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Review of price regulation regimes for district heating

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ABSTRACT

Europe is facing a great technical and regulatory challenge in transitioning the energy supply from fossil fuels to sustainable renewables. Within the heating sector, the Heat Roadmap Europe studies have demonstrated great potential and benefits from expanding district heating (DH) throughout the continent. However, as a monopoly structure, DH grids require well-thought-out regulatory regimes to be accepted by cities and consumers. Effective regulation must safeguard consumers against misuse of monopoly prices and set the right incentives to enhance efficiency and to introduce new technologies. Founded upon the approach of concrete institutional economics, this paper contributes to the literature on DH regulation by reviewing and describing regulatory experiences in Denmark and other countries. This article demonstrates that a wide range of regulatory mechanisms are available for implementing DH and describes how regulation must take into account whether the DH companies are privately or publicly owned by municipalities or consumer groups. DH is typically a monopoly supply, which may result in higher consumer prices if proper regulation is not in place. Both privately and publicly owned DH supplies must be guided by various efficiency-enhancing measures. Regulated prices and the use of benchmarks must be carefully prepared in order to work by the book in an often-complicated organisational set-up. The use of private enterprises to develop and operate a public DH enterprise must involve the establishment of proper incentives and performance measures in the contract, etc. A mix of price-setting regimes and ownership models can be determined. The choice of model may depend on the specific circumstances, considering, among other concerns, the scale of the heat market, the local availability of waste heat, existing ownership of housing, access to (cheap) financing, a stable regulatory framework, and confidence-building measures for commercial or public investors.

Keywords

District heating;
Regulation of district heating;
Price regulation models;
Ownership and consumer prices;
Experiences with heat planning;
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1. Introduction

In the coming few decades, Europe is compelled to transition its energy systems towards a low- or zero-carbon supply. For this to happen, a key challenge is to achieve a substantial decrease in fossil fuel consumption in the heat sector. The thermal energy demand currently accounts for approximately 50% of final energy consumption in Europe [1].

Previous studies have demonstrated great economic and environmental potential in a wide expansion of DH systems across Europe [2]. The Heat Roadmap Europe studies suggest that DH systems should cover about half of the heat supply in 2050 [3].

Experience, however, has shown that a key barrier to establishing new DH systems in many countries are some institutional obstacles. Most notably, questions of ownership and price regimes are central questions to address, which have been dealt with at a theoretical level [4,5].

Previous research has focused on local policies [6], the effect of electricity and fuel prices on DH investments and dispatch strategies [7–12], and the effect of

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DH tariffs schemes on energy savings [13–15] and customer experiences [16]. Wissner looks into the general necessity of district heating regulation in Germany [17]. Sandberg et al. review DH regulation, but the study is limited to existing regimes in Nordic countries [18].

With respect to specifically addressing the price regulation models within district heating, there seems to be a gap in the literature. None of the existing contributions provide an overview in which a broader range of empirical observations are systematically reviewed and described.

This paper reviews and describes regulatory regimes regarding price regulation in district heating systems. First, seven different principles for regulating DH systems are described and reviewed. Afterwards, price regulation is set into a regulatory context, and seven mechanisms are described which surround price regulation in order to strengthen the development of efficient DH systems. Finally, main points are summarised in the conclusion.

2. Methodology

The methodological approach for this study is to describe and collect real-world experiences with price-setting regimes and bring them into the context of the academic literature. This approach is connected to a theoretical approach to concrete institutional economics [19]. This theory is based on the conception that theories within economics and public policy often do not address the real-world institutional structures that exist and shape economic activity. The approach is related to Ronald Coase's scientific paradigm of describing "the world of positive transaction cost" in order to inform and improve economic theories and practices within public policy [20–23]. In the context of this paradigm, the systematic description of the diversity of existing real-world institutions has an important role in enhancing the regulatory toolbox for addressing regulatory problems. The collection and description of institutional diversity contributes to theoretical understanding by conveying practical experience to the academic literature.

The following review is primarily based on lifelong experience in heat planning in the context of the Danish Energy Agency, combined with academic and theoretical reflections. Hence, in reviewing empirical regulatory regimes, the aim of the paper is also to describe and convey the informal and tacit knowledge gained through practice and set it into dialogue with academic literature.

3. Price regulation regimes in district heating systems

DH differs from electricity supply or natural gas supply in a significant way that warrants special regulation. The electricity sector can easily be made competitive, as individual producers can opt in or out as suppliers of electricity to a large grid, which can be interlinked on a regional or even national scale. Natural gas is also delivered by regional or national grids, although the supply is usually characterised by few suppliers. But DH is a locally bound supply of hot water or steam, where the heat loss often restricts large supply grids. Large DH grids can of course be established by cooperation between the heat producers, but DH is typically a natural monopoly with restricted competition.

