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Abstract: This paper addresses economic aspects of heat savings in the context of strategic heat planning. The analysis uses the city of Aalborg, Denmark, as a case where municipalisation through a recent acquisition of a coal-fired cogeneration of heat and power (CHP) plant has made an update of a municipal strategic energy plan necessary. Combining datasets on buildings and insulation techniques with economic methods, we investigate how the local district heating tariff can be adapted to improve the conditions for heat savings and support the transition to lower supply temperatures in line with the requirements of future fourth generation district heating systems. The paper concludes that implementing a fully variable heat tariff scheme improves the financial incentive for heat savings, while also making the system development less vulnerable to fluctuations and shortages in capital markets. The paper supplements existing literature on heat savings with novelty in its approach and in its systematic investigation of the interplay between tariff policies and interest rates.

Keywords: district heating; heat savings; strategic heat planning; economic optimisation; renewable energy

1. Introduction

In the ongoing international transition towards renewable energy systems, cities and local authorities play an important role [1,2]. Cities and local authorities, for instance, have a role to play particularly when it comes to heating, where planning procedures may give them the competence to set requirements for type of heating installation. Municipalities and local authorities may even take on a leading role as owners of district heating systems. This paper takes its point of departure in two international tendencies that are observed in the district heating sector. The first trend is the phasing out of (fossil fuel-based) cogeneration of heat and power (CHP) [3] and the second trend is the re-municipalisation of district heating systems [4–7].

The first trend challenges the viability of district heating systems since it undermines a traditional competitive stronghold; the utilisation of fossil fuels at high efficiencies. Facing this technological change in electricity production, district heating grids are risking being left as uncompetitive stranded assets. However, research addressing this issue has identified large potentials for district heating systems in a renewable energy system, the so-called fourth generation district heating (4GDH) system [8–10]. The strategic role of district heating in this vision—from which it may derive its future economic value—implies, among others, the ability to convert excess electricity from fluctuating renewables to heat at high efficiencies. Converted electricity may not only provide heat consumers with a cost-competitive supply but also provide a storage capacity to the energy system [11]. It also implies that district heating grids should be able to pick up waste heat from various sources including, e.g., industrial waste heat and waste heat from the production of electrofuels in the future [12].

The technical measures for establishing this strategic position is to lower the temperature in the district heating grids [13,14]. This increases efficiencies in heat pumps and CHP units, lowers heating grid losses, and makes more potential waste heat streams accessible for district heating. Additionally, investments in heat pumps and heat storage units at the utility level and investment in heat savings at a household level can be vital for district heating systems to remain competitive in the transition to a renewable energy system [15].

The second trend of re-municipalisation can increase the democratic and political power of cities and local communities, and therefore potentially open up possibilities for local 4GDH avenues. As municipalities are confronted with the task of strategic energy planning during the transition from fossil fuels to renewables [16–18], ownership of supply capacity increases the array of action possibilities to control the development for the common good.

In this paper, the city of Aalborg in Denmark is used as a case study. Aalborg municipality has recently acquired a coal-fired CHP plant that plays a central part in the city's district heating supply. This plant is planned to be decommissioned before 2030, thus, the city of Aalborg is facing the challenge of building up a new renewable supply system. Via the acquisition of this plant, the municipality has placed itself in a central role for shaping its future energy supply. This is contrary to the trend in earlier decades of privatising public infrastructure which in some cases has weakened cities' abilities for strategic heat planning [19,20]. For achieving the most efficient supply system, the investments in new supply capacity must be coordinated with investments in energy savings [21,22]. This requires a planning process that transcends the immediate incentives of traditional production companies.

There is now a considerable knowledge base on needed technical components and building modifications necessary for 4GDH [9]. A recent publication highlighted a need for research into the field of regulatory framework for the advancement of 4GDH [23]. In another recent publication, 100% variable district heating tariffs have been proposed [21]. Some studies are looking into the costs of preparing buildings for low-temperature district heating [24]. An earlier study finds that district heating tariffs can be decreased in a 4GDH system due to cheaper production technologies based on renewable energy [25]. It is, however, unclear to what extent these results can be transferred to district heating systems with high shares of CHP and (industrial) waste heat. In a related study, the authors conclude that low district heating tariffs is a barrier to energy efficiency investments and long-term investments in the district heating supply system [26]. In addition, this contribution shows that finding optimal levels of buildings' heat demand reduction also reduces the investments needed in a 4GDH system.

The relevance of the present case study goes beyond the case. A review of best practices of business models for lowering the return temperature highlights the tariffs as one of the key components [27]. However, the study does not have a direct focus on investments in the building envelope to achieve heat savings, nor does the study carry out any concrete analysis or quantifications of tariff models. The research into district heating tariffs has also been carried out outside Europe, where the problem of below-cost tariffs in China has been investigated, also addressing the question of energy efficiency [28].

Taking a point of departure in these studies, the aim of this paper is to investigate which local tariff policies can be applied to motivate building owners to invest in economically optimal heat savings. The term 'economic' includes costs for the whole heat supply system and building renovation costs and not only the private financial costs.

