natural gas	1,174,842	882,172	273,754	3,173,472	2,520,422
Floor heating		292,222	52,396	237,533	714,340	134,739
Energy for floor heating	Solid fossil fuels	17,056	7,238	9,591	42,649	16,987
	Biomass	9,204	5,071	4,021	25,020	13,225
	Natural gas	236,605	31,810	203,233	575,316	82,938
	Electricity	18,829	5,802	12,842	47,117	15,601
Local heating		357,039	163,462	190,206	779,764	375,507
Energy for local heating	Solid fossil fuels	28,203	21,552	6,370	57,090	41,520
	Biomass	58,473	45,625	12,228	142,365	107,646
	Natural gas	143,198	32,533	110,182	285,271	68,387
	Electricity	115,218	56,548	56,788	270,203	143,042

11.2.6 Summary of emission trading applicability

Based on discussed aspects of emission trading I found this tool as inappropriate for addressing distortions effects of emerging environmental legislation. Subject to the fact that EU ETS represents too complex system to accommodate huge number of new participants it is not realistically applicable to installations below 20 MW thermal input also from administrative and regulatory point of view.

11.3 Carbon taxation

I identified carbon taxation as another possible option how to address discrepancies on the heat market.

11.3.1 Perspective of "carbon tax"

There is no uniform approach to "carbon tax" theory. Most conservative and accessible solution is to include this type of taxes between the so-called environmental taxes, but some types of CO_2 taxes

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[70] Czech Statistical Office, Population and Housing Census 2011 – Final results, Occupied dwellings by type of heating, heating energy, decisive moment midnight from March 25 to March 26, 2011

application could be seen more as a consumer (energy) taxes or even as property taxes (Zimmermanová *et al.*, 2010).

From the perspective of economic theory, most important are environmental taxes; where many studies exist and are often mutually contradictory against each other. Some economists support environmental taxation as an effective instrument of government policy, others are fundamentally opposed to any taxation of energy or emissions. Some economists advocate for individual responsibility and minimal state interventions to the behaviour of individuals and businesses (Bazin *et al.*, 2004), some on the contrary consider state intervention as the only tool to compel individuals and businesses towards ecological behaviour (Bovenberg *et al.*, 1997; Hoerner *et al.*, 2001).

The first design of environmental tax was made by A. C. Pigou (Pigou, 1920 to 1932). This new type of tax is known as “Piouvian tax” and is defined as a polluter tax paid per unit of pollution, which just equals to the total marginal social damage caused by pollution and subsequently determines the effective level of pollution. Social costs of pollution thus exceed the private costs to polluters. Pigouvian taxes and related theories are also discussed in other works like Carlton *et al.* (1980) and Kolstad (2000).

In practice, it is essentially impossible to put in place Pigouvian tax, theoretical concept has a number of problems in the empirical application. One of the reasons, in particular, is the difficulty of determining the amount of marginal social cost of pollution avoidance. This fact was pointed out by Baumol *et al.* (1971), who proposed instead of a complex and more or less impossible definition of the correct Pigouvian tax to establish a set of environmental quality standards and the subsequent introduction of payments for pollution in the form of resource based pricing.

Other approach could be found in indirect environmental taxes that are levied in order to affect the environmental footprint, while avoiding the problems associated with Pigouvian taxes trying to measure the amount of discharged pollutants. Indirect environmental tax is vicariously levied on the use of production inputs or consumer goods and there is a direct link between the use of these goods and emissions or other environmental damage (Bovenberg *et al.*, 1997). Therefore this tax is not levied directly on pollution or environmental damage (Kubátová, 2000). Indirect environmental tax is advantageous in situations where there is constant relation between the quantities produced or consumed goods and the amount of emissions, which is the case of CO_2 emissions from burning fossil fuels.

11.3.2 Current examples of carbon taxation

As it is show on the list of countries below, carbon taxation is already proven and viable measure for 20 years. States introduced this tool mainly as a regulation for smaller installations and it is seen as an ideal approach in terms of enforcement by competent authority and in terms of administration from installations’ perspective. Besides a strong stimulation effects on governmental budgets has carbon tax has also important effects on environmental policies (for example in UK carbon tax lead to reduction in energy consumption in public services and household sector by 15%[71]).

Table 54. Examples of carbon taxation in certain European countries[72]

Country	**Starting Date**	**Tax Rate [EUR/tCO_2]** (unless noted otherwise)	**Annual Revenue [EUR]**	**Revenue Distribution**
Finland	1990	20	500 mil.	Government budget; accompanied by independent cuts in income taxes
Netherlands	1990	~15	3.2 bil.	Reductions in other taxes; Climate mitigation programs
Norway	1991	~11.4 to ~44.2	660 mil.	Government budget
Sweden	1991	Normal rate: ~100 Industry rate: ~21.9	2.7 bil.	Government budget
Denmark	1992	~12.1	670 mil.	Environmental subsidies and returned to industry
United Kingdom	2001	0.0054 EUR/kWh for electricity; 0.0019 EUR/kWh for natural gas provided by gas utility; 0.0121 EUR/kg for liquefied petroleum gas or other gaseous hydrocarbons supplied in a liquid state; and 0.0147 EUR/kg for solid fuel	880 mil.	Reductions in other taxes
Ireland	2013	10 raised to 20 in 2014	550 mil.	budget gap, reduction in income taxes
France	2014	7 gradually increased to 56 in 2020	340 mil. (in 2014)	energy transition plan, accelerate household renovations to improve energy efficiency, widening of subsidised for gas and power tariffs for the fuel-poor households and boost employment in green sector

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[71] HM Treasury, Complete Budget report 2009, http://www.hm-treasury.gov.uk/bud_bud09_repindex.htm, p. 156.

[72] Data based on information from NREL, Ministry of Environment Finland, VROM, Ministry of Environment Norway, Swedish Environmental Agency, Ministry of Trade Denmark, DEFRA, The Office of the Revenue Commissioners Ireland, French Ministry for agriculture and food

11.3.3 Revision of the Directive on the taxation of energy products

In April 2011 the European Commission presented a proposal for a revision of Directive 2003/96/EC on the taxation of energy products and electricity. According to the draft energy commodities such as coal or natural gas should be taxed by two-component taxes:

- The first component can be called as energy and depends on the energy content of the commodity. At present, this principle is also applied in the Czech Republic within the framework of the so-called environmental taxes (see Risk factor Energy taxation).
- The second component can be called as carbon tax and it would tax fuels based on fuel emission factor. Different fuels have different emission factor and emits different amounts of CO_2 when they are burned. Coal would be therefore taxed more than natural gas. This component would apply only installations outside the EU ETS.

This proposal was seeking to elegantly solve Europe-wide emissions outside the emissions trading system and essentially was replacing trading system for smaller installations producing GHGs emissions. Unfortunately after 3 years of problematic negotiation in European Council without any compromise workable for all the Member States[73], proposal was withdrawn by new Commission in December 2014.

11.3.4 “Carbon” tax in the Czech Republic

Carbon tax in the Czech Republic could be easily introduced by minor change in existing Act. no. 261/2007 Coll. on stabilization of public budgets without substantial increase in administration and management costs[74].

As a first step it would be reasonable to cancel unfounded exception for natural gas for household use from “ecology” tax[75]. As the next step “ecology” tax rate could be increased for fuel consumption outside EU ETS (in installations without permissions according to Act no. 383/2012 Coll. on Emission Trading) based on CO_2 emission factors.

Introduction of these two measures will raise the annual “ecology” tax revenue as follows:

- cancellation of exception for natural gas for household use could bring approx. 1 bil. CZK – based on natural gas consumption figures from Customs Administration and Czech Statistical Office[76]

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[73] since legislation concerning taxation has to be approved by each EU Member State

[74] Legislation proposal amending Act. no. 261/2007 Coll. on stabilization of public budgets was already in interdepartmental comment procedure in January 2013, but was withdrawn because of political reasons.

[75] This action was already discussed in Parliament during 2009.

[76] CZSO, Total Sources of Gaseous Fuels, Consumption in Transformation Sector, at Fuels Extraction and Transport and Total Final Consumption, Year 2013; Customs Administration of the Czech Republic, Tax on natural gas and some other gases (according to individual groups), Year 2013

Table 55. Additional ecology tax revenue after cancellation of exception for natural gas for household use

Indicator	Unit	Value
Total Final Consumption	PJ	244
	TWh NVC	67.9
Annual revenue of ecology tax	mil. CZK/year	1,242
Ecology tax rate	CZK/MWh GCV	30.6
Taxed natural gas for heat production	TWh NVC	36.9
Tax free natural gas	TWh NVC	31.0
	TWh GCV	34.1
Additional annual revenue of ecology tax after cancellation of exception for natural gas (without VAT)	mil. CZK/year	1,044
Additional annual revenue of ecology tax after cancellation of exception for natural gas (with VAT)	mil. CZK/year	1,263

Note

own calculations

- increase of ecology tax CO_2 related component for installations outside EU ETS – “carbon tax” could bring additional revenue depending on method used for deriving emissions subject to carbon taxation
  - based on natural gas consumption figures from Energy Regulatory Office data and solid fuels final consumption statistics from Czech Statistical Office[77],

Table 56. Emissions subject to Carbon tax based on ERO and CZSO data

Indicator	Unit	Natural gas - households	Natural gas – retail customers	Lignite - final consumption	Hard coal - final consumption	Total
Fuel consumption	TWh/year or PJ/year	26.3	13	27.5	3.3	
Emission factor	tCO_2/MWh	0.180	0.180	0.1	0.092	
Emissions subject to carbon tax	th. $tCO_2/year$	4,736	2,305	2,751	304	10,097

Note

own calculations

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[77] ERO, 2014: Annual Report on the Operation of the Gas Distribution System, Year 2013; CZSO, 2015: Final Consumption of Solid Fuels by Sectors, Year 2013

  - based on National Inventory Report[78] submitted by Czech Hydrometeorological Institute, sector 1A4 – Other sectors, which could be generally defined as heat production processes for internal consumption stands for 12,991 th. tCO_2,

Total annual revenue of "carbon" tax in the Czech Republic could be then estimated as follows:

Table 57. Total annual revenue of "carbon" tax in the Czech Republic for different rates (without VAT) depending on method used for deriving emissions

	„Carbon" tax revenue		
Indicator	Rate 5 EUR/tCO_2	Rate 10 EUR/tCO_2	Rate 20 EUR/tCO_2
Emissions derived from ERO and CZSO data	50,485	100,970	201,940
Emissions from NIR 2015	64,955	129,910	259,820

Note
own calculations
Data in th. EUR

11.3.5 Arguments for indirect "carbon" tax

- Removal of market distortions. This is especially the case of heat market – large installations (in EU ETS) will have to buy allowances from 2013 while small installations (outside EU ETS) will not have this obligation.
- Move from direct taxation to indirect taxation, which is commonly seen as a preferable option with positive impacts on economy. Indirect "carbon" tax will tax only activity itself (fuel consumption) with impact on environment. There are no side-effects like in case of VAT increase with negative impacts to public services sector.
- Boost motivation for energy savings and creation of new jobs in relation with implementation of savings measures. Energy savings will also have positive impacts on trade balance of the Czech Republic (lower natural gas import).
- More efficient taxation system – current annual "ecology" tax revenue is approx. 100 mil. EUR (Act. no. 261/2007 Coll.)[79]. Increase in rate and cancellation of natural gas exception will not bring substantial administrative costs and leads to higher efficiency of the tax itself.

