AALBORG UNIVERSITET
STUDENTERRAPPORT

HOW DOES THE LEGAL FRAME FOR SECTOR COUPLING IN DENMARK INCENTIVISE ENERGY-INTENSIVE INDUSTRIES TO INTRODUCE WASTE HEATINTO DISTRICT HEAT?

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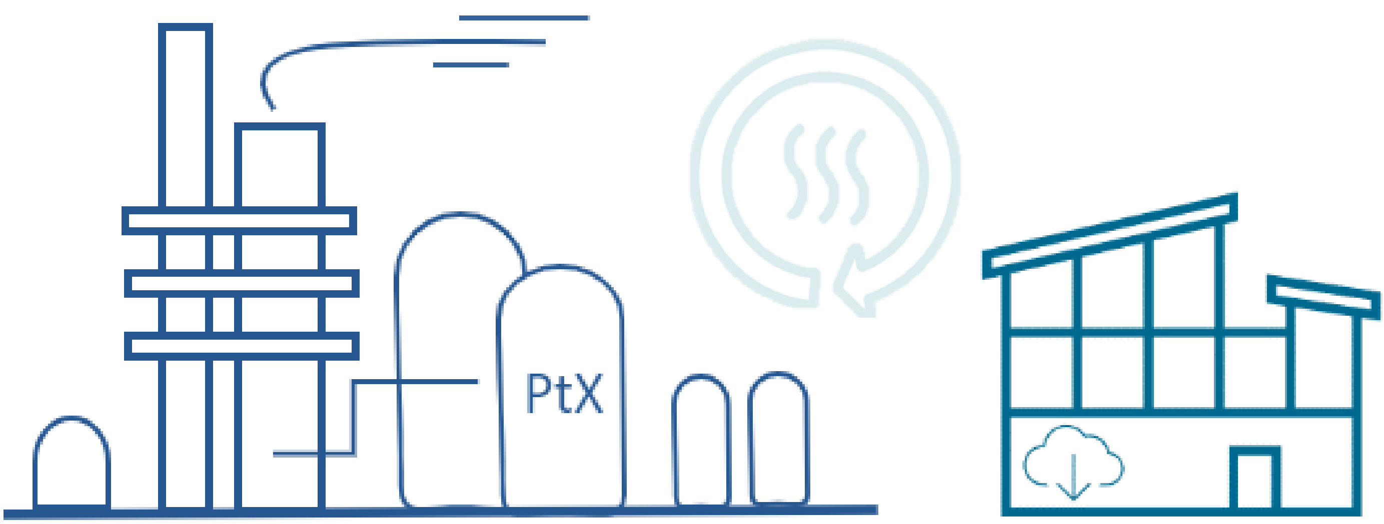
Cities and Sustainability



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Word definitions and Abbreviations

Waste Heat: There is not an overall consensus among scholars or companies what to call the heat created as a byproduct of another production. The most common terms found were ‘Surplus Heat’, ‘Excess heat’ and ‘Waste heat’. As to be consistent throughout this rapport, the term ‘waste heat’ was chosen and will be used, excluding direct quotes. The term waste heat was chosen as this rapport's focus is on the lack of utilising the ‘free’ heat and thus considers the not-utilised heat as a wasted resource.

PtX	Power-to-x
4GDH	4th Generation District Heating
3GDH	3rd Generation District Heating
RE	Renewable Energy
CHP	Combined heat and power

Introduction

For the past five months, I have been interning at Gate 21, which is a green partnership for municipalities, regions, companies, and knowledge institutions, such as universities, that focuses on climate and environmental actions and issues. The projects are run with support from a large number of foundations, programmes, agencies and other pools for green development and demonstration projects.

At the beginning of the internship, I was assigned to two main projects: EPT33 - Energi på Tværs (Energy Across) and DG-RESU-LT (Danish German Renewable Energy Storage and Utilisation – Local Transition). EPT33 is a longstanding project dating back to 2012. I was supposed to work with the solar panels on the roof area of the project, but due to staff changes, the project being handed over and the fact that it was in the transition to go into a more implementation phase, my contribution would have been minimal. Thus, I was more involved in the DG-RESU-LT project, which was and still is in its conceptual phase. A proposal is being put together for presentation in April 2024.

The project is part of the *Interreg* program between Germany and Denmark, an EU programme with the function of stimulating cooperation between regions inside and outside of the EU. The focus of this project was investigating and analysing the potential of sector coupling in line with "Sustainable Energy Parks". Also, part of the project was the STRING Megaregion, which works with "Sustainable Energy Parks," focusing on sector coupling, storage, and better utilisation of renewable energy and waste heat.

After researching all types of Energy Parks, I created different types of matrices, categorising based on the goal and function of several different kinds of parks for a better overview.