The study takes its point of departure in the existing tariff scheme in Aalborg district heating area. The paper analyses (a) the economic optimal level of heat savings, (b) the financial optimal level of heat savings for building owners given the current tariff design. It then (c) analyses the effect from a change in tariff policies on financial incentives for heat savings and (d) analyses how two different tariff designs—the current design and an alternative—will perform against fluctuations in capital markets.

The paper applies a marginal cost-based economic method. Based on the marginal cost of heat savings and the marginal cost of district heating supply, the economic optimal level of heat saving can be identified.

The paper further develops the analysis presented in an earlier study [29] and supplements recent literature and research on strategic energy planning in municipalities utilising the same municipal case [30–32]. It contributes to existing literature by quantifying the effect on heat savings from tariff policies using detailed data on buildings and a specific heat supply system. Compared to Nielsen et al., it provides novelty by looking at financial structures and investigating how these structures can be a barrier for the socioeconomic optimum identified in Nielsen et al. [30].

An earlier study investigates the cost components of district heating tariffs in Latvia but does not address how different tariff designs may affect heat savings through investment in the building envelope [33], while also another study addresses the question of benchmarking models in North-Eastern Europe [34].

A recent publication applies an approach that is very comparable to the present analysis [21]. Compared to Hvelplund et al., the present study brings novelty by investigating how tariffs policies can be an instrument in strategic local policies under influence of capital markets [21]. Further, while Hvelplund et al. quantifies on a national level for Denmark, this study takes advantage of the case study approach to apply more updated and detailed data.

The paper proceeds by first describing a theoretical framework for addressing the problem. Second, the building owners' financial incentive for heat savings is analysed and compared with the optimal level of heat savings using an economic approach. The analysis of financial incentives only includes monetary costs held by building owners. The economic approach includes the systems costs but does not quantify externalities. Third, the paper outlines policy proposals for aligning the financial incentives with the economic optimum at system level. Then, the paper examines how the use of district heating tariff policies makes the development in local heating systems less vulnerable to external conditions, such as fluctuations in capital markets, before presenting the overall conclusions of the research.

2. Materials and Methods

This section first describes a theoretical framework for analysing the problem. Second, the method and data used is outlined and described.

2.1. Theoretical Framework

The energy planning happening at a local level is carried out in the context of national and international transitions towards radical reductions in the use of fossil fuels for energy provision. The case study used in this paper is situated in a Danish context. In Denmark, there is a long-term policy of reaching a 100 percent renewable energy supply in 2050 [35,36]. Several scenarios for a 100 percent renewable system in 2050 have been developed previously at a macro scale. This paper takes point of departure in the scenarios made by the Danish Energy Agency and the scenarios developed by Danish universities in the research project CEESA as well as the IDA's Energy Vision 2050 strategy made for the Danish Society of Engineers by Aalborg University [37,38]. Common characteristics for the scenarios include very large wind power capacities, a minimised use of biomass, and large degrees of sector coupling in smart energy systems [39].

The consequence for the district heating sector of these national scenarios will be that CHP can no longer be the basis of district heating systems. So how should the district heating sector develop while still providing a system benefit when the national energy system changes towards the 2050 scenarios?

The 4GDH concept has addressed this question [3,8]. The technical solution is to lower distribution temperatures with forward/return temperatures reduced to around 55/40 °C. Lower distribution temperatures allows access to larger amounts of waste heat from industries, increases the efficiencies of renewable heat sources, and increases the coefficient of performance (COP) of large-scale heat pumps when converting renewable-based electricity to heat [9,40,41]. The third element makes it possible for the district heating sector to balance the fluctuations from wind and solar electricity generation and provide access to large-scale heat storage units [42,43].

In order to achieve lower temperatures, the district heating companies are dependent on coordination with investments by individual building owners. Investments in building renovation must be carried out to reduce the heat demand in individual buildings which then allows the district heating company to lower the supply temperature in the grid.

Since the district heating company owns the supply system but does not own the buildings, a vital part of the technical system is, in principle, out of managerial control [44].

The economic elements motivating building owners to invest in heat savings is assumed to be (1) the heat tariff and (2) the interest rate. This means that the district heating company does control part of the economic decision determinants for heat savings. The question is then: how can this control be used to optimise the efficiency of the system (a) in context of the technological transition and (b) in context of not being able to control—nor foresee—the development in the interest rates in the international capital markets?

The conditions for decision-making and economic optimisation in this context are very different from what is often assumed in neoclassical economics. Neoclassical economics is here defined by the assumptions of full information and no institutional hindrances for economic optimisation. These conditions also imply that prices do not deviate from real costs [45].

Contrary to the neoclassical standard assumptions, the current problem of economic optimisation is characterised by high degrees of uncertainty—that is, imperfect information.

The question of how to deal with this kind of uncertainty strategically has partly been addressed by Lund et al. [46]. This paper addresses the question of how to rationally use price projections when analysing future scenarios for the energy system and suggests designing systems that performs well under fluctuating and unpredictable price developments—as opposed to optimising against a fixed price projection.

