**CZECH TECHNICAL UNIVERSITY IN PRAGUE**

# DOCTORAL THESIS STATEMENT

**Czech Technical University in Prague**

**Faculty of Electrical Engineering**

**Department of Economics, Management and Humanities**

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# MODELLING OF IMPACTS OF $CO_2$ AUCTIONS ON THE DISTRICT HEATING SECTOR

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# 1. CURRENT SITUATION OF THE STUDIED PROBLEM

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).

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.

DH 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[1], 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.

According to Ministry of Industry and Trade[2] 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 (see Table). Totally 54 PJ of heat was delivered to households, which corresponds to approx. 1,6 million of households (around 38 % of households in the Czech Republic).

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.

[1] Aalborg University, Halmstad University, PlanEnergi, 2012: *Heat Roadmap Europe 2050*, first pre-study, 2012
[2] 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

**Table 1.** Heat consumption in the Czech Republic in 2013 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** |

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[3]. Possibility to utilize low quality fuels, positive systemic grid effects, lowering energy dependency could be listed among other DH's effect.

Broadly used convention on calculation based on primary energy factors[4], which could be used for describing effectiveness of certain solution for covering energy needs, as well as concept of 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[5], rank district heating systems with employed combined heat and power technology as one of the most efficient way how to cover heat needs. District heating thus serves the public interest and deserves adequate protection against inadequate distortion effects.

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. 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[6] 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.

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).

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[3] According to calculation described in the doctoral thesis, CHP technology is currently saving in the EU-28 approx. 1035 PJ of primary energy (fuel input).

[4] 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

[5] 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 $_{sek}PM_{2.5}$).

[6] Dynamic Actor Network Analysis.

## 2. AIMS OF THE DOCTORAL THESIS

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.

With a view to fulfill the primary and partial objectives of the thesis and assess examined causalities, I applied quantifying models relating to the district heating (eg. assessment of the objectives of the legislation, analysis of the positions of stakeholders on heat market etc.).

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).

I set these following 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)
- Risk factors influencing heat market could be modeled by optimization model of differential NPV comparing situation business-as-usual and new circumstances.
- Among environmental measures $CO_2$ costs are main driver for future development and refurbishment of district heating industry, other environmental legislation has limited impacts.
- Indirect carbon taxation offers effective tool to address heat market distortions caused by future environmental legislation.

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). The 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.

## 3. WORKING METHODS

To achieve the main objectives of the thesis, four hypotheses in various areas are used to determine and 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.

As a first step I described the 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 $4^{th}$ 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.

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. 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.

Application of different legislation tools on installations is summarized in following table.

**Table 2.** 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 | YES(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.

In order to assess impact into heat price for modelled installation evaluation of incurred costs driven by effects on heat market needs to be done. 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.

Key aspect for general evaluation of investments is creation of excess financial resources (profit) for investors. These excess defined as overall economic efficiency (Net Present Value) as follows:

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

where:

| | |
|---|---|
| *L* | lifetime of the project |
| *DCFL* | 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.

I can calculate effectiveness of project under new circumstances caused by new legislation according to following formula:

$$NPV = \sum_{i=0}^{T_E} \frac{R_{Ex,i} - E_{Ex,i}}{(1+r)^i} \qquad (2)$$

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.

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:

$$I_{Total} = I_{CO2} + I_{ENV} + I_{PF} + I_{WF} + (I_{TAX} + I_{VAT}) \quad (3)$$

where:

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

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.