Therefore, the choice of price regulation and investor security has a significant impact on the development of DH. This should be considered before the establishment of DH as part of a national policy framework. The use of market forces and regulation must be based on thorough and well-tested experiences in order to ensure a well-functioning DH sector with affordable consumer prices and continuous technological improvements.

Based on Danish and European experiences, the following seven main types of regulation principles will be described: 1) true costs, 2) true costs plus investor return, 3) prices set by the market, 4) substitution price, 5) price cap, 6) private operation under public ownership, and 7) an ESCO (Energy Service COmpany) model. Consumer prices may differ greatly according to ownership in at least two of the seven models, which will be elaborated upon.

3.1 True-cost principle

The true-cost principle implies that the consumer price equals all necessary costs of production and distribution. Thus, only necessary costs are allowed to be paid by the consumers. This price setting protects consumers against potential misuse of the natural monopoly supply, as the prices are largely non-profit. Denmark has adopted this mechanism for most of its DH supply. Prices and delivery conditions are supervised by national independent authorities.

The Danish experiences point to several advantages in terms of low prices and a high level of security of supply. However, the precondition is that each DH supply has been carefully designed and approved on the basis of a thorough feasibility study that documents that

DH is the least-cost option compared to alternative heat supplies. The calculation method applied is a levelised cost of energy, whereby low consumer prices over a 20-year period are obtained through investments in quality pipes, energy efficient plants, and well-insulated buildings. This standardised feasibility study must also be applied in the case of major renovations, investments in new technology, and revised/extended supply areas, and so on.

The reason for this is that the increased energy efficiency of a carefully designed and integrated energy system can bring about lower consumer prices in the medium to long term, as the saved energy more than outweighs solutions with low capital investment costs and also if fuel prices are cheap.

This regulatory set-up is not a guarantee of low consumer prices and efficient solutions at all DH plants, as local mismanagement can occur and cause discontent. A rule of thumb is that between 5 and 10% of the small DH supplies—often owned by the consumers—can improve their local management and obtain lower DH prices.

Nearly all DH supplies outside large cities as well as some in the big cities are owned by municipalities or consumer groups, which are usually not driven by a profit motive or the like. These DH supplies are typically financed by municipally guaranteed loans with low interest rates. The loans are not subsidised, and the credit scheme is non-profit and based on true costs.

The disadvantage can be that there is no direct economic incentive to lower consumer prices via investment in new technologies or other efficiency-enhancing measures.

However, specific means have been devised to enhance efficiency in publicly owned DH companies under the true-cost regime in order to obtain low consumer prices (described later). It is difficult to quantify the effect of these means, although incomplete international comparisons suggest that Danish DH prices are relatively low. Euroheat & Power has compiled relevant gross data for all EU member states [24]. However, an international comparison must be based on true costs, and no true cost analysis of the consumer prices are made, as these must be based on standardised prices, taking direct and indirect subsidies into account. Likewise, the countries' different energy taxes and fees must be adjusted for in order to compare the true costs. Furthermore, some countries have policies demanding co-production of power and heat at the DH plants in order to enhance the energy efficiency of the electricity production, while other countries have restricted the use of fossil fuels in order to promote renewable energy. The Danish Energy Agency has made preliminary attempts to adjust for some of these parameters, and the unpublished data suggest fairly low consumer prices in Denmark per delivered GJ district heat. The Danish District Heating Association has also made an attempt, and their analysis suggests that consumer prices in Sweden and Germany are 6% and 19% higher than in Denmark when the differences in taxes and fees have been adjusted for [25].

3.1.1 Requirements for special regulation of privately owned DH supply

The true-cost principle has the disadvantage that privately owned DH companies have an incentive to boost expenses, as high costs will also be covered by the consumers. The Danish regulation aims to prevent such behaviour by stipulating that all costs must be market conducive [26,27]. If a local DH company purchases fuel and services from a mother company, the prices must not be higher than the market price. Thus, transfer pricing must explicitly be prevented.

However, the Danish experiences with a large, transnational energy company show that the principle of non-profit costs can be circumvented, when daughter companies purchase equipment, fuel, and services from a mother company. There is no fixed definition of a so-called market-conducive price, i.e. some actors purchase fuel, equipment, and administrative services at relatively high prices, whereas others do so at relatively low prices. All decentralised heat plants were financed with loans obtained from the mother company at very high interests. Thus, by selective price setting, among others, at several combined heat and power plants, it proved possible to increase the local DH costs and thus consumer prices substantially from 2007 onwards. Some DH companies increased the consumer price by 40-60% in the course of roughly 4 years. The Danish Utility Regulator publishes the consumer prices for all DH companies at regular intervals [28]. If January 2009 is taken as the base period for comparison, the DH plants in Hjortekær, Gørløse, Skævinge, Ørslev Terslev, Annebjergparken, and in other locations have experienced significant increases in their consumer prices. All these plants are or were owned by the transnational energy company E.ON.