Given that district heating companies do not control international capital markets—and thereby the interest rates that influences the incentive for heat savings in buildings locally—it is suggested that district heating companies also treat interest rates as a fundamentally uncertain variable. Given this uncertainty of a key economic condition of the system, the question is how this should and could be handled economically rationally. The neoclassical approach for rational optimisation does not suffice in this case, because the analytical condition of full information and certainty is not fulfilled.

Existing literature on renewable energy systems and district heating highlights the importance of a concrete institutional approach [47,48]. Further, it has been pointed out that understanding the dynamics between the concrete institutions and the technical change is pivotal for transitioning energy systems [3,49]. The importance of the technical understanding and analysis for planning and economic assessments has also been highlighted specifically in guidelines for strategic heat planning at all governmental levels [50,51].

To sum up, the theoretical approach to the problem must consist of several elements. The energy system will, in coming decades, be subject to a fundamental change where policies should seek to minimise the use of fuels of any kind and increase its capability to integrate the fluctuating renewable energy sources. In this systemic change, the district heating sector will fit in through lowering the distribution temperature in the grid which is enabled by heat savings in buildings. Therefore, strategic investments for the district heating system have to be carried out in places which are beyond the direct control of supply companies (see Figure 1). Applying an economic approach, the investment decisions by building owners are influences by the heat tariffs and interest rates. Interest rates is a variable in the investment costs for building owners while the heat tariffs are the major source for financial benefit from heat savings. Since interest rates are beyond the control of supply companies and local public agencies, the key economic policy instrument is the heat tariffs. The task of designing the optimal heat tariffs must consider the fundamental uncertainty characterising the development in capital markets. Further, the approach must be based on an analysis of the interaction between institutional and technical elements.

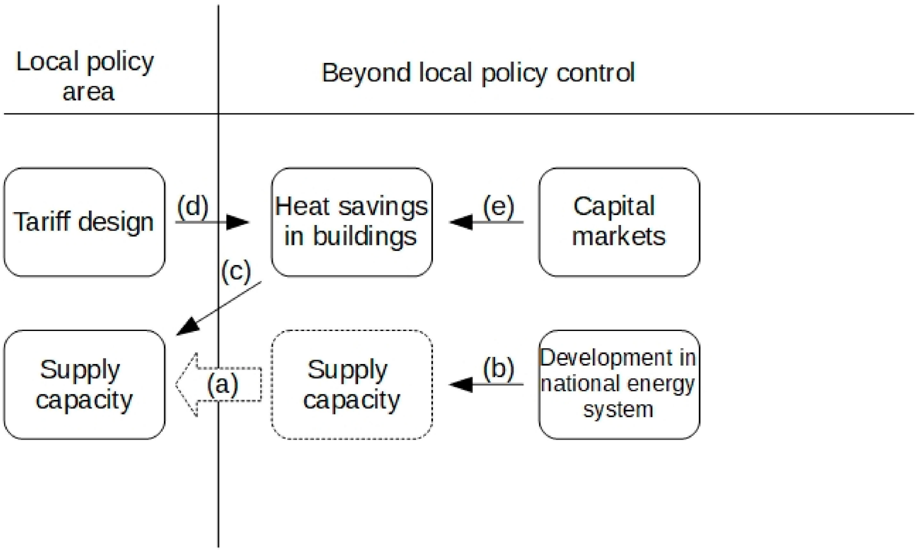

Figure 1. Key relations relevant for the local strategic heat policies. The municipalisation of exiting supply capacity (a), the influence of radical changes in the national energy system on the local supply system (b), the influence of heat savings in buildings on the supply capacity (c), and the influence from heat tariffs (d) and capital markets (e) on heat savings in buildings.

2.2. Methods and Data

In order to apply a concrete institutional approach, the analysis is based on a case study; Aalborg Municipality in Denmark. As explained in the introduction, the heat sector in the city of Aalborg is in a transitional phase from being based primarily on a large-scale coal-fired CHP plant to being part of a renewable energy system. Thus, the technical challenges described in the section above is present in Aalborg Municipality.

Two different cost datasets are applied. The first dataset is the economic costs of heat savings and the economic cost of heat supply. The other dataset consists of the financial costs for building owners of heat savings and heat supply, respectively.

The cost datasets on heat savings are derived from the same source data [52]. These costs are then annualised with different cost of capital, i.e. different interest rates. Applying an economic interest rate thus returns the economic costs of heat savings. Applying a financial interest rate returns the financial costs of heat savings. No other costs differences have been included for the heat savings.

The financial cost of supply is the marginal cost of heat consumption determined by the tariff scheme issued by the Aalborg district heating company.

2.3. Capital Costs

The economic cost of capital is defined to be 2 percent. Other analyses on renewable energy systems often apply an interest rate of 3 percent, e.g. [38]. However, this analysis is conducted in context of the Danish district heating sector where the energy supply side has access to interest rates for financing investments at the supply side. Thus, it is argued that the interest rates at this low level should be the regarded as the economic cost of capital.