Furthermore, I created maps where all current and future Power-to-X facilities (PtX) were planned in the Interreg area (South Denmark and Slegsvig-Holsten) for the Energy Team in Gate 21 to use in meetings with potential partners. Later, I also mapped out wastewater sources as it was made clear in the research that any PtX facility would have to be near a water source other than groundwater, with wastewater being more accessible to clean than seawater, as the process requires a large amount of water. In general, the DG-RESU-LT project focuses heavily on the concept of sector coupling or symbiosis with other installations or facilities. This also included recovering waste heat that PtX facilities will produce and either having it enter the district heating grid or the possibility of exchange of by-product resources between facilities, in a similar practice at the well-known Kalundborg Symbiosis.

In my time at Gate 21, working primarily on the DG-RESU-LT and helping in a minor capacity with other projects, certain problems associated with the utilisation of waste heat in Denmark kept cropping up in the conversations I had, as well as meetings and conferences I participated in.

It is, in particular, the new price cap on waste heat from the Danish Supply Authority (Forsyningstilsynet) that took effect in January 2023, which utility companies have criticised for halting new and existing projects and facilities that are or are wanting to utilise waste heat (Dansk Fjernvarme, 2023).

Other discussed problems I often encountered were the location of larger installations, such as data centres or future PtX, that are often ill-placed relative to district heating networks and the fact that the operators of the data centres may have little interest in prioritising waste heat recovery in their plans.

Based on these observations I decided to delve into the Danish energy landscape with focus on the untapped waste heat potential from data centres and future PtX facilities. The project will elucidate the evolving landscape of district heating networks with emphasis on the significant role waste heat recovery can play in elevating the overall energy efficiency by examining some of the barriers mentioned during my internship.

This research and informal interviews have culminated into these sets of questions:

- Why are PtX and data centres relevant facilities to discuss together with district heating?
- What are the primary mentioned barriers for introducing more waste heat in the district heating network?
- How does the concept of waste heat in legislation affect the incentives to connect to the district heat system?

Which I will use to answer my main research question

How does the legal frame for sector coupling in Denmark incentivise energy-intensive industries to introduce waste heat into district heat?

Data collection and sources

The primary purpose of this research is to understand the newly implemented regulations evolving around the price cap and to understand in what way sector coupling with energy-intensive industries and district heat is possible. For this purpose, peer-reviewed academic literature, sector reports, etc., and expert insights are all invaluable, as they provide different sources of valid information. Knowledge, know-how and critiques among sector professionals and experts are rarely fully accessible to researchers, but as I have described in the section above, this is essentially where I have started my research, hearing these perspectives. Therefore, a secondary purpose of this research was to understand the comments and understandings of the sector experts.

The sources I used substantiate perspectives and numbers I heard during my internship were collected from the academic database Science Direct and from district heating sector-specific, energy-specific, or regulatory reports or repertories, such as the International Energy Agency (IEA), Dansk fjernvarme, Rambøl, COWI and the energy agency. Data, thus, include sector reports- and documents and either heat-supply related legislation. The data also includes participation in district heating sector workshops and conferences through my internships.

I have chosen to use these conversations, observations, presentations, and conferences I have been part of as part of my data in the rapport. The informal interview method was used for the conversations I have had with members of the energy team of Gate 21 and of an energy planner from VEKS. This means that the conversations were without a fixed structure, which occurs when and if an opportunity arises to converse with a resident about a relevant or interesting topic (Kvale & Brinkmann, 2014). The characteristic of informal interviews is that there is no interview guide and seldom any audio recording as they are often done more spur of the moment (Kvale & Brinkmann, 2014). Due to this lack of records, I kept field notes on what was discussed.

During my stay, I attended three bigger conferences, which added to my knowledge and data.

DI Energi (Industriens Hus) “Brugen af Overskudsvarme” (Eng. Usage of Waste Heat) 6th november 2023
EnergiTopMøde (hosted by Gate 21) 10th Oktober 2023
Energy Cluster Denmark “PtX fra AtZ - Lovgivningens rammer” (Eng. PtX from AtZ - The legislative framework) hosted by Bech-Bruun the 25th september 2023.

This rapport has been conducted through an explorative course of action, as it has been based on repeated wonderings and questions created from the continuous themes coming up in conversations, the conferences and meetings related to the DG-RESU-LT project.

For this rapport, I have chosen to focus on those problems and barriers associated with utilising waste heat in Denmark, primarily expressed through informal interviews, presentations, and conferences.

These are **1)** The new price cap on waste heat, which is creating uncertainty, **2)** The placement of installations with huge potential for waste heat recovery, **3)** the lack of regulations and legislations and **4)** The general lack of knowledge and resources with local planners.

In the 1st barrier about the price cap, it is especially the conference by DI Energi about the usage of waste heat where the criticism of the price cap by, among others, utility companies was clear. This is coupled together with research into documents about the price cap - its function and purpose, to research what effect the price cap has on utilisation of waste heat.