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[78] CHMI, 2015: National Greenhouse Gas Inventory Report of the Czech Republic, Submission under the UNFCCC, Reported Inventories 1990-2013, November 2015

[79] Customs Administration of the Czech Republic, Statistics of environmental taxes

11.3.6 Arguments against indirect "carbon" tax

There are several theoretical arguments against "carbon" tax.

- Social consequences. This argument is not valid because of more than 1,4 mil. of households (approx. 4. mil. of inhabitants) often with low incomes connected to district heating systems is paying "carbon" price from 2013 because of inclusion into EU ETS.
- Impact on competitiveness of small and medium-sized enterprises ("SME"). These impacts should not be essential, major part of SMEs' costs is labour costs. Shift to energy taxation could have even positive results in this respect. "Carbon" tax is going to be implemented in all European states so international competitiveness should not be affected.

11.3.7 Summary of carbon taxation applicability

Taking into account discussed aspects of carbon taxation I found this tool as appropriate for addressing distortions effects of emerging environmental legislation. Indirect carbon taxation should not bring substantial increase in administrative costs thanks to the fact that existing legislative instruments could be used. Indirect carbon taxation as a tool for remedy of heat market distortions could be considered as realistically applicable to installations below 20 MW thermal input also from administrative and regulatory point of view.

11.4 Proper design of carbon costs addressing tool

Introduction of carbon tax has to take into account share of free allocation for heat production within EU ETS Directive 2003/87/EC in order to proper reflect distortion effects of reference case. This share is changing thorough the period from 2015 to 2030 subject to legislation provisions of Article 10a and subsequent legislation. I estimate situation in 4th trading period 2021-2030 based on latest information from EU ETS revision process.

Table 58. Share of free allocation for heat production according to provisions of Directive 2003/87/EC up to year 2020

Year	Cross-sectoral correction factor - Art. 10a (5)(1)	Decrease in free allocation - Art. 10a (11)	Share of free allocation
2018	85.90%	44.29%	38.04%
2019	84.17%	37.14%	31.26%
2020	82.44%	30%	24.73%

Note

(1) Defined in Commission Decision 2013/448/EU[80]

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[80] Commission Decision of 5 September 2013 concerning national implementation measures for the transitional free allocation of greenhouse gas emission allowances in accordance with Article 11(3) of Directive 2003/87/EC of the European Parliament and of the Council

Table 59. Share of free allocation for heat production according to provisions of Directive 2003/87/EC from 2021 to 2030

Year	Cross-sectoral correction factor - Art. 10a (5)(1)	Decrease in free allocation - Art. 10a (11)	Decrease of heat benchmark value(2)	Share of free allocation
2021	100.00%	30%	85%	25.50%
2022	100.00%	30%	85%	25.50%
2023	100.00%	30%	85%	25.50%
2024	100.00%	30%	85%	25.50%
2025	100.00%	30%	85%	25.50%
2026	100.00%	30%	80%	24.00%
2027	100.00%	30%	80%	24.00%
2028	100.00%	30%	80%	24.00%
2029	100.00%	30%	80%	24.00%
2030	100.00%	30%	80%	24.00%

Note

(1) Correction factor could be introduced if there will be lack of free allowances according to Art. 10a as it happened in the current 3rd trading period

(2) According to the Commission proposal of Art. 10a (2)

In fact, most of the installations within the EU ETS have lower average annual efficiency than the value considered for calculating the benchmark value for free allocation and additionally there are losses in the heat distribution networks. Therefore, the real effective free allocation will be significantly lower. Based on existing and theoretical provisions of EU ETS legislation, I recommend to set "carbon" tax according to following formula reflecting 25% share of free allocation.

$$Carbon\_tax\_rate = CO_2 price \cdot CO_2 emissions \cdot (1 - FreeAllocation) \qquad (17)$$

where:

CO_2price	price of EUA in the EU ETS system[81],
CO_2emissions	CO_2 emissions from using fossil fuel (CO_2 emission factor),
FreeAllocation	share of free allocation for EU ETS installations.

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[81] There are already 2 possible "official" EUA prices calculated each year by Energy Regulatory Office for the purposes of heat price regulation and by Ministry of Environment for purposes of National investment plans and accounting of eligible investments. For the purposes of calculation of carbon tax rate, "ERO" EUA price could be considered as more appropriate.

11.5 Remedial tool application on the heat market

I am presenting possible model situation on the reference case heat market with application of remedial tool – indirect carbon tax in following Figures. Comparison is relevant only for fossil fuels based installations suffering from CO_2 costs. I chose as major examples lignite and natural gas fired installations.

I am using model results and transform them into the change in heat price. The way how to transform risk factors induced externalities into heat price for consumers is described in following figure.

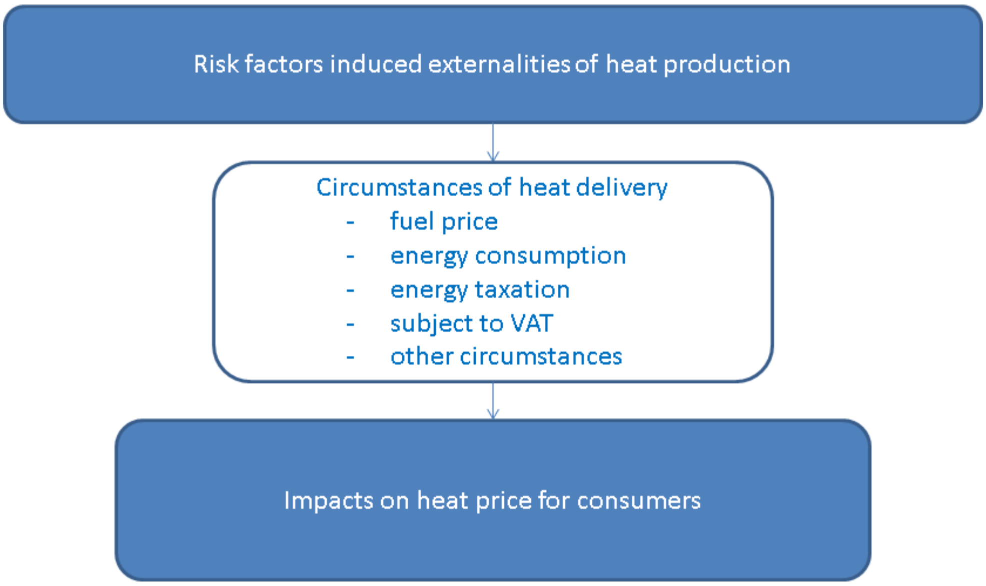

Figure 41. Transformation of risk factors into heat price for consumers

11.5.1 Heat market for industrial consumers

For calculation of externalities of heat production for industrial consumers I am using following assumptions:

- VAT is not applicable – consumers are VAT payers (subject to VAT)
- Ecology tax is not applicable – heat for industrial consumers is usually produced in CHP process[82] which is excluded from energy taxation
- heat distribution losses are not applicable – heat is consumed close to the production facility
- heat price – based on data from ERO[83]
- fuel price – based on EUROSTAT and ADH CR data[84]

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[82] According to CZSO data (Transformation Processes in the Energy Sector of the Czech Republic – 2014) is Total fuel consumption used for heat generation 201 PJ translating into 172 PJ of produced heat. Total fuel input used for heat generation in CHP installations (142 PJ) and condensing power plants (7 PJ) counts for approx. 75% of the total. Considering higher efficiency of heat production in CHP facilities, share of CHP heat could be estimated even above 80% of heat production in the Czech Republic.

[83] ERO, 2015: Evaluation of thermal energy prices and their evolution to 1st January 2015, November 2015, price for heat delivery from heat installation below 10 MW thermal output

[84] EUROSTAT, 2016: Gas prices for industrial consumers, Year 2015, Band I3 : 10 000 GJ < Consumption < 100 000 GJ; ADH CR internal database

- nominal costs, discount factor 0% to ensure comparability
- DH installations with thermal input above 50 MW, local installations with thermal input below 1 MW

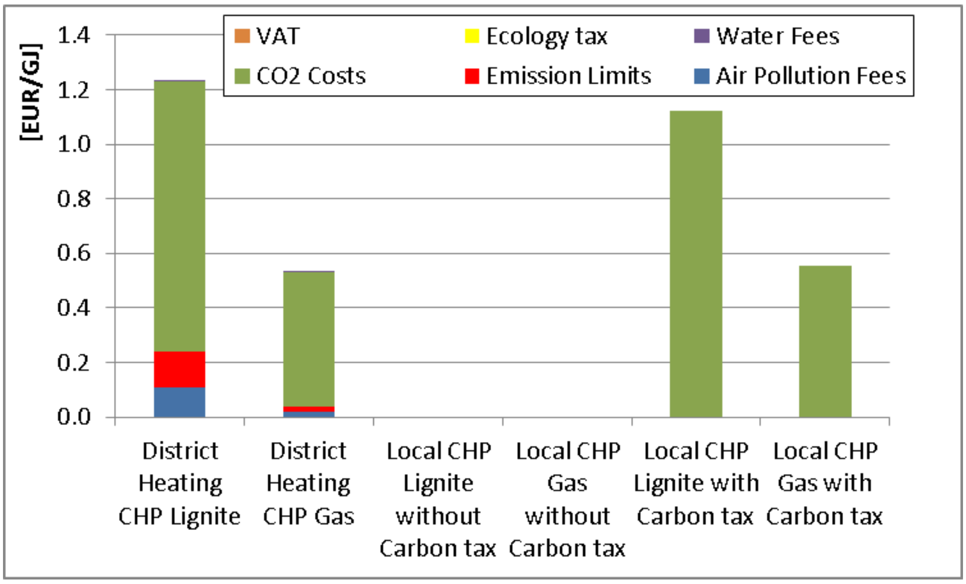

Figure 42. Comparison of externalities per produced GJ of heat for industrial consumers for District heating (Legislation Scenario 2, CO_2 price Scenario 1, DF = 0%) and Local boilers in year 2020 with inclusion of carbon tax tool

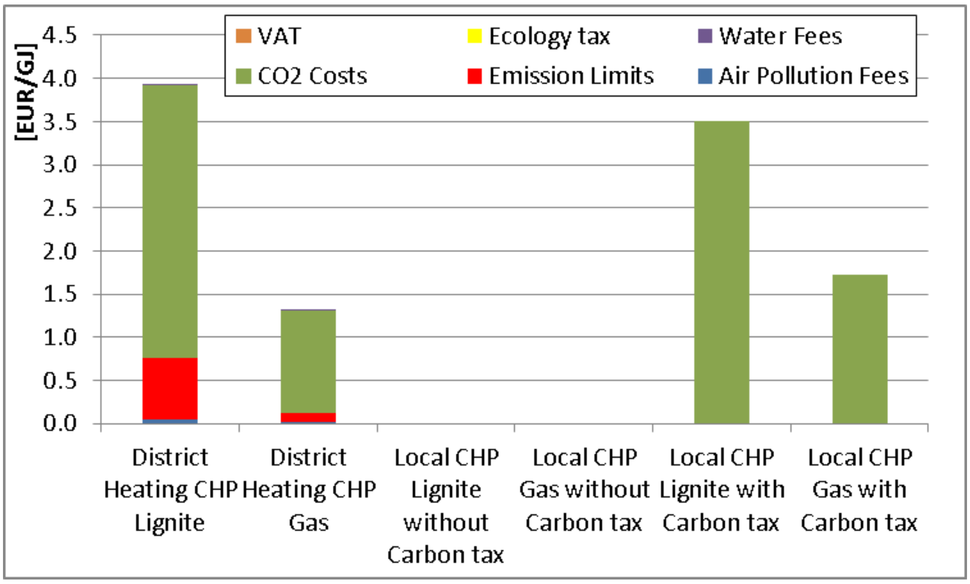

Figure 43. Comparison of externalities per produced GJ of heat for industrial consumers for District heating (Legislation Scenario 2, CO_2 price Scenario 1, DF = 0%) and Local boilers in year 2030 with inclusion of carbon tax tool

Comparing the situation of different fuels:

- lignite fired facilities are exposed to significantly higher overall legislation induced costs compared to installations firing natural gas because of higher CO_2 emissions per produced energy output.