When owned by this transnational energy company, each DH company was organised as a daughter company

directly under the mother company of the transnational energy company. The consumer prices consequently rose considerably due to three factors:

1. Relatively high market prices for the purchase of fuel and administrative services, etc., from the mother company.
2. High costs for repayment of loans to the mother company. This was due to the unexpected use of a legal option; the mother company could charge consumers an amount for the repayment of loans that was higher than the actual loan expense.
3. A previous agreement on the consumer price that was entered into between the DH company and consumers was cancelled.

After consumer prices rose by roughly 50% over the course of 4 years, several municipalities decided to buy back the crisis-ridden DH supplies from the transnational energy company in 2013. This resulted in lower consumer prices at several DH companies, which is illustrated in Table 1 below.

The six DH companies still owned by the private transnational company experienced nearly unchanged or higher consumer prices during 2013.

The three DH companies that were transferred to local municipal or consumer ownership saw declining prices in the range of 4,591 DKK to 18,788 DKK over the course of one year for a standard household.

One of these (Slagslunde) is now owned by a consumer cooperative, which has lowered the price from 30,205 DKK in 2012 to 25,614 DKK in 2013 and to 17,278 DKK by 2016. Thus, several expenses have been notably reduced since the transfer of ownership. The transnational company reported and charged for a daily water loss of 2,000 litres, which has been brought down to 8–9 litres per day. The annual administrative costs declined from 1.3 M. DKK to 0.3 M. DKK. The annual interest on the capital investments was lowered from 7% to 2%. These cost reductions constitute important reasons behind the attainment of favourable consumer prices.

Most of the DH supplies owned by the transnational energy company by the end of 2013 were transferred to municipal ownership during 2014 and 2015. Significantly lower consumer prices were obtained for all DH supplies. This was possible due to a special municipality credit scheme in Denmark. A credit institution jointly owned by all municipalities was established in 1899 and has since offered financing for all municipalities' investments in infrastructure (energy, schools, roads, etc.). It operates on a non-profit basis and offers financing 2–3% less than normal commercial loans. The credit scheme has not had any bad loans during its more than 120 years of operation [29].

Thus, the true-cost principle may in general secure low consumer prices when the owner exhibits no interest in bypassing the intended regulation by using substantial legal and administrative resources. Thus, low consumer prices under a private ownership regime require:

- a carefully prepared and detailed regulation, which takes time to prepare and implement.
- access to a substantial amount of data from DH producers and distributors.
- efficient and independent authorities with sufficient legal authority and staff to monitor prices and delivery conditions and to handle complaints and investigate possible infringements, etc.

Table 1: DH consumer prices for DH companies owned or previously owned by the transnational energy company E.ON (Danish Kroner per year)

Name of DH company	DH price: 15 Dec. 2013	DH price: 18 Dec. 2012	Change in DH price	Change in ownership
Hjortekær	37,090	37,096	–6	No. Privately owned
Annebergparken	31,793	31,803	–10	No. Privately owned
Ørslev-Terslev Kraftvarmeforsyning	31,041	31,005	36	No. Privately owned
Slagslunde Kraftvarmeværk	25,614	30,205	–4.591	Yes. Consumer group buys DH supply
Præstø Fjernvarme	23,573	21,329	2.244	No. Privately owned
Lendemarke Varmeforsyning	18,971	13,151	5.820	No. Privately owned
Skævinge Fjernvarmeforsyning	17,178	27,901	–10.724	Yes. Municipality buys DH supply.
Frederikssund Kraftvarme	17,653	17,653	0	No. Privately owned
Gørløse Fjernvarme	16,338	35,125	–18.788	Yes. Municipality buys DH supply.

Consumer prices are listed for a typical house (130 m2, 18.1 MWh heat consumption). 1 Euro ~ 7.5 Danish Kroner.

The need for independent supervision and monitoring of prices at private DH companies is also acknowledged in, for example, Estonia. Most DH systems in Estonia are owned by private enterprises. In 2003, Estonia enacted the Law of District Heating, which provides local governments the right to establish central heating districts/DH zones and to require the private DH companies to supply these buildings with DH. The DH companies are ensured a supply period of up to 12 years; thus, a supply monopoly is granted. The consumer price is regulated by the Estonian Competition Authority, and in 2010 detailed principles for determining the upper limit of the consumer price in a district/zone were established. All prices related to heat supply must be approved by the Estonian Competition Authority in order both to protect consumers and to ensure that the DH company can recover its operating costs and earn a sufficient profit [30,31].