The financial cost of capital is historically quite unstable. Figure 2 depicts the development of the average interest rate on bonds in Denmark from 1989-2012 (The source lacks data for 2013–2019). The effective interest rate for current 30 year loans is currently around 2 percent [53]. In the financial calculations, varying interest rates are applied as the financial cost of capital is highly dependent on the specific time and geographical location. Hence, it is of interest to examine how shifts in financial capital costs affect the incentives for heat savings.

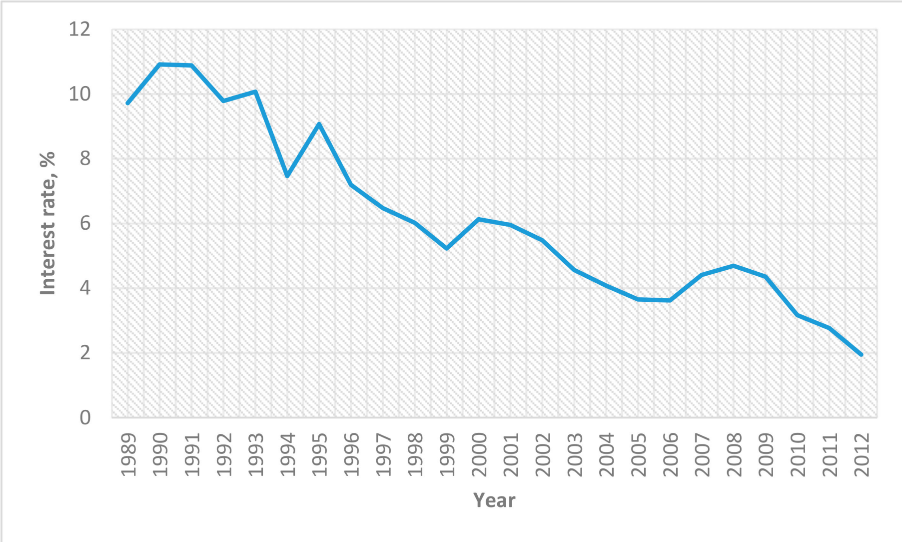

Figure 2. Interest rate on bonds in Denmark (Q1) [54].

2.4. Heat Savings Costs

The study applies default data on heat savings based on a study carried out by the Danish building research institute (SBI) [52]. This source defines seven steps of heat savings and estimates the energy savings effect of each step and the associated costs.

The dataset has a two-dimensional categorisation of buildings as a basis for estimating costs of heat savings, namely building type and construction year. Table 1 shows the different building types in the dataset and Table 2 shows the construction year categorisation.

Table 1. Building types in the dataset.

Building Types	*Farmhouse*	*Detached Single Family House*	*Terrace House*	*Multi-Storey*	*Service Sector*	*Institutions*

Table 2. Building construction year categorisation in dataset.

Construction Year Categories	*Pre 1850*	*1850–1930*	*1931–1950*	*1951–1960*	*1961–1972*	*1973–1978*	*1979–1998*	*1999–2006*	*Post 2007*

In the dataset, seven steps of building renovation initiatives are defined. Each building type in a construction year interval is associated with a cost for each step of building renovation.

Based on this dataset, the energy savings costs are annualised applying the standard equation for annualization. Based on the annualization, a building renovation cost curve is derived. For the present study, the focus is delimited to single family houses built between 1961 and 1972.

2.5. Supply Costs

For the heat supply, the study takes point of departure in the current tariff structure in Aalborg district heating. The current scheme consists of a subscription fee, a capacity payment using the floor area of the building as a proxy, and a heat consumption part varying with the volume of district heating water flowing through the building on a yearly basis. The tariff scheme in Aalborg is found in Table 3.

Table 3. District heating tariff scheme in Aalborg.

Tariff Scheme		
Subscription		
<50 m^2	625	DKK
>50 m^2	1250	DKK
Capacity	18.06	DKK/m^2
Consumption	18.06	DKK/m^3

2.6. Modelling Supply Costs for Individual Building

The existing tariff scheme is then reformulated into a fixed part (subscription fee + capacity payment) and variable part (consumption payment), meaning, the fixed part of the heat tariff does not vary with the households' heat consumption while the variable part does vary with households' heat consumption. This basic tariff structure of having a fixed part and a variable part is representative for district heating companies in general [21]. Further, the data is translated into a DKK/kWh format in order to ensure consistency with the heat savings cost data. For the conversion, a so-called 'standard house' in Danish heat planning is assumed. Data for this standard is given in Table 4.

Table 4. Characteristics of standard building.

Standard Building		
Floor area	130	m^2
Heat consumption	18.1	MWh/year
Heat consumption per m^2	139.2	kWh/m^2

Based on the technical assumptions presented in Table 5, a yearly heat bill for a standard house was computed and divided into a fixed and variable part, presented in Table 6 and Figure 3.

Table 5. Technical assumptions in district heating supply.