Comparing different legislation induced effects:

- CO_2 costs dominate legislation induced factors and create major part of distortion effect on the heat market for reference case.
- Second most important risk factor represent new emission performance standards (emission limits). These are applicable only for district heating installation within defined assumptions for this reference case.
- Air pollution and water fees are having negligible effects on overall level of legislation induced costs.
- VAT and ecology tax are not applicable within defined assumptions for this reference case.

I model current situation by column 1 to 4, columns 3 and 4 then show the case of local installations without inclusion of carbon tax based tool. By comparison of column 1 and 3 for lignite and 2 and 4 for natural gas I demonstarate major discrepancies in level of externalities caused by legislation. In current situation DH utilities will suffer from serious competition distortion on heat market. These disrepancies are increasing rapidly in the period between year 2020 and year 2030.

Columns 5 and 6 represents situation with inclusion of CO_2 tax based tool, which is allocating price of carbon also to installations below EU ETS limits. I can confirm by comparing columns 1 and 2 with columns 5 and 6 the fact that CO_2 tax could remedy severe dispropostions on the heat market for reference case towards unifrom externalities for fossil fuels based heat market participants. Thus I am confirming that carbon tax based tool could balance out identified undue distortions on the heat market for industrial consumers.

11.5.2 Heat market for households

For calculation of externalities of heat production for consumers in households I am using following assumptions:

- VAT is applicable – consumers in households are not VAT payers (subject to VAT)
- Ecology tax is applicable – heat for consumers in households connected to district heating is usually produced in CHP process (see assumptions for industrial consumers above) however energy taxation example is included for natural gas district heating installations, local heat solutions examples assumes heat-only installations
- heat losses are applicable (takes place in reality), however for the sake of correct externalities comparison between local and district heating installations losses are not taken into account because they would exaggerate effects of legislation-induced risks towards district heating facilities
- heat price – based on data from ERO[85]
- fuel price – based on EUROSTAT and ADH CR data[86]
- nominal costs, discount factor 0% to ensure comparability
- DH installations with thermal input above 50 MW, local installations with thermal input below 1 MW

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[85] ERO, 2015: Evaluation of thermal energy prices and their evolution to 1st January 2015, November 2015, price for heat delivery for final consumers from in-house heat exchange station

[86] EUROSTAT, 2016: Gas prices for domestic consumers, Year 2015, Band D2 : 20 GJ < Consumption < 200 GJ; ADH CR internal database

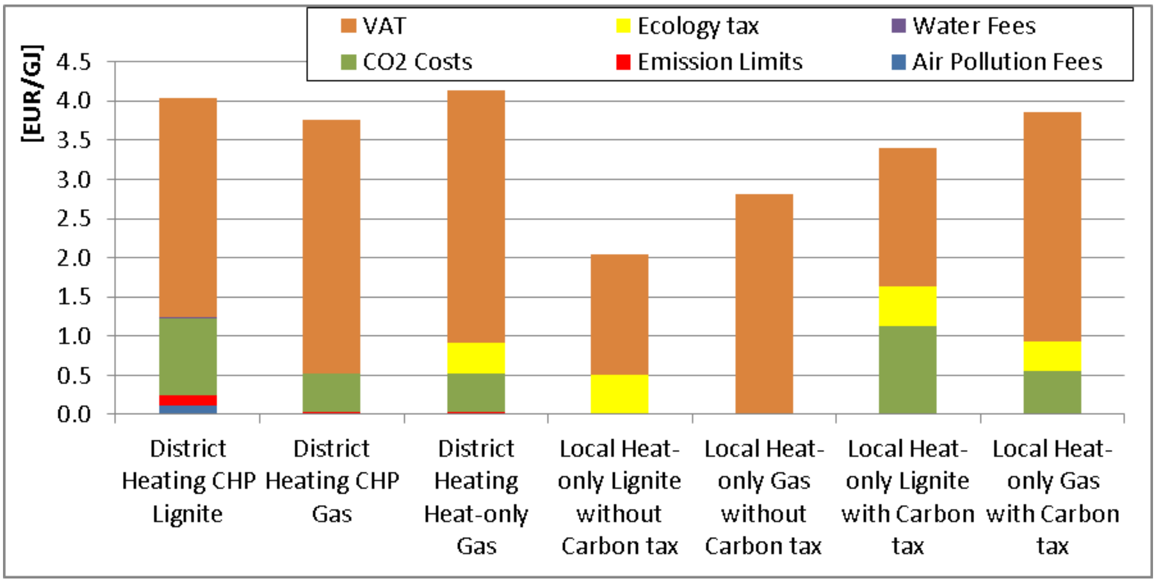

Figure 44. Comparison of externalities per produced GJ of heat for households for District heating (Legislation Scenario 2, CO_2 price Scenario 1, DF = 0%) and Local boilers in year 2020 with inclusion of carbon tax tool including VAT and Ecology tax

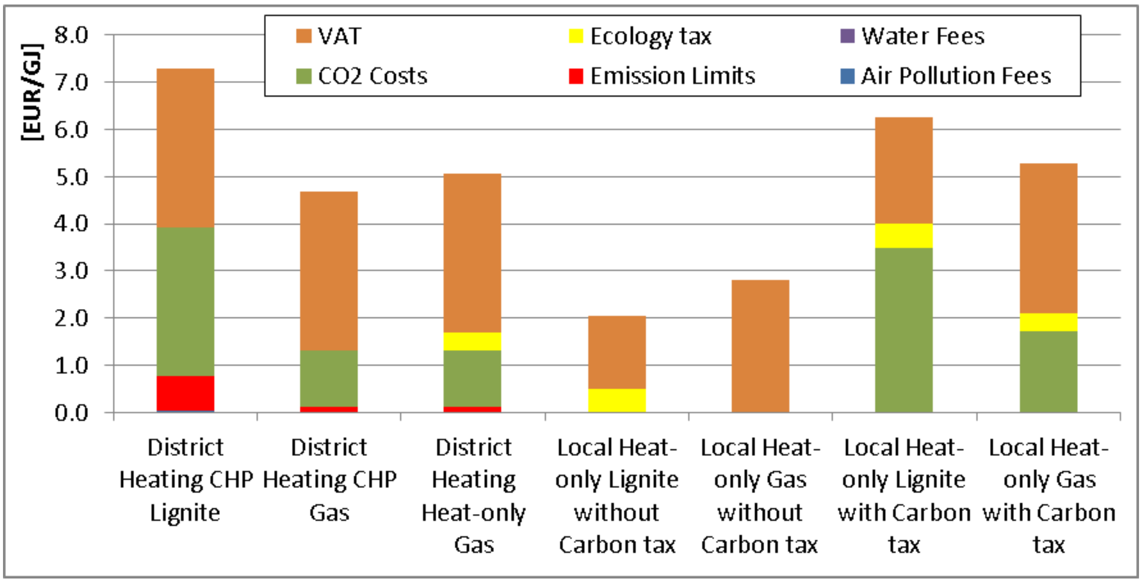

Figure 45. Comparison of externalities per produced GJ of heat for households for District heating (Legislation Scenario 2, CO_2 price Scenario 1, DF = 0%) and Local boilers in year 2030 with inclusion of carbon tax tool including VAT and Ecology tax

Comparing the situation of different fuels:

- Similarly to model situation of heat market for industrial consumers lignite fired facilities are exposed to significantly higher overall legislation induced costs compared to installations firing natural gas because of higher CO_2 emissions per produced energy output.

Comparing different legislation induced effects:

- In the case of heat market for households VAT dominates among legislation induced costs, this effect is derived from overall costs of heat production and higher legislation induced risk factors (such as CO_2 costs) also lead to higher VAT
- CO_2 costs are representing second most important legislation induced externality and are becoming more important towards year 2030
- Air pollution and water fees are having negligible effects on overall level of legislation induced costs.
- Ecology tax is applicable only in case of heat-only installations. In current situation heat-only natural gas fired installation in household are not subject of ecology tax.
- New emission performance standards (emission limits) have relevant effect only for district heating installation within defined assumptions for this reference case.

I model current situation by column 1 to 5, columns 1 to 3 present situation for district heating installations and collumns 4 and 5 then show the case of local installations without inclusion of carbon tax based tool. By comparison of column 1 and 4 for lignite and 2, 3 and 4 for natural gas I demonstarate major discrepancies in level of externalities caused by legislation. In current situation DH utilities will suffer from serious competition distortion on heat market and even reducet VAT rate is not efficint enough to remedy this deformation. These disrepancies are increasing rapidly in the period between year 2020 and year 2030.

Columns 6 and 7 represents situation with inclusion of CO_2 tax based tool, which is allocating price of carbon also to installations below EU ETS limits. I can confirm by comparing columns 1 to 3 with columns 6 and 7 the fact that CO_2 tax could remedy major part of severe dispropostions on the heat market for reference case towards unifrom legislation externalities for fossil fuels based heat market participants. Thus I am confirming that carbon tax based tool could balance out identified undue distortions on the heat market for households.

11.6 Hypothesis about solution for remedial tools on the heat market

This chapter was devoted to discussion about possible solutions for remedial tools to solve heat market distortions caused by new environmental legislation. Modelled situations on the heat market in 2020 and 2030 have shown positive influence of carbon tax tool introduction for overcoming the competition distortions stemming from non-equal approach to market participants. Relevant hypothesis: "Indirect carbon taxation offers effective tool to address heat market distortions caused by future environmental legislation." could be considered as valid.

12 Conclusions and summary

12.1 The main outcomes and recommendations

- **As I have shown, the district heating sector accompanied by combined heat and power technology offers effective solution for covering heat demand from energy and environmental perspective and has also other highly positive side effects on energy systems. District heating thus serves the public interest and deserves adequate protection against inadequate distortion effects.**
- **I presented that the district heating sector as such will be influenced by a whole range of new environmental legislation, especially EU ETS revision and gradually emerging CO_2 auctions (new allocation model after 2013) which could have severe impacts on the prices of heat from district heating plants covered by the system. With implementation of other new environmental legislation, such as new emission limits and higher pollution fees, this could lead to a severe loss of competitiveness of district heating plants on the heat market.**
- **To avoid future distortion of competition on the heat market, I confirmed that it is necessary to impose equivalent environmental measures on the plants outside the scope of the current legislation – probably in form of a new environmental ("carbon") tax. I made a complex evaluation of the current and proposed environmental measures (their interactions, parameters and methodology for their assessment) in order to properly construct this new tool.**
- **Taking into account actual situation and modeled future scenarios, this new carbon taxation tool should be implemented as soon as possible. I identified existing legislation instruments capable of delivering CO_2 price into price of products for subjects currently outside the scope of equivalent measures in administrative and regulatory effective way.**
- **I demonstrated that carbon taxation tools are broadly used within European territory and depending on the selected parameters (eg. carbon tax rate) could bring significant tax revue into the state budget.**

12.2 Summary of primary and partial targets

I set one primary and two partial targets within this doctoral thesis.