3.2 Regulated return to investor

Another way of setting the DH consumer price is to base the heat price on the true costs, as described above, but to allow for a higher loan cost. Thus, external investors can provide credit based on market conditionality.

This is typically the case for the use of waste heat from industries to DH in Denmark. In order to establish an economic incentive for companies which are not necessary a part of the DH supply a real interest rate of typically 8% can be added to the true cost for heat in terms of waste heat [32]. However, the negotiated price must not be higher than the alternative heat costs, and in the case of complaints, the price must be approved by independent authorities. Waste heat is usually cheap and efficient to use for DH; thus, the industries are given an economic incentive to sell their excess heat at a reasonable profit.

DH companies owned by municipalities and consumer groups can obtain relatively cheap loans granted by a joint municipality-owned credit institution that offers an interest rate of about 2–3% less than market-based credit institutions [33,34]. This is to the benefit of consumers at the DH plants owned by municipalities and cooperatives, but it limits the access of more commercial- and market-based actors in the DH sector.

It can be argued that fair earnings on commercial investments should be encouraged in order to achieve greater diversity in the ownership structure and access to large investment funds, especially among investors with an interest in stable, long-term investments, such as pension funds, etc. and those with a preference for secure and not necessarily high-earning investments. This can be considered in countries where there is no access or only limited access to cheap loans and financing.

One possible means to achieve fair earnings would be to introduce a market-based interest rate on the actual capital investments. A possible market-based interest level could be the interest of long-term bonds and maybe 2–3% per year for a 20-year period. The external investor would then have to adhere to a set of contractual obligations regarding corporate investment responsibility, etc.

The long-term interest of consumers can eventually be secured by:

- public ownership of the DH production company in which the external funds are invested with restricted or prescribed management according to carefully prepared management and decision-making structures.
- public ownership of the DH transmission and/or distribution net, which prevents external investor control of the entire DH supply; thus, the distribution company can choose another supplier in the case of unforeseen or undesired misuse of market power.
- essential endorsement of incentives to improve efficiency, as the true cost principle does not necessarily impose such pressure.

The disadvantage is that large investments from pension funds, etc. require carefully prepared projects based on detailed regulatory specifications for investment protection and possible shared management and so on. This is typically not compatible with smaller DH companies. When pension funds invest in wind farms, solar PV parks, etc., it is a more standardised set-up with easy-to-forecast rates of return. Small-scale DH supplies are much more heterogeneous with regard to choice of fuel mix, heat density, and specific local demand fluctuations from industries, among other aspects.

3.3 Liberalised price set by the market

Another option is to fully liberalise DH consumer prices, which can be set on a market driven by supply and demand. The theoretical advantage to this is that the market forces are in full swing to increase competition and lower costs. The disadvantage, however, is that DH is a natural monopoly, where market force can be exerted and misused against consumer interests. One such example is Sweden, where the heating sector was deregulated

and opened to competition in 1996 (with the exception of some municipalities which are forced to use cost pricing, i.e. true costs). The 2008 DH Act introduced negotiated prices and means to strengthen transparency in pricing. In a 2010 survey among 150 DH plants, 28% indicated that profit maximisation was their highest priority, while others prioritised issues such as municipal policy objectives and non-profit operation.

Due to limited competition on the heat production side, DH prices increased by 30% between 2006 and 2011. DH producers simply increased the price to a level close to the alternative heat price of individual heating [35]. The incidence of higher prices due to the privatisation of natural monopolies was also concluded in a report to the Swedish Ministry of Finance in 2011 [36].

Therefore, the Swedish government introduced new reforms in 2012 in order to strengthen a new price-setting scheme to the benefit of consumers. The Market Regulation Authority and the Swedish Competition Authority were granted the authority to supervise the price in the heat-supply market and to control the behaviour of the DH producers. A bargaining mechanism has been enforced, which requires the DH companies to submit their operation reports to the regulatory bodies and be committed to the provision of information [37].

The Swedish reforms also endorsed the privatisation of DH supplies. Eighty-three municipality-owned companies were privatised. In order to secure lower heat prizes, 21 of these 83 DH companies have been re-transferred to public ownership by the municipalities [38].

Thus, the Swedish experiences suggest that liberalised price setting of DH requires competitive and available heat alternatives for consumers. This is rarely the case in most places due to at least two reasons. First, heat customers in cities usually live in apartment blocks with limited access to individual heat devices, apart from costly or inefficient heat supply from air conditioners and the like. Second, suburban areas with individual housing often face exit costs if they choose to exit the DH supply and opt for individual heating. Many DH customers can only leave the DH supply if they pay off their share of the debt in the DH supply, after which a capital investment or entry cost payment shall be made to an individual heat technology.