Parameter	
Supply temperature, °C	80
Return temperature, °C	40
Δt, °C	40
Energy content, J/K	4.18
Consumption, m^3/house	389.71

Table 6 estimates the heat bill for a standard household in Aalborg Municipality based on the current tariff structure and the technical assumptions above. Based on the assumptions, a variable heat price per kWh can be estimated at 0.39 DKK/kWh. The variable heat price is of interest since this is the heat cost that varies for the heat consumer when reducing heat demand, given the current heat tariff scheme.

Table 6. Modelled yearly heating bill for standard building.

Heating Bill		
Subscription	1250	DKK/year
Capacity	2348	DKK/year
Consumption	7038	DKK/year
Yearly payment	10,636	DKK/year
Variable tariff	0.39	DKK/kWh

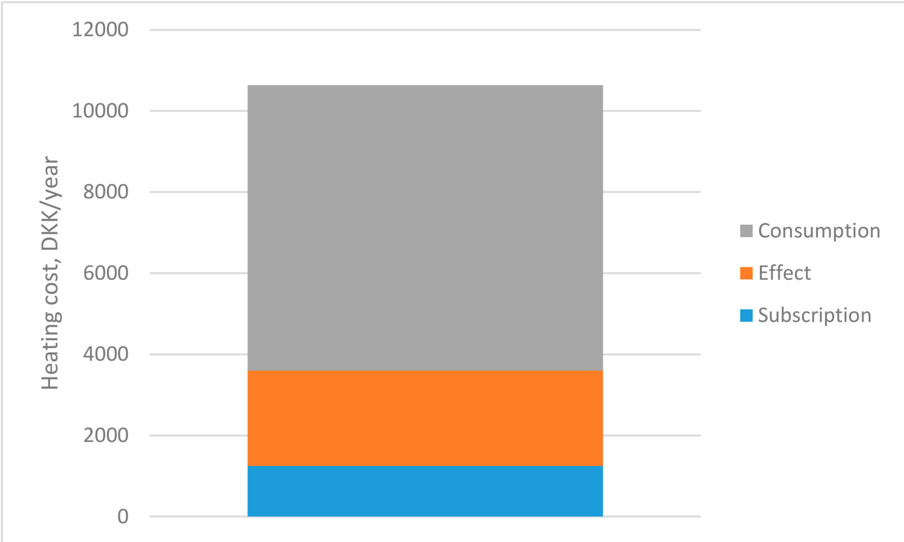

Figure 3. Distribution of yearly heating bill for standard building.

Figure 3 visualises the yearly costs on the heating bill for a standard building. About one third of the current heat bill is fixed and independent of the heat consumption. This means the building owners are not confronted with the long-term cost of increasing or decreasing heat bought from the district heating company while the building owners carries the full costs of investing in building renovations. In the context of balancing investments in energy supply and energy savings, it is therefore pertinent to discuss a reform of the tariff structure. The purpose of this reform should be to confront consumers with the full costs of consumption. When consumers are not confronted with the full costs of consumption on the margin, the tariff structure is effectively subsidising energy consumption through the consumption independent part of the heat bill. A tariff scheme signalling the full costs of supply to the consumer would have to be designed as 100 percent variable, meaning all long-term costs of supply is internalised in the variable price per kWh. Table 7 includes the variable tariff for the current scheme and the variable tariff if the scheme was reformed to be 100 percent variable.

Table 7. The current and an alternative tariff design.

Tariff Design	*Variable Tariff, DKK/kWh*
Current tariff design	0.39
100% variable tariff	0.59

3. Results

The analysis proceeds by addressing the following questions: (1) What is the optimal level of heat savings from an economic approach? (2) What is the private economic optimal level of heat savings? (3) How does a change in tariff scheme affect the private economic incentive for heat savings? This question in assessed with regards to different levels of private costs of capital. (4) Which recommendations for local tariff policies can be derived from the analysis?

3.1. The Economic Optimal Level of Heat Savings

The economic optimal level of heat savings is found at the intersection of the marginal savings costs and the supply costs. For the subcategory of single-family houses built between 1961–1972, the economically optimal level is illustrated in Figure 4. The intersection is found around 40 kWh/m^2, meaning that the current heat demand of around 140 kWh/m^2/year for a standard building should be reduced to around 100 kWh/ m^2/year.