Concerning primary target of the doctoral thesis to assess position of district heating and effects influencing its development in the future:

- I described current state of the art in terms of studies and other relevant scientific work concerning district heating in the Chapter 6. Despite the apparent positive effects district heating systems are facing problems with recognizing their true benefits, because each actor on the heat market sees his/her situation differently. Subject to the fact that heat market is always by definition perceived at semi-local or district level, only a minority of scientific work is focused at assessment of position and relationship of different actors there. Thus I devoted this doctoral thesis to description and interpretation of factors (oriented on crucial emerging environmental legislation) influencing heat market with focus on district heating systems as one of the major actors.

- In Chapter 8 I thoroughly described and explained effects influencing the heat market. I identified legislation factor as the most important in this respect because it is politically driven and could severely influence conditions on the market. New legislation concerning environmental performance such as emission limits within the modalities of Industrial Emissions Directive and Medium Combustion Plant Directive and EU ETS Directive are causing uncertainties on the heat market. In particular EU ETS system constitutes variety of complex issues with influence on free allocation of emission rights (allowances) for installations within the system and thus impacting the CO_2 price reflection in the production outputs. Among other outcomes I identified major discrepancies in application of legislative tool based on differentiated approach to installations according to their size, larger installations are in general subject to stricter regulation instruments. This is particularly the case of EU ETS and allocation of carbon costs, where installations below 20 MW thermal input are not subject of any similar measures.
- I created economic model to compare the legislation development in business-as-usual situation and under the new requirements. I chose optimization model of differential NPV as adequate solution for comparing the effects on the heat market in the future. described the model in Chapter 9. . I transformed each legislation effect into risk factor influencing future heat prices. Then I applied general structure of the model to reference case of the Czech Republic and included fundamental assumptions and essential background.
- I formulated main outcomes from my model in Chapter 10 within two legislation scenarios (Strictest implementation and Pragmatic Implementation) on differentiated implementation of legislative tools accompanied by three CO_2 price scenarios (based on estimated price by Ministry of Environment, European Investment Bank and forecast based on market data from 3rd trading period). I can also identify fuel-switch costs in 2 basic scenarios (lignite to biomass and fuel oil to natural gas). As I envisaged in Chapter 8, I confirmed by comparison of risk factors dominance of CO_2 costs in all the risk factors, presenting major disproportions between installations within and outside the EU ETS. I also carried out sensitivity analysis describing relation between model results and different discount factor rates and energy efficiency (heat demand reduction) scenarios.

Concerning partial target to confirm district heating as effective method to cover heat needs while maintaining a high degree of flexibility, low overall energy consumption and limit environmental impacts of production of heat and power and thus deserving adequate protection against inadequate distortion effects:

- According to result presented within the Chapter 7, I identified that the district heating constitutes important requirement for application of certain effective measures such as Combined Heat and Power technology which is one of the most important energy efficiency measures, delivering significant primary energy savings, possibility to utilize low quality fuels, positive grid effects, lowering energy dependency and others. I assessed district heating (especially with CHP technology) according to the “Primary Energy Factor” methodology used for energy efficiency calculation as one of the most advance heating solution comparable to most sophisticated ones. From environmental assessments I used method of potential for production of particulate matter fraction below 2.5 µm (EPS 2.5) which identifies district heating as environmentally effective as well.

Concerning partial target to develop possible tools for remedy of heat market distortions:

- Subject to the outcomes from modeling in Chapter 9 and 10, I discussed various approach how to address distortion effects on the heat market of reference case of the Czech Republic in Chapter 11. Taking into account the results of discussed alternatives, I designed new regulation tool based on indirect carbon taxation, which could be realized by using existing legislation tools for energy (“ecology”) tax. I described application of this possible new remedial tool on the reference case of heat market of the Czech Republic for the case of industrial consumers and households. I confirmed by these analyses that there is a necessity to introduce this type of tool as soon as possible in order to avoid undue competition distortions on the heat market in the Czech Republic.

12.3 Summary of hypotheses

I formulated following four hypotheses within the doctoral thesis:

1) New environmental legislation focuses on key environmental issues and all stakeholders on the heat market are covered in non-discriminatory way and its effects are not differentiated by the scale of emitter (“Polluter-pays-principle” is ensured)

- Description of factors influencing heat market shown major role of emerging environmental legislation as politically driven consequently with severely impacts on the market conditions. New emission performance standards or requirements within the framework of Industrial Emissions Directive, Medium Combustion Plant Directive and EU ETS Directive are causing significant uncertainties on the heat market. EU ETS could be seen as most complex system influenced by implementation issues of free allocation of emission rights (allowances) and in consequence affecting the CO_2 price in the outputs of installations within. Significant revision of EU ETS for 4th trading period currently takes place and could trigger off additional effects on heat market participants. Comparison of legislation requirements in relation to the installations’ size demonstrates different approach to large and small scale emitters. Smaller installations are usually outside the scope and in preferential position towards regulatory authorities, thus “Polluter-pays-principle” is not always ensured. I consider relevant hypothesis as not valid.

2) Risk factors influencing heat market could be modeled by optimization model of differential NPV comparing situation business-as-usual and new circumstances.

- Based on assessment of legislation effects and their transformation into risk factors, optimization model of differential NPV was chosen as optimal for modelling situation in various circumstances. This approach to modeling ensures that all relevant economy factors could be taken into account (such as different age of installations, time value of money etc.). Model structure was tailored to 4 model segments in order to best fit to application of legislation tools with thoroughly description of essential background data and fundamental assumptions. I consider the hypothesis as valid.

3) Among environmental measures CO_2 costs are main driver for future development and refurbishment of district heating industry, other environmental legislation has limited impacts.

- Assumptions of economic optimization model were formulated within 2 legislation and 3 CO_2 price scenarios resulting in complex picture of future influence of risk factors on the heat price. Comparison of risk factors leads to significant results in terms of dominance of CO_2 price component among other factors. However only installations of certain size are subject to these costs. This fact supports outcomes from assessment of legislation tools and confirms that CO_2 price represents major distortions factor on the heat market, with problematic effects if not properly addressed. I consider relevant hypothesis as valid.

4) Indirect carbon taxation offers effective tool to address heat market distortions caused by future environmental legislation.

- Results of previous chapters confirmed that there is a need for remedy the distortive influence of CO_2 price in order to restore fair competitive environment on the heat market. Various approaches how to factor in carbon costs could be identified. Among specified solutions indirect carbon taxation was claimed as most progressive way how to address non-symmetrical application of legislation tools. This instrument could utilize existing legislation tools in form of energy (“ecology”) tax. Modeled application of possible remedial tool on the heat market, described in the Chapter 11.5, shown that using indirect taxation sufficient share of CO_2 costs could pass to price of product and counter undue effects of competition distortion on the heat market. I consider relevant hypothesis as valid.

12.4 Future environmental legislation summary

As I have shown by the description of risk factors on the heat market, new environmental legislation is targeted mainly at larger unit and installations. This approach is understandable in the point of view of administration and regulation bodies responsible for operating the regulatory systems and instruments.

All new legislation instruments are seeking for further limitation of polluting substances or greenhouse gasses. Impacts of the legislation instrument are different, but dominated by CO_2 costs as a main driver for future retrofits and refurbishments.

In the case of small emitters, it is not effective to apply sophisticated economic tools such as emission trading because of the administration and regulation barriers stemming from system architecture. However the polluter-pays principle should be valid no matter of scale of pollution volumes. Tax based tools could be seen as more appropriate for small scale emitters. To consider application of these tools, clear relation between impacts and products needs to be defined.

Carbon tax based tools could offer both aspects, manageable applicability to small scale polluters in terms of regulative and administrative burdens and clear fixed ratio between pollution and product. Thus future environmental legislation should take carbon tax tools into account as a complement of existing CO_2 price allocation mechanisms such as EU ETS.

12.5 Model summary

In the economic model I am simulating the impacts of the new EU ETS Directive, the Industrial Emissions Directive, the Medium Combustion Plants Directive, the Air Protection Act and the Water Act for the reference case of the Czech Republic. It was shown that new environmental legislation will cause strong effects on the future prices of heat and electricity generated in district heating plants. I discovered that there will be a significant increase in prices, especially as a consequence of implementation of new EU ETS modalities. As the main problem in this respect I identified the loss of competitiveness of large heat producers on the heat market caused by emerging stricter environmental legislation, which is not applicable to their competitors (smaller heat installations). There is also lack of clarity about the modalities of free allocation as well as about future development of the whole carbon market after 2020 (the future European allowance price).

As I presented in the figures above, future prices of heat generated in district heating plants under EU ETS and the IED will be heavily influenced mainly by the implementation of Directive 2009/29/EC, which introduces a new tool for free allowance allocation. Benchmarks, as they are referred to, are used for all EU ETS installations in the district heating sector regardless of fuel used for heat production. It is also very problematic to estimate the future EU allowance price. The European Investment Bank estimates the EUA price to reach 40 EUR in 2025, while Ministry of Environment uses price of 15 EUR and according to the carbon market data I expect the price around 8 EUR (the average EUA price with delivery next year). Besides, there remain many unclear modalities as regards free allocation of allowances after 2020. Implementation of the IED (new emission limits derived from BREF documents) could also cause additional significant distortion effects. I found that pollutant fees for air and water pollution discharge will not have major impacts on the energy prices as such but could be seen as one of the marginal reasons for fuel switch or plant closure.

I identified several ways through which the ultimate emission reduction target could be attained, which is formulated within legislation scenarios. However, the way forward could bring about “price shocks” in the case of strict application or a gradual price increase in the case of pragmatic approach to legislative tools.

Implementation of the new environmental legislation will lead to an increase in the energy prices of District heating plants. In the case of heat prices, there will be no direct impact on costs or revenues for these companies because of heat price construction (regulated by the Energy Regulatory Office). The most severe impact in this respect I see in the loss of competitiveness of heat producers in EU ETS. Customers in the Czech Republic do not care much about the environmental background of heat production; their main concern is the total price of heating. The main competitors on the heat market (local heat plants below EU ETS thresholds) are in a much better position in this respect. They are not influenced by EU ETS, the IED, pollution fees or the environmental tax (in the case of local boiler houses).

I confirmed that the new environmental legislation is deforming competition on the heat market. A new “carbon tax” for plants outside EU ETS needs to be established as soon as possible to take this issue into account.

12.6 Main contributions of the doctoral thesis

The main contribution of the doctoral thesis is based on a comprehensive analysis of the position of district heating installations on the heat market and its effectiveness as heating solution among other alternatives with modelling the effects of different emerging legislation tools on prices of the heat in the medium term period. As integral part of the work I built and tested an economic optimization model based on theory of differential NPV, the outputs of which assesses the impact on the price of energy from district heating utilities for reference case of the Czech Republic. Using this model gives clear results that there is an unequal treatment of polluters based on the size leading to competition distortion on the heat market with escalation in the future if no remedial tools will be established.