Therefore, liberalised price setting often requires substantial regulation with access to multiple data delivered from the market actors if the price setting is to be transparent. It may take time to ensure effective capacity building of the independent authorities and to develop new procedures. These must be in place before liberalised price setting is implemented.

Denmark has in recent years introduced another variant of negotiated prices at the large combined heat and power plants around the big cities. In order to establish an incentive to convert from coal and maybe gas to alternative sources, a new incentive has been introduced. Danish energy taxes and fees on fossil fuels are among the highest in the OECD, but biomass is exempted from most of these taxes and fees. Therefore, there is a substantial financial incentive to use biomass as a fuel. However, most of these large-scale DH producers are commercially owned, and the owners will not receive the benefits from exempted taxes and fees. Only consumers will receive benefits in the form of lower prices, as consumer prices must reflect true costs. In order to give commercial owners a share of this economic benefit, the DH Act has been amended so that the benefit from exempted taxes and fees can be shared between the DH producer and consumers. Independent authorities must approve the price in the case of complaints, as the price cannot be higher than the alternative heat cost. This was endorsed for the substitution of coal with biomass by political agreement in parliament on 22 March 2012 [39]. This opened up the possibility for additional policies regarding regulated and controlled profit connected to the use of all types of renewables, and a broad political agreement in parliament o 29 June 2018 settled this pricing policy for all renewables [40].

Thus, a part of the DH price is officially negotiated for the group of 16 so-called centralised combined heat and power plants (CHPs), i.e. the largest CHPs and the earliest DH companies in Denmark which have a special regulation in parts of the Heat Supply Act. This arrangement has had a significant effect, as nearly all of the large-scale DH producers have converted or decided to convert to biomass-based DH before 2023. Denmark's largest utility Ørsted has decided to convert from coal to biomass by 2023 at the latest [41]. Only 1 of 16 centralised CHPs will not have converted to biomass by 2023—Nordjyllandsværket, which aims to use excess heat and renewables other than biomass, is expected to have phased out coal by 2028 at the latest [42].

There is as yet no analysis of how these partly negotiated prices affect consumer prices, i.e. if some costs are higher relative to the previous costs.

3.4 Natural gas-based substitution price of heat

Another way of regulating the DH price is to link the consumer price to the same level as heat produced in individual natural gas boilers. Thus, if DH is established, the heat cannot be sold for more than the heat price for individual natural gas. The advantage would be that DH cannot exert a potential misuse of a monopolistic supply to the detriment of consumers.

This price setting faces at least two disadvantages. Firstly, the (market) price for coal or biomass, etc. varies according to supply and demand of these particular fuels, and the prices are different from the (market) price of natural gas. If the production of, for example, straw has been limited due to a natural condition, the procurement price for straw will often increase due to a limited supply. If the DH company cannot cover its true costs, as the consumer price is linked to natural gas, then the DH company will face a deficit. If this occurs several years in a row, the DH company may accumulate a deficit, which will make the company unable to invest in operation and maintenance, which are crucial for long-term sustainability.

Alternatively, the state could subsidise DH by financing the gap between the actual DH production price and the substitution price of individual natural gas. This is a political option, but such an arrangement entails the risk of a continued financial burden on the state budget and consequently a lack of funds for other prioritised purposes.

Secondly, the price of individual natural gas can to some extent be influenced by the natural gas supply companies, which may be used strategically to limit the establishment of competition from DH using other fuels. For example, the natural gas company can lower the consumer procurement price on natural gas—and thereby the consumer price for DH—by extending the pay-off period of the loan granted to the gas distribution net. This may also be a strategic option if supply zones for individual natural gas were considered for conversion to DH zones.

Danish experience has shown that lower market prices for natural gas and extended periods for loan repayments, among others, have made natural gas heating more competitive vis-a-vis DH. In 2012, only 5.2% of all DH consumers paid more for their heating compared to heating from individual natural gas boilers. In 2013, the share had increased to 27.4% of DH consumers, partly due to longer periods for loan repayments as well as cheaper gas prices [43]. The case illustrates the difficulties in linking the DH price to natural gas heating.

Thus, it is not an easy task to establish transparent and justifiable benchmarks or substitution prices for DH. It requires careful preparation and a continuous difficult administrative supervision and monitoring. This regulatory approach has been considered in some countries, but has only been implemented few places. But the substitution price of natural gas is used as a benchmark when choosing between DH and natural gas for heat zones in Denmark.

3.5 Price cap based on alternative supplies

Another way of regulating the DH price is to regulate the price according to the heat price of the alternative DH supply. This can be applied to DH produced from waste or excess heat from industries, etc., which is sold to a DH supply company.