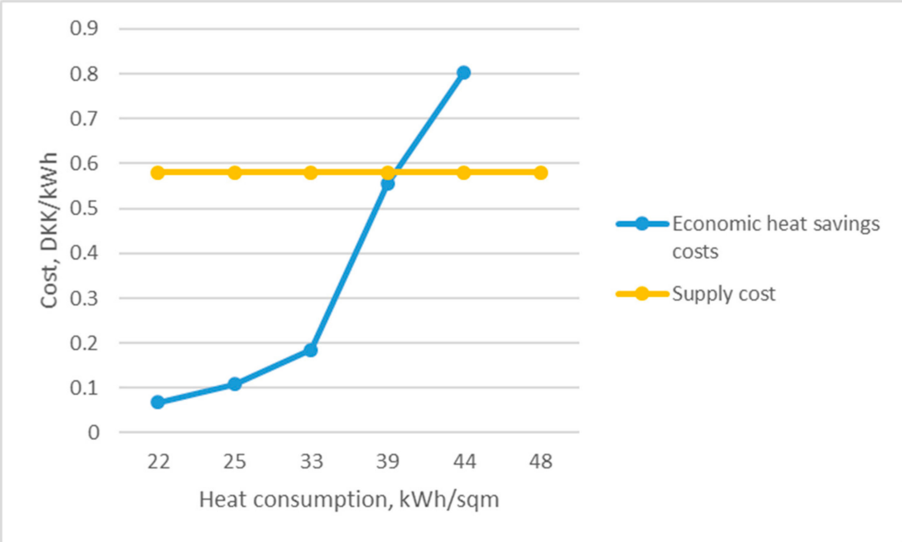

Figure 4. Economic optimal level of heat savings (Single-family house, 1961–1972).

3.2. The Private Economic Optimal Level of Heat Savings

The private economic optimal level of heat savings is found in the intersection between private marginal savings costs and the variable tariff curve. For the subcategory of single-family houses build between 1961–1972, the private economic optimal level is illustrated in Figures 5 and 6, varying the financial conditions for the household investments.

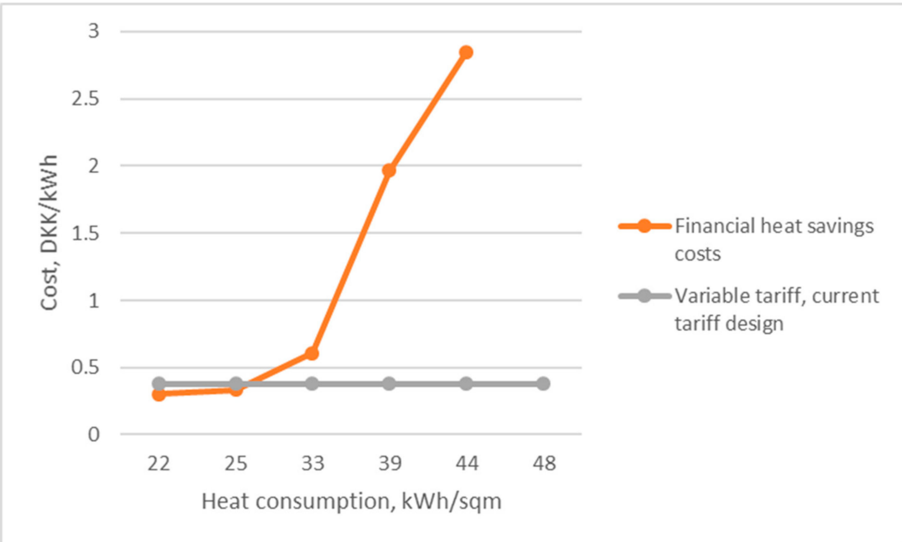

Figure 5. The financial optimum of heat savings for building owners given current tariff regime design and interest of 5 percent with 10-year lifetime.

The analysis shows that the private economic incentive for heat savings are sensitive to capital costs. In the extreme low interest rate periods, the private building owners are incentivised to almost double the heat savings in the building compared to periods with higher capital costs.

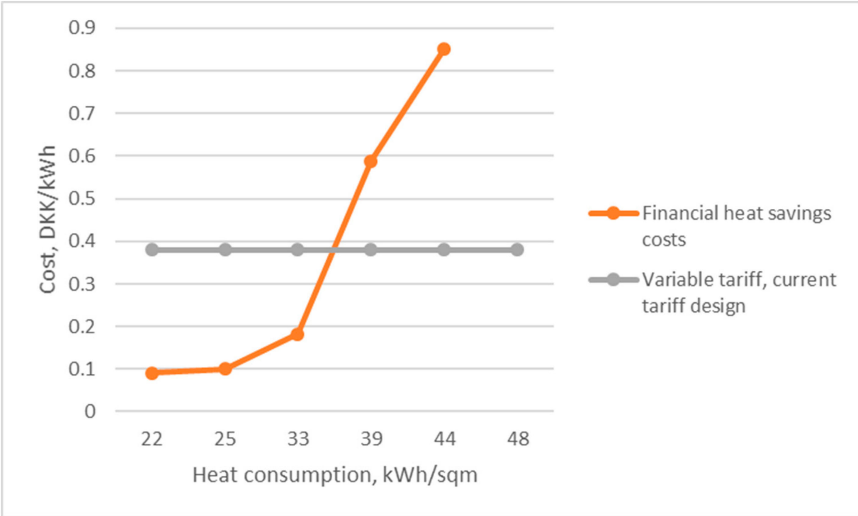

Figure 6. The financial optimum of heat savings for building owners given current tariff regime design and interest of 1 percent with 30-year lifetime.