The original contribution of this work is also in detailed comparison of the effects of different legislation tools – emission limits, air and water pollution fees and EU ETS with a description of some problematic elements setting and the interactions, which could lead to weakening the overall economic and environmental efficiency of regulation. Within the doctoral thesis I demonstrated significant dominance of EU ETS among legislation instruments. However only heat utilities of certain size are subject to this legislation, this situation inevitably leads to distortion and unwanted effects towards other suboptimal alternatives, which needs to be avoided. Among possible remedial tools I have shown that indirect carbon taxation offers manageable solution how to include CO_2 costs into cost of production of smaller installations ensuring “polluter-pays” is secured.

The results of the doctoral thesis should serve as a methodology for the regulation of the environmental legislation tools affecting the heat market and their interconnections and for optimizing system-level efficiency in the development of Government policies in the energy sector (affecting heat market). Modelled outcomes of heat price impacts could be also used with the respect to the heat price development scenarios in the future and is then also well applicable in commercial sector.

12.7 Recommendations for further work

Taking into account the conclusions of this doctoral thesis the following topics can be formulated as recommendations for further analysis:

- Although presented economic model offers range of possible applications to different situations on the future heat market, further research could be done in the analysing situations of installations below 1 MW installed thermal input in terms of application of new Eco-design Regulation for new units. There is a possibility that a gap between provisions laid down by Medium Combustion Plants Directive (applicable from 1 MW installed thermal input) and Eco-design regulation will be created, which could lead to detrimental effects on the heat market towards giving the preference to solutions in this regulatory gap. There is also possibility to expand the model towards more fuel-switching scenarios (e.g. lignite to natural gas scenario). This would need more background information about necessary investment and operational costs implied by new production regimes.

- Analysing the impacts of indirect carbon taxation tool on the development of the heat market in the future in line with the analysis considering possible structural changes in the EU ETS with a view to strengthening the overall stability, predictability and effectiveness, and increase resistance to external influences with regard to the application of other instruments of climate and energy policy and decision-making in the energy sector.
- Expand the modelling to scenarios of future developments on the electricity market and the assessment of appropriate economic instruments that would lead to offset the distortion impacts of other EU legislation (Renewable Energy Directive, Energy Efficiency Directive etc.) and provide for incentives for investments in conventional energy sources, which are necessary to the safe and efficient operation of the energy systems. Assessment should also cover the economic implications, incl. calculation of costs and impacts on electricity prices for end users.

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14 List of candidate's works relating to the doctoral thesis

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Annexes

Annex I – Assessment of potential for an increase of energy effectiveness of district heating infrastructure

1. Step one – assessment of potential for energy savings in district heating systems
2. Step two – technical/economical costs of refurbishment or development of new infrastructure

Length of steam distribution network	Unit	Value	Data source/Note
Steam distribution in total	km	1,458	ERO data, licences August 2015
Steam without industrial consumption	km	1,129	Total without steam in industry
Steam for refurbishment	Share	0.8	Expert estimation

Method – From total length according to ERO valid licences are identified 90 most important areas (more than 96%) and steam in industry is subtracted (esp. chemical, iron and steel industry etc.). The rest is considered as theoretical potential for refurbishment.

Cost of refurbishment of steam to hot water grid	Unit	Value	Data source
Total refurbishment – open “green” area	mil. CZK/km	16.5 – 17	ADH CR Statistics
Total refurbishment – city area	mil. CZK/km	22 - 23	ADH CR Statistics
Total refurbishment – grid junction	th. CZK	235 – 240	ADH CR Statistics
Number of grid junctions per km		20	Expert estimation

Method – Total cost of refurbishment in “green” area (cheapest alternative) and city area (most expensive) alternative is considered including of costs of add-ons (grid junctions) based on real data from district heating industry. Real projects could consider higher share of city areas – total estimated costs around 27.2 mil. CZK/km.

Heat distribution losses	Unit	Value	Source
Average heat distribution losses in steam grids	GJ/m*year	7.35 – 9.80	ADH CR Statistics
Average heat distribution losses in hot-water grids (preinsulated pipes)	GJ/m*year	1.61 – 2.00	Products catalogue, ADH CR Statistics

Method – Refurbishment from steam to hot-water grid (conservative assumption of steam distribution losses at lower range). Hot water parameters: heating season/outside heating season – feeder line 110/80°C, return line 70/55°C, ambient ground temperature 10/15°C, preinsulated pipe losses (isolation class 2) 0.361 W/m*K, duration of heating season 240 days. Preinsulated pipe losses were checked with data from energy audits.

Results

Item	Unit	Value	Note
Steam distribution in total	km	903	calculation
Total costs for refurbishment of steam to hot water grid	mil. CZK/km	21.2 – 27.8	calculation
Total costs for refurbishment of all steam grids for reconstruction	bil. CZK	19.2 – 25.1	calculation
Average energy savings caused by refurbishment	GJ/m*year	5.74	calculation
Total energy savings if all steam grids for reconstruction would be refurbished	PJ/year	5.2	calculation

Annex II – Calculation of energy savings caused by CHP technology

Energy savings caused by CHP technology could be calculated based on EUROSTAT data concerning fuel consumption in CHP in comparison with fuel input for theoretical production of the same amount of energy in separate production processes (based on average efficiency mentioned in European Commission EU Reference Scenario 2016[87] concerning efficiency of electricity production).

	Fuel used for CHP [PJ]	CHP Heat production [PJ]	Fuel input for separate heat production [PJ]	CHP electricity generation, [PJ]	Fuel input for separate electricity production [PJ]	Total fuel input for separate production [PJ]	Total CHP savings compared to separate production [PJ]
EU-28	6,152.2	2,899.3	3,624.1	1,375.3	3,562.9	7,187.0	1,034.8
Belgium	167.3	27.1	33.9	45.6	118.2	152.1	-15.3
Bulgaria	72.2	40.4	50.4	13.4	34.8	85.2	13.0
Czech	251.4	120.9	151.1	43.1	111.6	262.7	11.3
Denmark	249.4	103.1	128.9	63.3	164.0	292.9	43.5
Germany	1,220.7	654.0	817.5	283.2	733.7	1,551.2	330.5
Estonia	20.9	12.6	15.7	4.4	11.5	27.2	6.3
Ireland	23.5	12.4	15.5	7.3	18.9	34.4	10.9
Greece	22.2	10.5	13.1	7.0	18.1	31.2	9.1
Spain	398.5	174.9	218.6	86.8	224.8	443.4	44.9
France	238.4	150.7	188.3	50.1	129.7	318.0	79.6
Croatia	24.0	13.3	16.6	6.1	15.8	32.4	8.4
Italy	839.6	212.8	266.0	132.0	341.9	607.9	-231.7
Cyprus	0.6	0.2	0.2	0.2	0.6	0.7	0.1
Latvia	24.9	11.3	14.1	8.6	22.2	36.3	11.4
Lithuania	25.3	15.3	19.2	6.0	15.5	34.7	9.4
Luxembourg	5.8	3.4	4.2	1.5	4.0	8.2	2.3
Hungary	50.5	27.0	33.7	14.0	36.2	69.9	19.4
Malta	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Netherlands	426.4	217.9	272.4	125.2	324.3	596.7	170.2
Austria	175.7	110.8	138.5	35.5	92.0	230.6	54.9
Poland	424.2	257.4	321.8	94.0	243.6	565.4	141.2
Portugal	119.4	68.4	85.5	25.7	66.7	152.1	32.7
Romania	103.6	57.9	72.4	23.8	61.6	134.1	30.5
Slovenia	19.4	10.8	13.5	4.1	10.7	24.3	4.9
Slovakia	292.3	27.8	34.7	79.9	207.0	241.7	-50.5
Finland	411.2	251.2	314.0	87.6	226.8	540.9	129.6
Sweden	267.3	165.1	206.3	56.1	145.4	351.7	84.4
UK	277.4	142.5	178.1	70.8	183.3	361.4	84.0

Note

Calculation based on average efficiency of separate electricity production 38.6% and heat production 80%. Negative total CHP savings in certain countries is caused by different real efficiency of separate production than used average.

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[87] European Commission, 2016: EU Reference Scenario 2016, Energy, Transport and GHG Emissions Trends to 2050, 15 July 2016

Annex III – Variable and fixed costs in heat generation and related effects

- Variable costs in heat generation are as follows:
    - fuel (coal, natural gas, heat oil, biomass, and others), including transport and environmental tax (where appropriate),
    - heat energy purchased,
    - electricity for operation of facilities purchased,
    - water for technology,
    - disposal of residues after incineration, ash, slag, etc.,
    - pollution fees,
    - European allowances purchased.
- Reduction in heat sales does not mean reduction in fixed costs. Fixed costs are as follows:
    - wages and statutory insurance,
    - repairs and maintenance,
    - depreciation,
    - lease,
    - statutory provisions,
    - manufacturing and administrative expenses.

- Lower heat sales increase the fixed cost share in the heat price and thus increase the heat price for customers. This causes new disconnections, thus escalating the price increase, so in the end the process could cause the whole district heating network to collapse.
- On the other hand, higher heat sales improve the economy of the district heating system and bring the heat price down. This is, however, seldom the case as new customers mostly stabilize heat sales. Gradual decrease in heat sales is caused mainly by thermal insulation of the buildings connected. Other factors impacting heat price is addressed in other parts of this doctoral thesis.

Annex IV – Harmonised efficiency reference values for separate production

Harmonised efficiency reference values for separate production of electricity (EU regulation no. 2015/2402)

Category		**Type of fuel**	**Year of construction**		
			Before 2012	**2012-2015**	**From 2016**
Solids	S1	Hard coal	44.2	44.2	44.2
	S2	Lignite	41.8	41.8	41.8
	S3	Peat	39	39	39
	S4	Dry biomass including wood	33	33	37
	S5	Other solid biomass	25	25	30
	S6	Municipal and industrial waste (non-renewable) and renewable/bio-degradable waste	25	25	25
Liquids	L7	Heavy fuel oil, gas/diesel oil, other oil products	44.2	44.2	44.2
	L8	Bio-liquids	44.2	44.2	44.2
	L9	Waste liquids	25	25	29
Gaseous	G10	Natural gas, LPG, LNG and biomethane	52.5	52.5	53
	G11	Refinery gases hydrogen and synthesis gas	44.2	44.2	44.2
	G12	Biogas	42	42	42
	G13	Coke oven gas, blast furnace gas, mining gas, and other recovered gases	35	35	35
Other	O14	Waste heat (including high temperature process exhaust gases, product from exothermic chemical reactions)			30
	O15	Nuclear			33
	O16	Solar thermal			30
	O17	Geothermal			19.5
	O18	Other fuels not mentioned above			30

Harmonised efficiency reference values for separate production of heat (EU regulation no. 2015/2402)

Category		**Type of fuel:**	**Year of construction**					
			Before 2016			**From 2016**		
			Hot water	**Steam**$^{(1)}$	**Direct use of exhaust gases**$^{(2)}$	**Hot water**	**Steam**$^{(1)}$	**Direct use of exhaust gases**$^{(2)}$
Solids	S1	Hard coal	88	83	80	88	83	80
	S2	Lignite	86	81	78	86	81	78
	S3	Peat	86	81	78	86	81	78
	S4	Dry biomass including wood	86	81	78	86	81	78
	S5	Other solid biomass	80	75	72	80	75	72
	S6	Municipal and industrial waste (non-renewable) and renewable/bio-degradable waste	80	75	72	80	75	72
Liquids	L7	Heavy fuel oil, gas/diesel oil, other oil products	89	84	81	85	80	77
	L8	Bio-liquids	89	84	81	85	80	77
	L9	Waste liquids	80	75	72	75	70	67
Gaseous	G10	Natural gas, LPG, LNG and biomethane	90	85	82	92	87	84
	G11	Refinery gases hydrogen and synthesis gas	89	84	81	90	85	82
	G12	Biogas	70	65	62	80	75	72
	G13	Coke oven gas, blast furnace gas, mining gas, and other recovered gases	80	75	72	80	75	72
Other	O14	Waste heat (including high temperature process exhaust gases, product from exothermic chemical reactions)	—	—	—	92	87	—
	O15	Nuclear	—	—	—	92	87	—
	O16	Solar thermal	—	—	—	92	87	—
	O17	Geothermal	—	—	—	92	87	—
	O18	Other fuels not mentioned above	—	—	—	92	87	—

Note

(1) If steam plants do not account for the condensate return in their calculation of CHP heat efficiencies, the steam efficiencies shown in the table above should be increased by 5 percentage points.