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

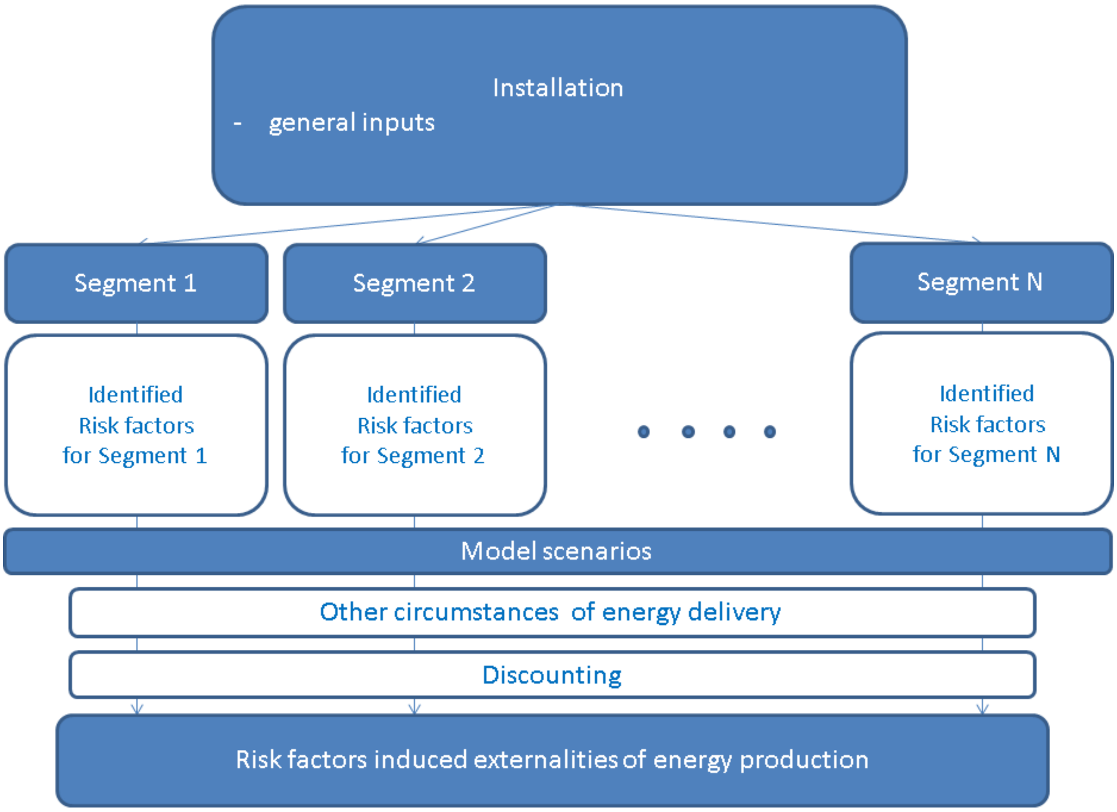


**Figure 1.** General structure of the model

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.

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 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.

## 4. RESULTS

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.