3.3. The Effect of Change in Tariff Scheme on the Private Economic Incentive for Heat Savings

For the building type analysed in the settings of Aalborg District Heating, the current tariff scheme has an impeding effect on building refurbishment. Since the consumption dependent part of the heating bill, the variable tariff, has a lower price per kWh than the heat supply cost at company level, the tariff scheme stimulates higher heat consumption and lower investments in heat savings than what is economically optimal. The lack of economic incentive is further decreased due to higher capital costs for individual households than what is the economic capital costs for the system. Thus, in periods with high discrepancy between social and private capital costs, the below-cost variable tariffs increase the economic distortions to the system. A 100 percent variable tariff, reflecting the long-term supply costs, thus increases resilience towards the fluctuations in the capital markets.

Figure 7 shows the intersections between private economic cost curves and socioeconomic cost curves—with current heat tariffs and a situation of scarcity of financial capital. While the private economic optimum induces heat savings of about 25 kWh/m^2, the economic optimum is at a heat saving of around 40 kWh/m^2. Thus, private economic incentives are far from optimising the total system costs.

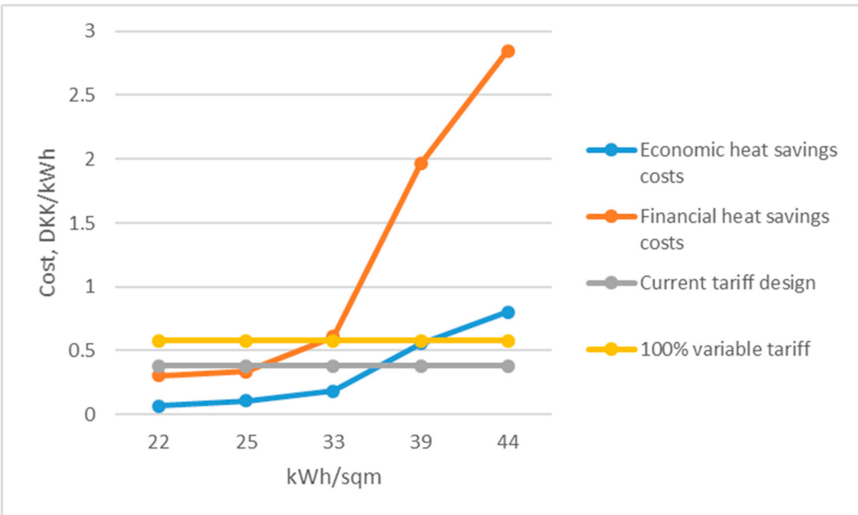

Figure 7. Economic and financial optimal levels of heat savings (Single-family, 1961–1972).

Taking a point of departure in Figure 1, interest rates are not within local policy control. As can be derived from the analysis above, interest rates have a major role in determining the economic incentives for building renovations and heat savings. It is therefore of relevance to examine the influence of interest rates under different heat tariff policies. Based on this, conclusions can be made on how this local uncertainty regarding internationalised capital markets should influence local decision making regarding economic optimisation.

Figure 8 depicts the variance of economic optimal levels of heat savings given variations in access to financial capital under the two alternative heat tariff designs. The conditions for access to capital varies in analysis from good to poor. 'Good access' is defined to be contracts where the lifetime of the loans is 30 years and the interest rate is 1 percent. 'Poor access' is defined as a 10-year loan contract with interest rate of 5 percent.

Figure 8 shows that the 100% variable tariff reduces the effect from fluctuations in access to capital on economic incentives for heat savings, compared to the exiting regime. With a fully variable tariff, the private economic optimal level of heat savings will vary between 33–39 kWh/m^2, depending on capital costs. With the existing tariff design, fluctuations in capital costs imply the economic incentivised heat savings vary from 25–36 kWh/m^2.

Hence, the analysis suggests that a 100% variable tariff is the most optimal and risk-minimising strategy for district heating companies in the transition towards a low temperature supply system.

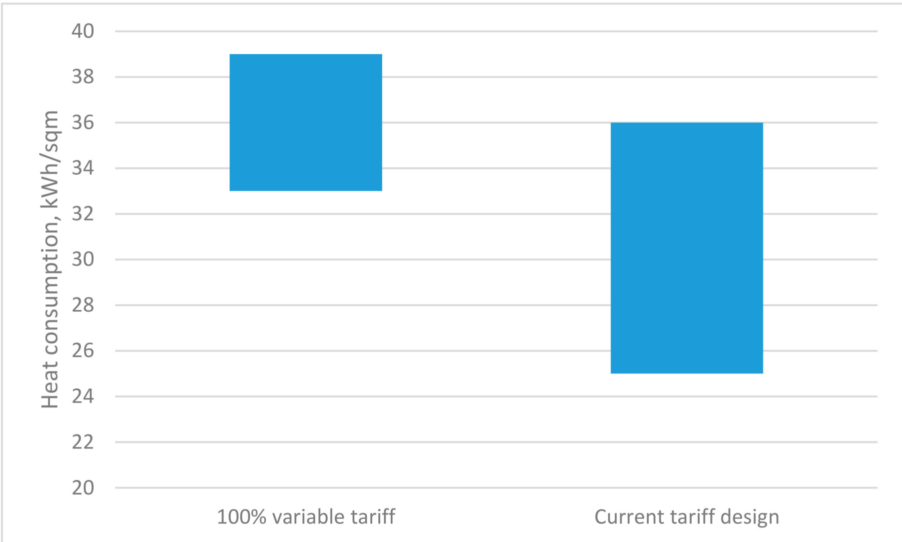

Figure 8. The financial optimal level of heat savings with varying capital costs.