Denmark has applied a price cap for DH produced from waste incineration as a special price setting for only this type of DH. The price cap for DH from waste incineration plants is set by the price for DH from the largest combined heat and power plants in Denmark [26]. The advantage of this system is that the DH supply companies/consumers are guaranteed a price that equals the price of the large-scale heat supply, and waste incinerations plants do not favour or disfavour local consumers economically.

However, a price cap may have a disadvantage in that it contains an incentive to set the DH price as the maximum allowed price. There is not necessarily an economic incentive to lower the price via increased efficiency, etc. for the waste incineration plant.

Another disadvantage—which is not the case in Denmark—is that the true costs may not be covered if the price of waste is relatively high. This could threaten the long-term economic sustainability. Alternatively, as mentioned above, the state could subsidise DH by financing the gap between the actual DH production price and the substitution price of individual natural gas, which may place a continued financial burden on the state budget.

3.6 Private operation under public ownership

Local governments may own a DH supply without operating it. This sort of public-private partnership (PPP) can be a relevant option if a municipality or the like lacks experience in proper operation and maintenance, does not possess experience in efficient business development,

or if the legal framework for public management is insufficient.

The private operation may be temporary or permanent. If the purpose is to promote a relatively quick development of DH, the contract can stipulate that the operation can be transferred to a public entity after, for example, 10 years with training of public staff during the last 3 years, for example.

Thus, the responsibility of the DH operation and related new investments are transferred to private enterprises through lease or authorisation contracts, in which the investments, management, and operation risks incurred from all facilities are transferred to private enterprises.

Joint finance can also take place; for example, the local government can contribute with equity in the form of transfer of assets or land.

The United Kingdom and other countries in Europe, plus China and other Asian countries, have developed this model for DH [44,45]. A variety of specific models has evolved in different countries [46]. Typical business models are reconstruction-operation-transfer (ROT) and transfer-operation-transfer (TOT). During the construction period, the private enterprise is typically tasked with project investment and financing, design, and construction. During the operation period, the private enterprise is responsible for the operation, maintenance, and the use of collected fees, and maybe a subsidy to cover construction and operating costs. When the operation period expires, all facilities are transferred to the local government. A building-operation model (BO) has also been developed for private operation under public ownership, which means the heating infrastructure is invested in and constructed by private enterprises. The company can also transfer the ownership, so the local government will own this infrastructure after the contract expiration. That is the case in the so-called building-operation-transfer model (BOT).

Thus, China has implemented a concession operation system for management of the DH supply in most of its towns and cities. The heating enterprises sign a contract with the local government through public bidding, after which the heating company participates in the construction, operation, and renovation of the plant and the heat distribution net. In short, the heating companies are given monopolies in heat production and distribution with integrated operation management. The heating price and other conditions are set up by the municipal departments and must be submitted to the provincial price authorities for approval.

The advantage of this system is that private management expertise can be used to improve the efficiency and service quality under a market regime. The disadvantage is that private enterprises take fewer risks, and the rate of return is typically fairly low; thus, the incentive to adopt long-term efficiency-enhancing measures may be limited. Based on experiences from the Danish Energy Agency, commercial investors often require 8% or more as an internal rate of return, while municipally owned or consumer-owned DH companies require a substantially lower return in order to make economic ends meet, as their purpose is to establish an affordable and locally controlled long-term heat solution. A similar trend is found in the UK [47]. Furthermore, the public-private contract must be very specific and extensive regarding the choice of quantitative criteria for measuring performance, etc., which often requires previous experience from the sector. It must also be taken into account that the BO and BOT models may cause undesirable costs because of the "buy or pay" provision due to the purchase guarantee; thus, the final consumer may encounter higher costs for the heat energy.

3.7 ESCO market for commercial owners

In order to allow market actors to gain a fair earning on their investment, while at the same time protecting consumers from unintended price hikes from misuse of market forces or insufficient provision of data, another option can be considered. If a new or retrofitted DH supply is planned, an energy service company (ESCO) can provide the required investment capital, technology, and information to establish DH.

In many countries, an ESCO is a well-tested means to improve energy efficiency by implementing energy-efficiency projects in the private and public sector. The advantage is that an ESCO offers a (group of) energy consumer(s) the energy service at a competitive price if the consumer(s) agrees to buy the service for a fixed period under specified conditions. Typically, heat is sold for a fixed price for a number of years in advance, which makes it easy for heat consumers to estimate the potential cost advantages. Thus, heat consumers are somewhat protected against unexpected price hikes, as they are guaranteed a fixed price.