(2) Values for direct use of exhaust gases should be used if the temperature is 250 °C or higher.

Annex V – Annual Green Bonuses for electricity from cogeneration

All listed values are based on actual valid Price Decision of ERO.

Annual Green Bonus for electricity from cogeneration with a total installed capacity of cogeneration units up to 5 MW_e output (inclusive)

Supported energy	Date of commissioning		Installed output [kW]		Operating hours [h/year]	Green bonus [CZK/MWh]
	from	till	from	till		
CHP electricity with exception of installation producing electricity with support for renewable energy sources, secondary energy sources or waste-to-energy	-	31.12.2015	0	200	3,000	1,580
	-	31.12.2015	0	200	4,400	1,115
	-	31.12.2015	0	200	8,400	215
	-	31.12.2015	200	1,000	3,000	1,140
	-	31.12.2015	200	1,000	4,400	740
	-	31.12.2015	200	1,000	8,400	135
	-	31.12.2015	1,000	5,000	3,000	800
	-	31.12.2015	1,000	5,000	4,400	470
	-	31.12.2015	1,000	5,000	8,400	45
CHP electricity produced in installation with support for renewable energy sources, secondary energy sources or waste-to-energy	-	31.12.2015	0	5,000	8,400	45

Annual Green Bonus for electricity from cogeneration with a total installed capacity of cogeneration units from 5 MW_e output

Supported energy	Date of commissioning		Installed output [kW]		PES [%]		Efficiency of energy production [%]		Green bonus [CZK/MWh]
	from	till	from	till	from	till	from	till	
CHP electricity	-	31.12.2015	5,000	-	10	15	-	-	45
	-	31.12.2015	5,000	-	15	-	-	45	60
	-	31.12.2015	5,000	-	15	-	45	75	140
	-	31.12.2015	5,000	-	15	-	75	-	200
CHP electricity produced in new /refurbished installation	1.1.2013	31.12.2015	5,000	-	15	-	45	-	200

Annual Supplemental Green Bonus for electricity from cogeneration

Supported energy	**Date of commissioning**		**Installed output [kW]**		**Biomass category and process**	**Green bonus [CZK/MWh]**
	from	**till**	**from**	**till**		
Biomass only installation	1.1.2013	31.12.2013	0	5,000	O	100
	1.1.2014	31.12.2015	0	5,000	O	455
Installation firing biogas from biomass gasification (separately)	1.1.2013	31.12.2013	0	2,500	O	455
	1.1.2014	31.12.2015	0	2,500	O	755
Biogas installation	1.1.2013	31.12.2013	0	2,500	AF	455
Biogas installation$^{(1)}$	1.1.2014	31.12.2015	0	2,500	AF	900
New biogas installation	1.1.2014	31.12.2015	0	550	AF	900
Installation firing mine-gas	1.1.2013	31.12.2015	0	5,000	-	455
Electricity from Waste to energy or firing waste with other fuels	-	31.12.2012	0	5,000	-	155
Installation firing natural gas (separately)	-	31.12.2015	0	5,000	-	455

Note

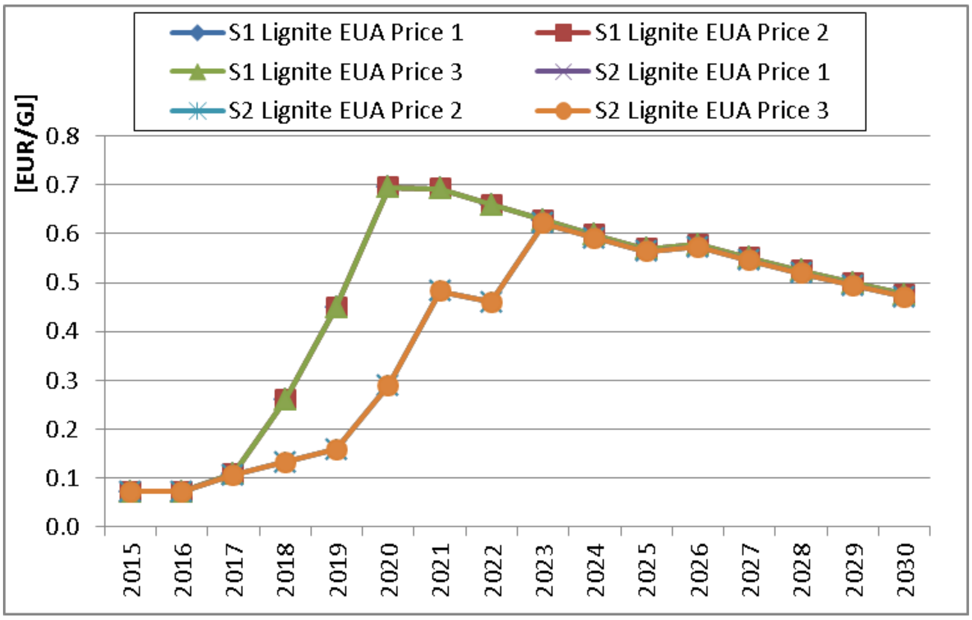
(1) Applicable only for additional unit increasing capacity of electricity generating plant. Maximum number of operating hours of support in a calendar year is fixed at 4,400 h / year.

Annex VI – Model outcomes for reference case

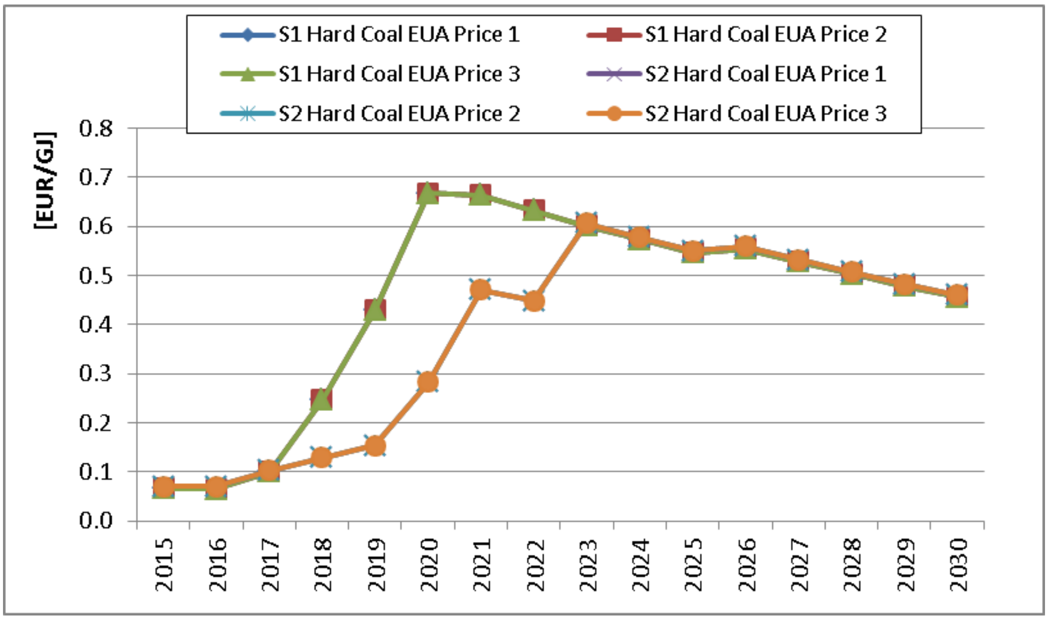
Model segment below 1 MW$_{th}$

There are no relevant development of legislation induced externalities for model segment below 1 MW thermal input for reference case.

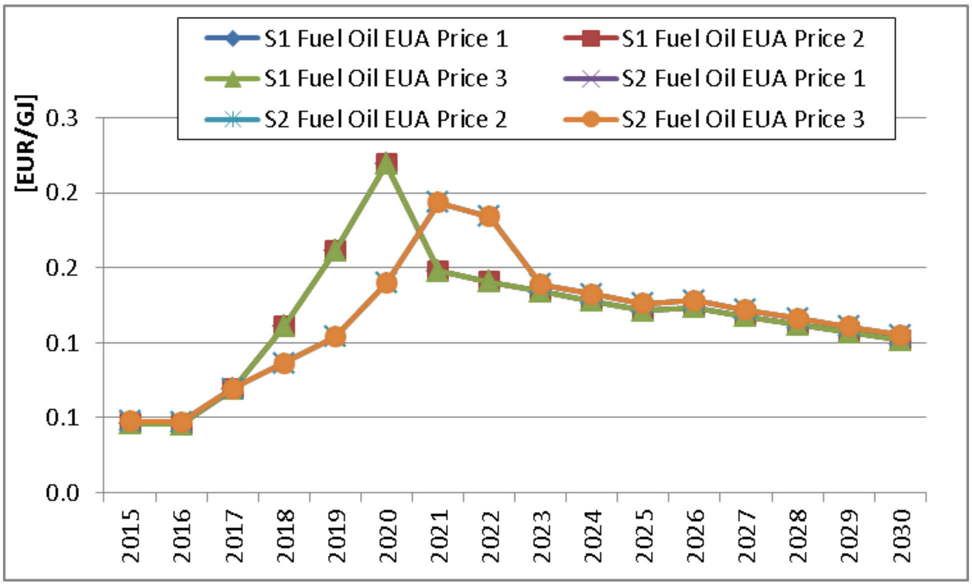
Model segment 1 to 20 MW$_{th}$



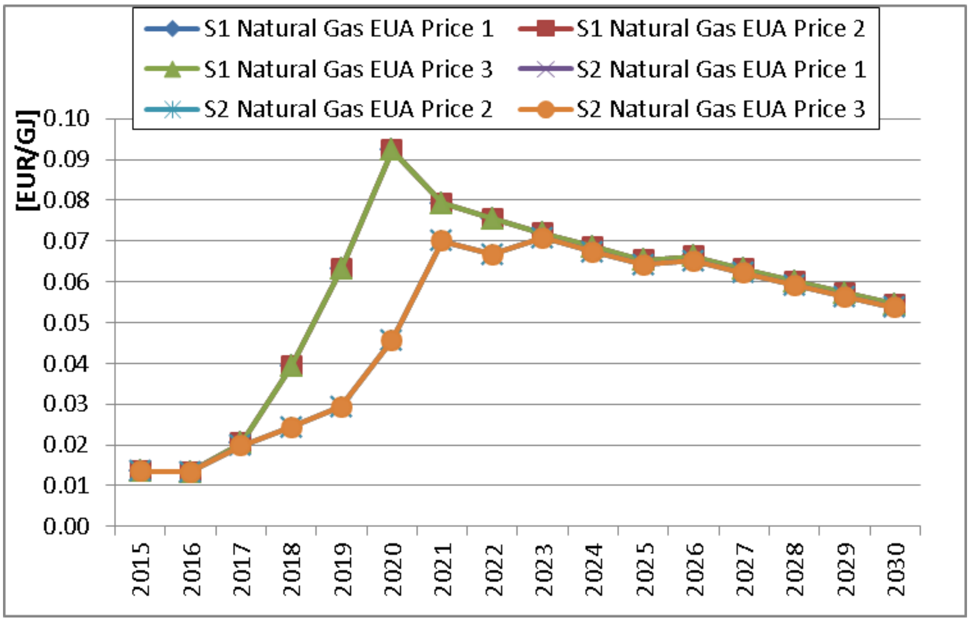
Model segment 1 to 20 MW$_{th}$ – development of externalities for lignite fired installation, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT



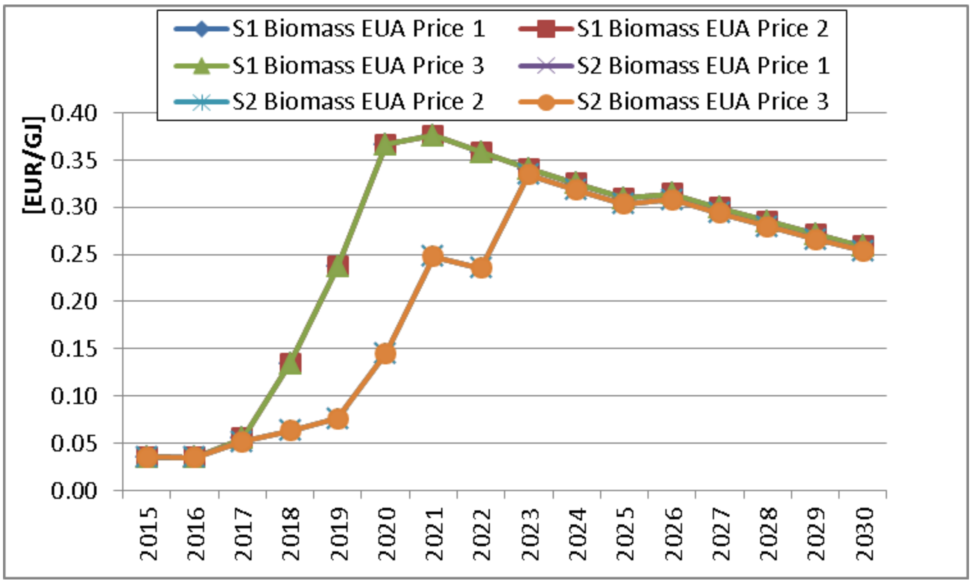
Model segment 1 to 20 MW$_{th}$ – development of externalities for hard coal fired installation, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT



Model segment 1 to 20 MW_{th} – development of externalities for fuels oil fired installation, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

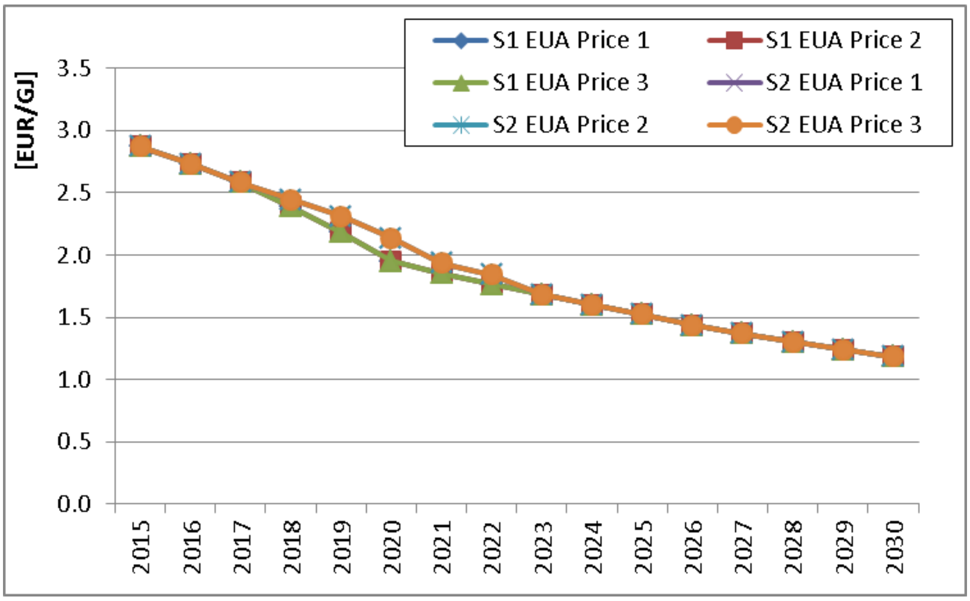


Model segment 1 to 20 MW_{th} – development of externalities for natural gas fired installation, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

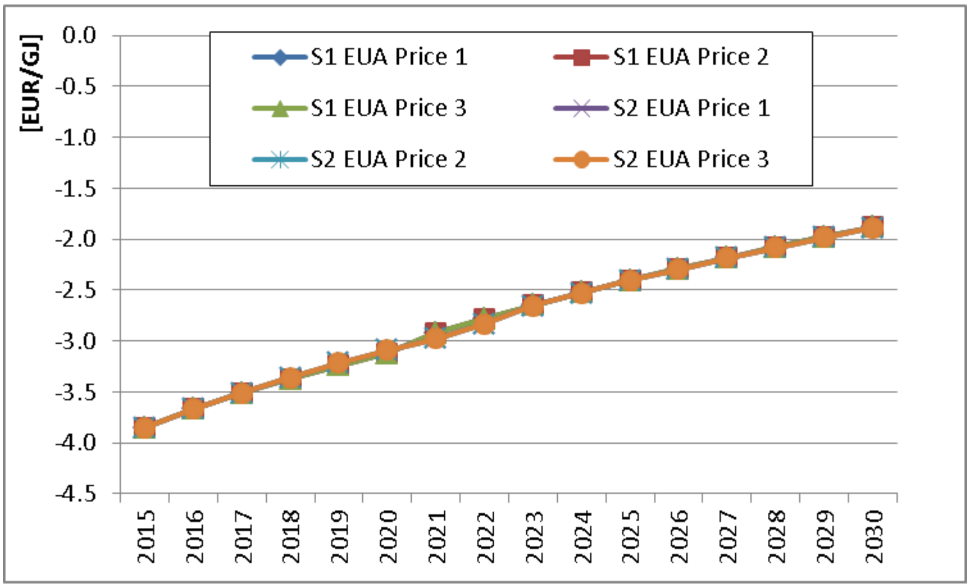


Model segment 1 to 20 MW_{th} – development of externalities for biomass fired installation, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

Model segment bellow 20 MW_{th} is not influenced by CO_2 costs, because EU ETS legislation applies only to installations above 20 MW installed thermal input. Increase in costs is thus driven by investments related to increase in environmental requirements and pollution fees.



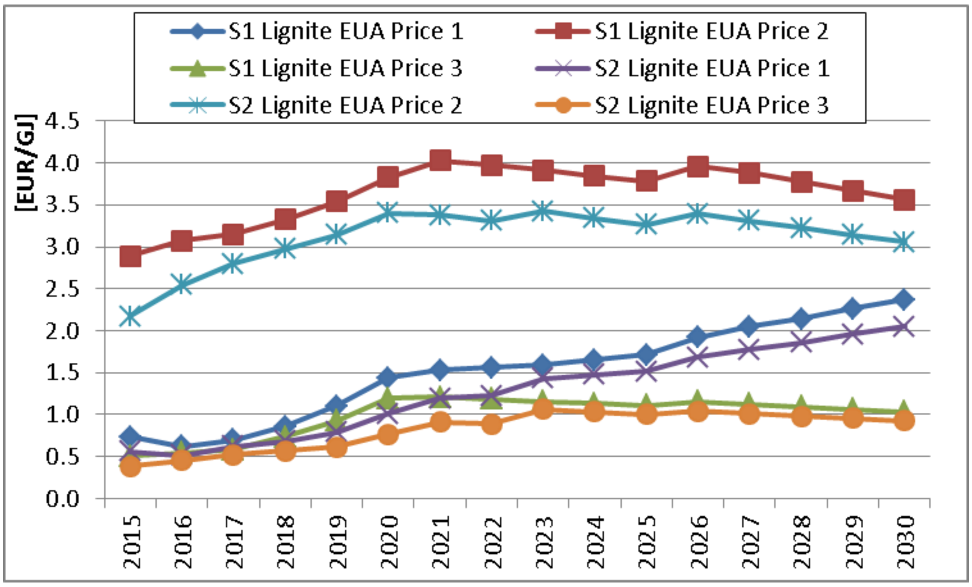
Model segment 1 to 20 MW_{th} – fuel switching from coal/lignite to biomass, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT



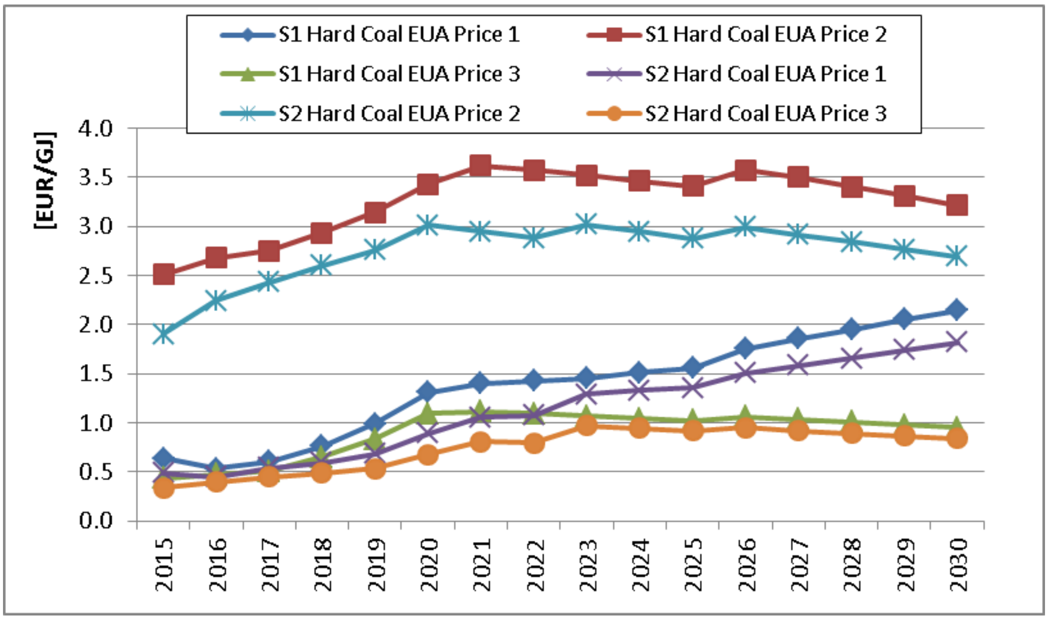
Model segment 1 to 20 MW_{th} – fuel switching from fuel oil to natural gas, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

Fuel switching from fuel oil to natural gas is highly positive for model segment 1 to 20 MW_{th}, mainly due to low prices of natural gas on the market. Fuel switching from coal/lignite to biomass could not be considered as beneficail for the entire duration of optimization period up to year 2030, even when the increase in environmental requirements takes place (mainly in emission limit values and pollution fees).