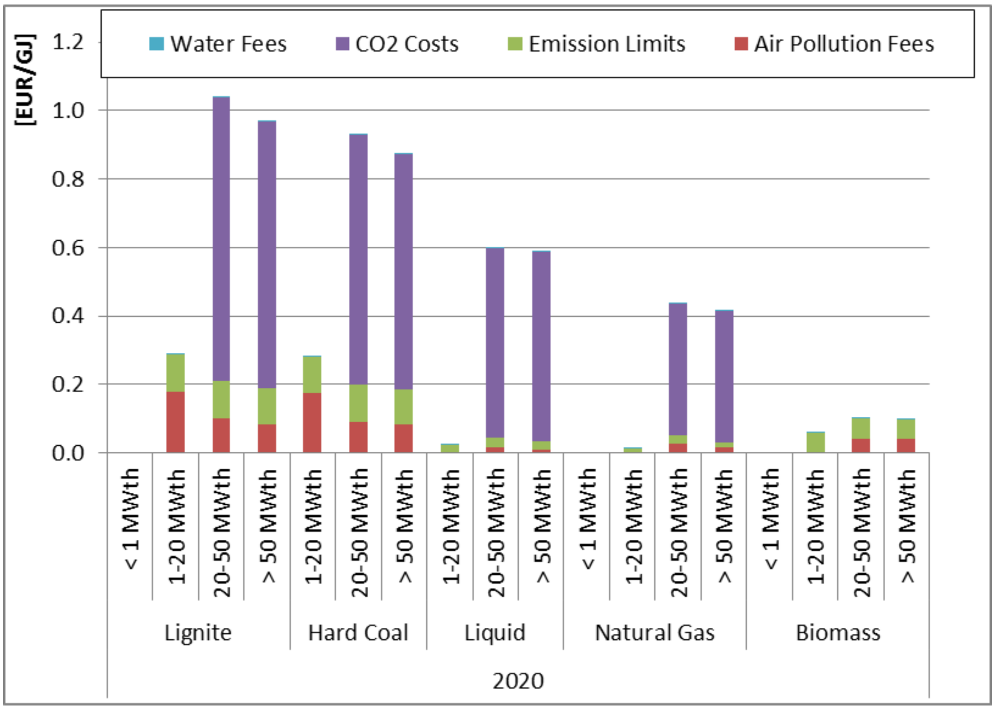


**Figure 2.** Comparison of risk factors in 2020 for Legislation Scenario 2 – Pragmatic implementation and $CO_2$ price Scenario 1, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

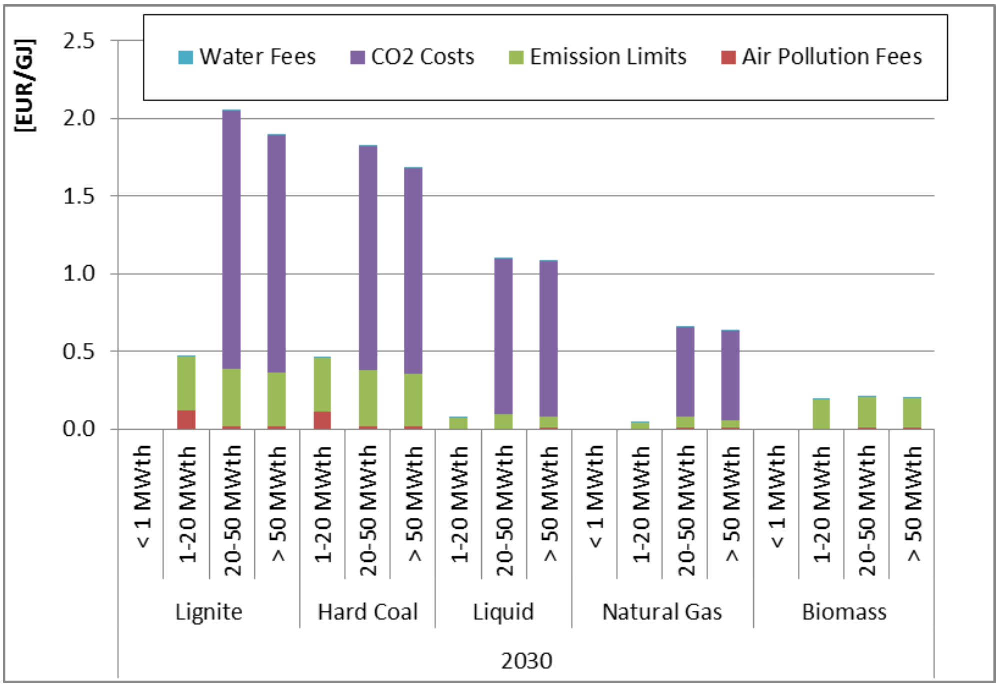


**Figure 2.** Comparison of risk factors in 2030 for Legislation Scenario 2 – Pragmatic implementation and $CO_2$ price Scenario 1, increase of costs per produced GJ of heat, optimization period 15 years, costs allocated to entire energy production, without VAT

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. In 2020 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.

### 4.1 Heat market for industrial consumers

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.