Danish experience with ESCOs in the heat sector is relatively new. Private ESCOs offer, for example, small villages the opportunity to replace their individual oil stoves with small-scale DH based on large heat pumps or large wood pellet stoves at favourable terms. The ESCO makes the investment, and establishes, runs, and

maintains the local heat plant at a fixed price, which typically is lower than the heat price of individual oil stoves. This business concept exists in various forms and can also be used to develop medium- or large-scale DH in other countries. The business model was analysed and recommended in a report for the Danish Energy Agency [48]. This paved the way for a new support scheme, where 4 enterprises won a public bid to promote heat pumps as a replacement for oil stoves [49]. Other DH plants offer small community heat solutions based on solar heating or biomass on similar ESCO terms.

However, ESCOs are very active in energy services with a high internal rate of return. Energy savings and increased energy efficiency at large industries are often preferred, as the investment can be repaid over the course of only 2–4 years. DH differs from such projects, as DH is a long-term investment with a stable but limited internal rate of return. The Danish experience is that ESCOs now are becoming very active in supplying small-scale DH to small villages and medium-sized communities if the present heat price is relatively high due to the heat source being individual oil stoves, etc. But the ESCO businesses are now considering business in medium- or large-scale DH, which may be an active future business. A fairly large number of such DH plants are now promoting renewable energy-based heat to villages, e.g. the village-based heat projects in the Rebild municipality [50].

One challenge with ESCOs (and possibly PPPs) is that the private company can (un)intentionally run into issues not specified in the contract, which then leads to renegotiations and legal challenges to raise the revenue for the private company. One solution is to let a third party standardise the terms and verification of the services under contract.

ESCOs typically require stable investment conditions, i.e. a stable regulatory framework and carefully prepared contractual obligations with regard to delivery conditions, maintenance, and calculation of costs. They also require the presence of several competing ESCOs in order to ensure competitive prices.

The ESCO model can be implemented in various forms. Establishing incentives to operate and maintain the DH plants sustainably, e.g. incentives to hand over the plant in an optimal technological state when the contract expires after maybe 20 years, should be considered. This can be achieved by the stipulation of proper incentives and technical specifications in the contract.

The use of ESCOs in larger DH supplies requires carefully prepared contractual obligations with regard to delivery conditions, maintenance, and calculation of costs. In order to minimise risks, standard contracts could be developed by key stakeholders in cooperation with the responsible ministry. In larger DH supplies, the consumers could also be safeguarded by establishing public ownership of the distribution net, i.e. production and distribution is unbundled.

4. Regulatory context of price models

Some types of price-setting regimes may serve as a favourable cornerstone in a country's DH model, but they may require a legal set-up, well-established institutions, and access to data, etc., and that takes time. Therefore, a gradual development of one or several preferred types of DH models may be an option. That would enable the central DH authority to implement DH in the short term, while developing the institutions, legal regulations, and so on needed for a preferred model at a later stage.

Furthermore, a uniform model may not be the best solution if the DH communities differ according to market size, size of population, proximity of excess heat, different types of housing and consumer groups, etc.

Thus, one specific DH model may apply for a small, geographically remote town, while the DH supply to a large city may benefit from another DH model.

Finally, the use of efficiency-enhancing regulation should be considered to the largest extent possible in all preferred DH models. The Danish experiences and specific means and policies listed below could be considered and adjusted to a specific setting in other countries. There are many local, well-functioning ways to address these issues, which could also be highlighted.

4.1 Means and incentives to ensure low costs when selling heat for true costs in Denmark

At least seven different means can be applied to strengthen the development of an efficient DH system with reasonably consumer prices:

4.1.1. Compulsory use of a standardised feasibility study

DH project approval must be based on a feasibility study built on a standardised and well-tested method. The feasibility study must document that DH is the least-cost option compared to alternative heat supplies. Calculations on, for example, the consumer economy and the

socio-economy must be performed. The calculation method applied is a levelised cost of energy, whereby low consumer prices over a 20-year period are obtained. The above-mentioned District Heating Assessment Tool has been developed to transfer this method to other countries [38].

4.1.2 An efficiency-enhancing measure exists due to competition via third party access

Third party access must be guaranteed if a feasibility study documents that an external heat supplier can lower the consumer price and enhance the socio-economic benefits.

4.1.3 Actual costs are covered by the consumer heat prices

A down payment or installation fee per installation can contribute to repayment of the capital investment loans. Thus, it ensures a guaranteed payment to the DH company, which facilitates safe repayment of the investment loan.

A tariff per gigajoule of consumption that covers fuel purchase and other running costs should be employed. Thus, consumers pay for the actual heat (GJ). This offers an incentive to save heat and have a lower heating bill.

Some DH supplies have also established a capacity price (e.g. GJ/h) to decrease peaks. Lower prices per GJ/h can also be obtained for a lower temperature of the return water—this is often executed by an app, where each heat consumer can follow the temperature and the lower price for the lower temperature, etc.