3.4. Recommendations for Local Tariff Policies During Radical Technological Change

For achieving the economic optimal level of heat savings in buildings, two economic preconditions are necessary. (1) A reform in the tariff scheme where the consumption-dependent part is reflecting the full costs of heat supply. This can be achieved through a 100 percent variable heat tariff. (2) Policies that ensure access to the social economic capital costs for heat savings. This would ensure that the private economic costs of building refurbishment are equal to the social economic costs of heat savings. Financial arrangements based on long lifetimes and the social economic interest rates are key parameters.

4. Discussion

It is relevant to discuss the assumptions in the analysis and the perspectives from the results.

In the analysis, the modelling of supply costs is simplified to equalise the long-term average costs derived from the yearly heat bill for a standard building. This is a simplification and future work could investigate if a more detailed modelling of the supply system would influence the results.

A detailed modelling of the supply system would make it possible to derive a marginal heat supply cost dependent on the aggregate heat supply. For example, Nielsen et al. is applying EnergyPLAN to simulate the supply system in order to identify a supply cost curve [30]. A better understanding of marginal system supply costs, could also be the basis of investigating alternative variable heat tariff schemes.

Perhaps most importantly, an expanded and more refined modelling of the supply system could assess the results in context of different supply system scenarios. Such analysis would be highly relevant since the supply capacity will change during the transition from fossil fuels to renewables. So, for the specific supply systems an analysis comparing long term costs of fossil systems and the long-term costs of renewable systems should be carried out as part of the strategic tariff policy.

The applied economic approach is only addressing the heat savings costs and the district heating supply costs. Some non-valued externalities could possibly also influence the results. However, although externalities are not addressed directly, the overall approach in the analysis is based on a future renewable energy path. As such, the analysis does not ignore pertinent externalities like carbon dioxide emissions.

Finally, future research could investigate the conclusions in this paper by exploiting the full dataset on heat savings costs. The dataset incudes cost data for building categories which has not been investigated in this paper.

The paper presents an analysis only including monetary factors. Although these determinants play an import role, other social and psychological factors may influence how and when buildings are renovated. This also includes factors related to information and knowledge sharing. Thus, a coherent strategic heat policy would have to include a broader range of factors than only the financial variables investigated in this paper. The overall assumption in this paper is that the right financial conditions are necessary but not sufficient for achieving optimal levels of heat savings in the building stock.

5. Conclusions

The transition to renewable energy systems implies large investments in new renewable supply technologies. To achieve an economic optimal transition, these investments in new production capacity must be coordinated with investments in energy savings.

For the heating sector, the concept of fourth generation district heating has been developed to describe how district heating systems should be re-shaped to fit into smart energy systems where primary supply is based on renewable energy sources. The fourth generation district heating system involves investments both in new supply capacities but also investments in reduced heat demand in buildings.

The paper supplements existing literature with novelty in approach and results. The approach adds to state-of-the-art by combining a rather detailed building dataset with specific technical and economic data from a case study. The analysis is framed in perspective of a strategic heating policy at local level and also brings novelty in assessing the influence of capital markets.

The paper presents an economic analysis of the optimal level of heat savings in buildings which is subsequently used as basis for analysing the financial incentives for investing in heat savings. As a case, single family houses constructed between 1961–1972 were examined in context of the current district heating tariffs in the city of Aalborg.

The case demonstrates that the current tariff structure does not provide sufficient financial incentive for building owners to invest in heat savings compared to the economic optimum. Further, fluctuations in the capital markets is shown to be a potential barrier for the planning of an economic optimal system. However, a 100 percent variable heat tariff could increase the financial incentive for heat savings. In years of easy access to cheap capital for building owners, the financial incentives may be near-optimal under a 100 percent variable tariff. In periods with more fluctuations in interest rates, the 100 percent variable tariff may dampen the distortions to investments in heat savings.

The results should inspire strategic policies in local district heating supplies and municipalities. It is demonstrated that there are potential long-term benefits from making building owners pay the long-term costs of marginal supply through a 100 percent variable tariff. The 100 percent variable tariff is an enabler for achieving a lower distribution temperature in district heating systems since it incentivises a higher level of heat savings.

The study could be improved by a more detailed modelling of the supply side and of the impacts of heat demands on marginal supply costs. It is also relevant to extend and test the result by looking into other cases and building types. Further, it is of relevance for policy development to look into elements beyond financial parameters that may influence investment decisions concerning heat savings in buildings.

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