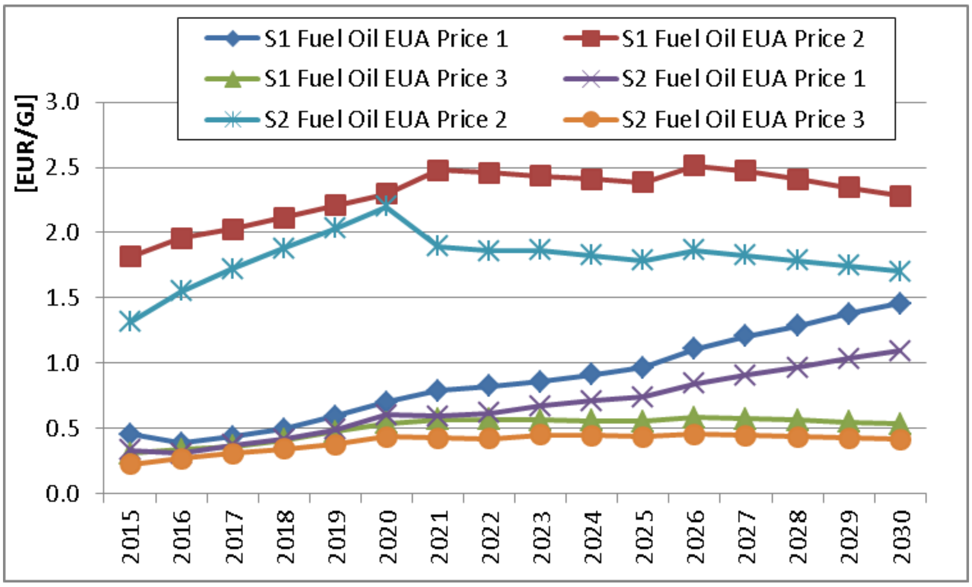
Model segment 20 to 50 MW_{th}



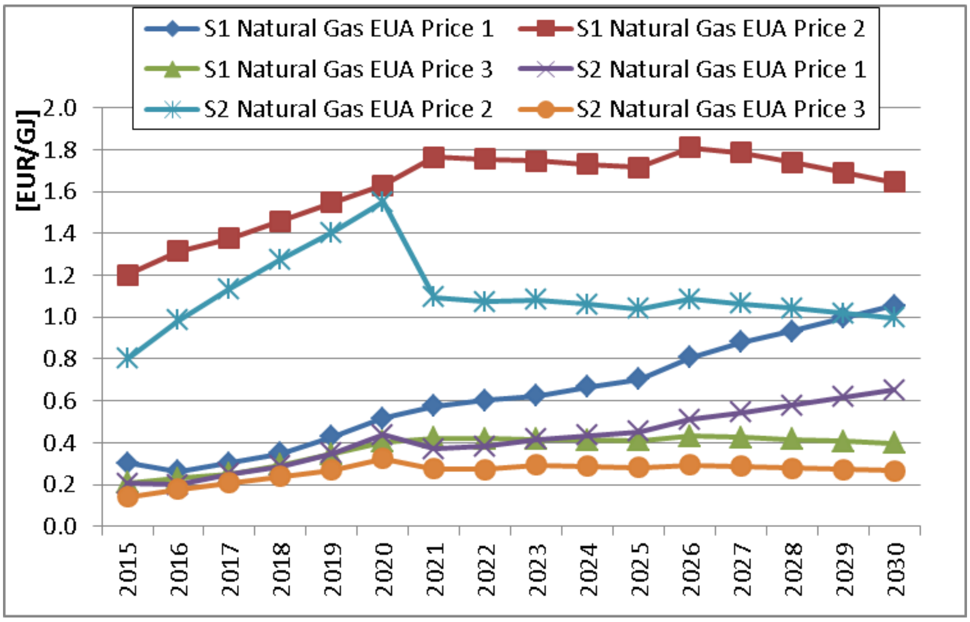
Model segment 20 to 50 MW_{th} – development of externalities for lignite fired installation, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT



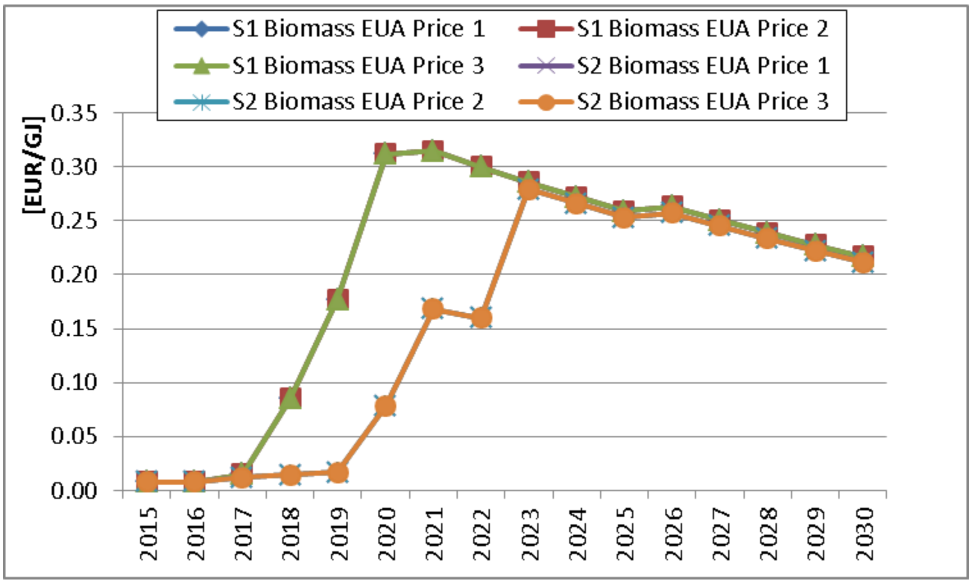
Model segment 20 to 50 MW_{th} – development of externalities for hard coal fired installation, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT



Model segment 20 to 50 MW_{th} – development of externalities for fuel oil fired installation, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

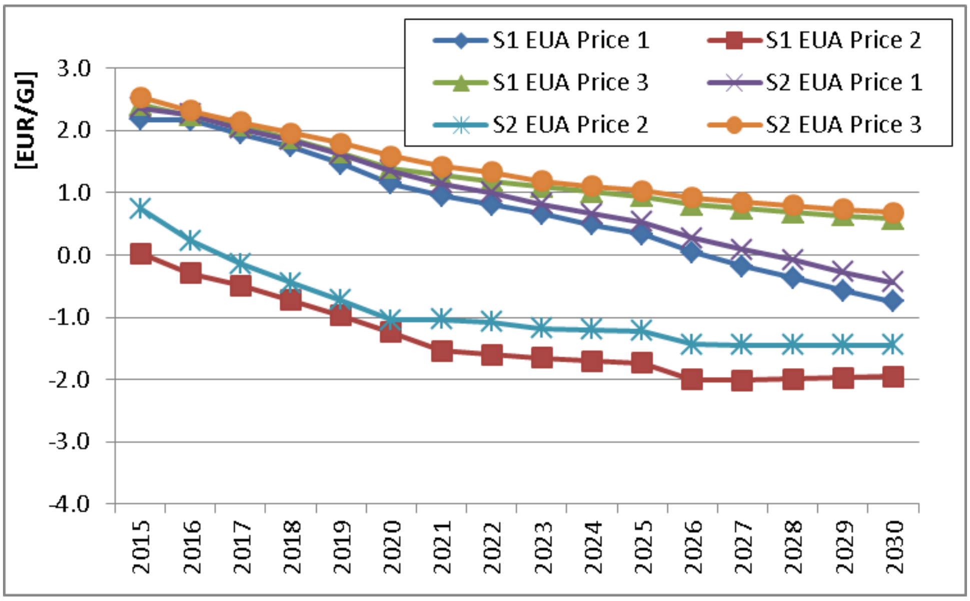


Model segment 20 to 50 MW_{th} – development of externalities for natural gas fired installation, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

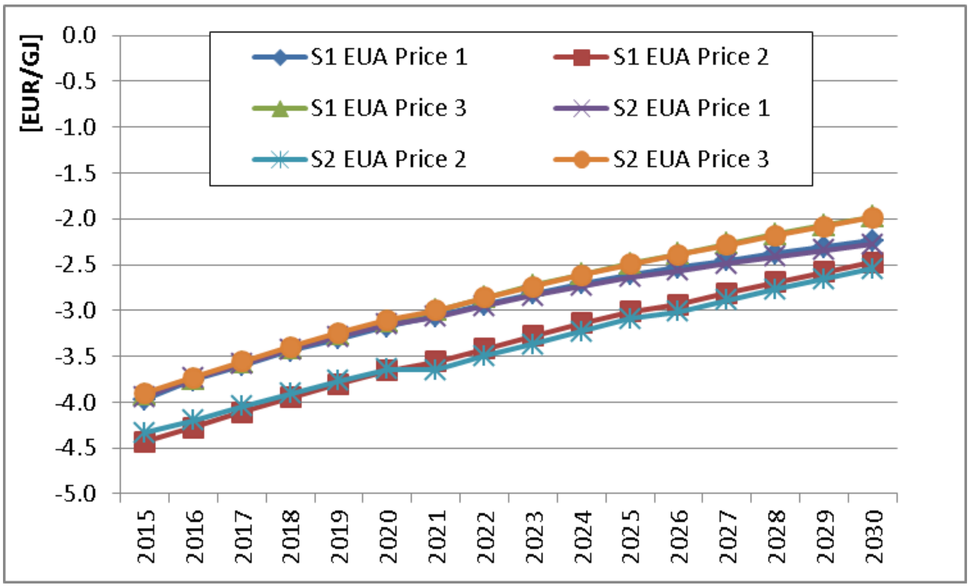


Model segment 20 to 50 MW_{th} – development of externalities for biomass fired installation, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

According to model outcomes for models egment 20 to 50 MW_{th} major impacts are pictured for lignite fired installations with highes CO_2 emissions per produced energy output. Biomass installation are not influenced by CO_2 costs thus suffer only from other externalities with minor impacts. There is significant difference between externalities of installations subject to EU ETS legislation and outside the scope of EU ETS, which has not any reasonable explanation in terms of different environmental impacts.



Model segment 20 to 50 MW_{th} – fuel switching from lignite to biomass, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT



Model segment 20 to 50 MW_{th} – fuel switching from fuel oil to natural gas, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

Fuel switching for this segment is again higly possitive for switching from fule oil to natural gas. In the case of switching from coal/lignite to biomass CO_2 costs creates stronger incentive for the change in the case of high CO_2 costs (such as the case of EIB future CO_2 prices).