4.1.4 Subsidies are passed on directly to DH plants and consumers

The central government passes on subsidies for biomass-based energy production, etc. directly to the DH companies. Thus, the transmission system operator, which has the data needed, administers and conveys financial subsidies directly to the DH company. It is not passed through local governments, which prevents the risk of local government expropriation of central state subsidies.

Targeted subsidies are available for low-income consumers, so the true-cost tariffs do not hurt vulnerable groups. In order to ensure that such subsidies reach the target groups, the heating bill—including possible subsidies—is sent directly from the DH plant to each individual consumer. The heating bill is not passed on through a local government authority.

4.1.5 Access to data and standardised consumer price benchmarks

Consumer price benchmarks for fixed and variable tariffs are made publicly available for all DH companies 2–3 times per year, which puts pressure on the DH company boards to continuously improve their economic performance. The statistics are published by the central authority for monitoring supply companies (Danish Utility Regulator).

All heat companies are obliged to hand over a standard set of detailed information on their prices, tariffs, delivery conditions, etc. to the relevant central authorities. Non-compliant heat companies can be punished by fines, and so on.

In order to ensure full transparency and proper benchmarking, DH companies must use a standardised account plan and the same accountancy period (calendar year).

4.1.6 Voluntary economic performance benchmarks

The national branch organisation calculates and publishes economic benchmarks for each DH company. This is widely used as a point of entry for the informal exchange of information among DH companies on how to improve company performance.

Furthermore, the national branch organisation for all DH plants offers voluntary courses in the adoption of new technology and advice on technical issues, etc.; thus, the branch organisation offers proactive consultancy on behalf of their members.

It takes time to establish such a national organisation, to gain the confidence needed among all stakeholders, and to task the branch organisation. Other countries may, alternatively or until a well-functioning organisation has been established, use third party organisations and consultancy companies for specific tasks.

4.1.7 Independent central authorities

Independent central authorities to monitor prices and handle complaints are pivotal for obtaining legitimate supervision and monitoring of prices and delivery conditions.

5. Conclusion

The collection of experiences of regulating DH shows the diversity of options available. In this paper, an attempt has been made to collect and categorise these experiences. They are based mainly on Danish experiences, but findings from other countries have also been

included. The general findings are summarised below, which of course should be adjusted to the specific local setting according to the culture, technological capability, existing energy structure, institutions, regulations, policies, etc.

5.1 True-cost principle

Danish experiences are mainly positive with regard to affordable consumer prices and increased efficiency, but efficiency-enhanced measures have been implemented, and proper regulation and supervision need to be applied.

5.2 Regulated return to investor

If the central or local authorities are short of investment funds or prefer to share the responsibility with professional, external investors, this system may be an option. However, investors with stable, long-term interests must be identified and detailed investment conditions, and maybe opt-out options, must be prepared. DH distribution nets can be owned or controlled by local heat authorities or the like, as unbundling is an important safety measure.

5.3 Liberalised price set by the market

Swedish experiences suggest the (potential) misuse of market power when DH is a natural monopoly. Thus, new reforms for price setting were adopted, which required active administrative interference with respect to regulation and access to multiple data from market actors. A similar tight public supervision and monitoring of DH data have also been found to be necessary in Estonia.

5.4 Natural gas-based substitution price of heat

Fixing of DH prices may cause unviable heat sale revenues, which threaten O&M and investments in new technologies. Furthermore, the price of individual natural gas can be lowered by strategic business decisions rather than increased effectiveness.

5.5 Price cap based on alternative supplies

If the price cap is too high, the cap may give an incentive to raise the price to the maximum price allowed. If the price cap is too low, it may threaten the long-term economic sustainability.

5.6 Private operation under public ownership

If a local government lacks expertise in developing or operating an efficient DH supply, such management may be transferred to a private enterprise through lease or authorisation contract. But undesirable costs may occur due to a "buy or pay" provision via a purchase guarantee or the like; thus, the final consumer may encounter higher costs. As the risk for the private enterprise is typically limited, and proper incentives must be prepared, performance measures must be specified in the contract.

5.7 ESCO market for commercial owners

ESCO may provide a framework for competitive market prices and delivery conditions. The advantage is that consumers are assured a fixed heat price. Compared to several of the above types of price regimes, relatively limited regulation and supervision is required. However, the use of standard contracts formulated by stakeholders and the ministry responsible should be considered.

Efficiency-enhancing means and policies must be considered in the planning phase and adopted in each specific DH supply.

A mix of price-setting regimes and ownership models, etc. can be chosen. The choice of model may depend on the specific circumstances, considering, among others, the scale of the heat market, the local availability of waste heat, existing ownership of housing, present and future development of a stable regulatory framework, and confidence-building measures for commercial or public investors.

This article has provided an empirical collection of approaches to price regulation. Further research could entail a deeper analysis of each of them and could more systematically investigate under which circumstances the different options would be most suitable.

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