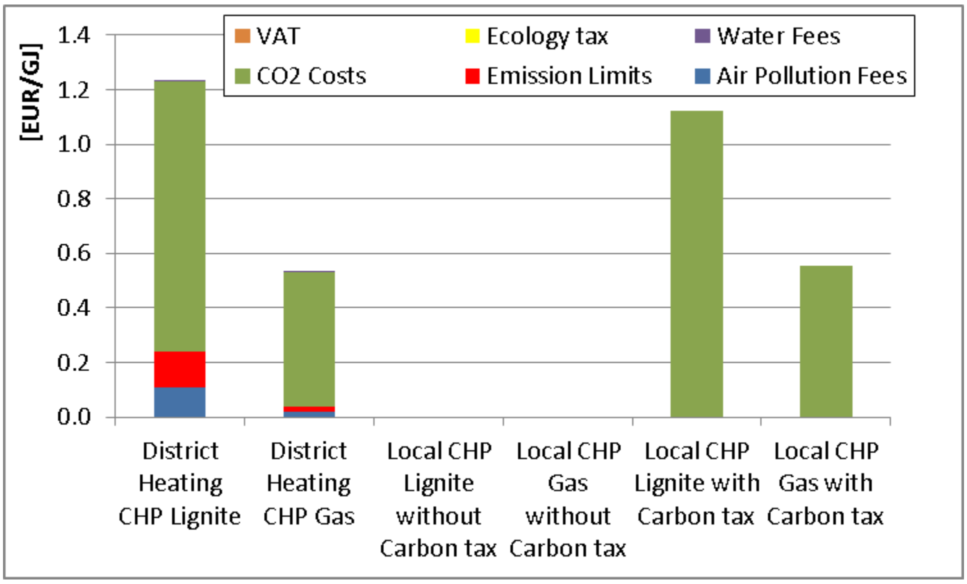


**Figure 4.** Comparison of externalities per produced GJ of heat for industrial consumers for District heating (Legislation Scenario 2, $CO_2$ price Scenario 1) and Local boilers in year 2020 with inclusion of carbon tax tool

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.

### 4.2 Heat market for households

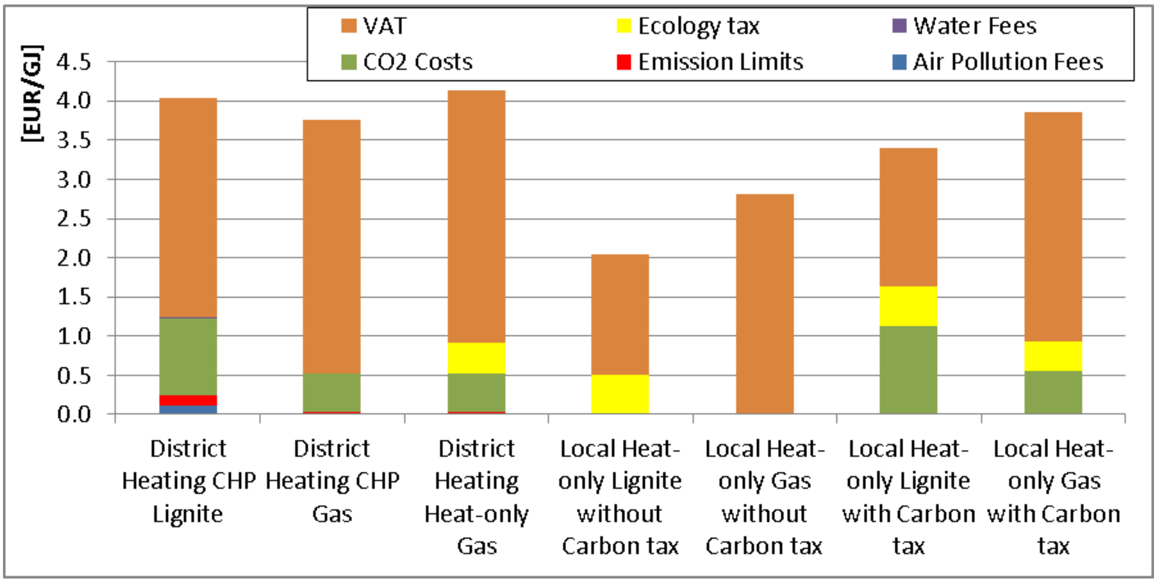


**Figure 5.** Comparison of externalities per produced GJ of heat for households for District heating (Legislation Scenario 2, $CO_2$ price Scenario 1) and Local boilers in year 2020 with inclusion of carbon tax tool including VAT and Ecology tax

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.

## 5. CONCLUSION

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.

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.

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**Response / No response and reviews**

**SUMMARY**

The 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.



**RÉSUMÉ**

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 CO2 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 CO2 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.