Regarding the placement of the installations (2nd barrier), the focus is on the municipality's ability to frame where future installations can and should be located. Therefore, the primary focus of this barrier is on the planning structure. Here, I will go through the planning framework around district heating and the municipality's range of possibilities in deciding where data centres or PtX plants will be built.

The information gained from informal interviews and observational notes will lay the ground for my questions, and then I will use literature and regulatory texts to follow up on the information.

The 3rd barrier is the lack of legislation and regulations; I have focused on searching through executive orders (Bekendtgørelser), including the EU Directive on Energy efficiency, and amending regulation 2023, an executive order for price cap and heat supply. During my research, I was also made aware that wastewater, despite being a heat source from a waste product, does not fall under the price cap regulations. Thus, I have also researched the Waste Act, Environmental Protection Act, and various legislations regarding waste management as wastewater is under Waste Management.

As I had little to no direct contact with local planners (the 4th barrier), but mainly interest organisations such as Gate 21 or consultants from i.e., VEKS, who could have a vested interest in providing local planners with information - I have chosen not to focus on the 3rd barrier of lack of knowledge and resources. This is due to the risk of a biassed representation of the involved parties.

Although I have been presented with numbers through conversation, presentations, and conferences', I have chosen to use numbers only from verified literature or official sources, i.e. Denmark's statistics, the Danish Energy Agency (Energistyrelsen).

Sector coupling and future industries

An analysis from the Ministry of Taxation (Skatteministeriet) estimates that overall, there is a potential of 10 PJ of waste heat from industry that is not being utilised today (International Energy Agency, 2023). Accumulated in the period 2020-2030, utilisation of waste heat can displace over 2 million tonnes of CO_2, and when the district heating companies have phased out fossil fuels, waste heat will minimise otherwise necessary investments in renewable energy (Regeringens klimapartnerskaber, 2021-2022). It is from this line of thinking that this analysis has been designed.

The 13 climate partnerships were given the task of solving the difficult and important task of developing concrete proposals for the government about which efforts will be able to contribute to achieving the goal of reducing Denmark's CO_2 emissions by 70 percent in 2030 and making Denmark a leading country for the rest of the world (Regeringens klimapartnerskaber, 2021-2022). The climate partnerships have recommended a number of measures to promote the utilisation of waste heat.

With the climate agreement, the content of the March 2019 agreement on increased utilisation of waste heat was confirmed. In addition, the parties to the agreement have agreed to remove the waste heat tax if the waste heat is certified or subject to a corresponding agreement scheme that ensures energy efficiency improvements at the supplier of waste heat (Regeringens klimapartnerskaber, 2021-2022). There have been political discussions for a concrete model for the agreement system and price regulation of waste heat in autumn 2020, but a final agreement on this is pending. The government has also allocated min. 750 million DKK for a subsidy scheme through a government tender for PtX projects. The purpose of the tender is to reduce production costs of green hydrogen and thereby contribute to a rapid scaling of PtX in Denmark and to increase Danish competitiveness (Regeringens klimapartnerskaber, 2021-2022). It has become a new buzzword to refer to CO_2 reductions in the same sentence as symbiosis, sector coupling or synergies. Where the idea is that surplus resources are shared between two or more industries, such as materials, energy, bioproducts and water. It has become extra relevant to deal with waste heat due to the newly implemented price-cap on waste heat.

As written in the introduction, I have decided to work primarily with Data Centres and PtX facilities as these two have been repeatedly seen as both full of potential but likewise webbed in barriers. In the next section of the report, I will elaborate on why these two energy-intensive industries are interesting to focus on. I will not be going into whether Denmark should prioritise differently, rather I will be focusing on understanding the layout of the land and the barriers for the prioritising made.

An energy intensive economic adventure

Denmark has proven to be an attractive location for the development of new data centre projects, for reasons such as reliable data and power infrastructure, as well as cold environment and low-carbon electricity (COWI & Energystyrelsen, 2018). Simultaneously the current Danish government has indicated an interest in accommodating this industry's growth in Denmark (Ea Energianalyse, 2017). Data centres are described as serving as the backbone of the digital society, housing the extensive infrastructure that power the information technology systems and the Danish Energy Authority is therefore prioritising the development of data centres in Denmark (EnergiStyrelsen, 2023). As a direct consequence the emergence of data centres in Denmark have mushroomed since 2015, from a negligible part of the energy system to a projected major contributor to energy consumption (EnergiStyrelsen, 2023).

Due to many different challenges and barriers, the energy consumption estimates of data centres vary significantly depending on the assumptions and methodologies used (Monsalves et al., 2022). A report by the International Energy Agency (IEA) estimated that data centres will consume between 220 and 320 TWh of electricity in 2021, equalling around 1-1.3% of global final electricity demand, excluding energy used for mining and production data-centre parts (Huang et al., 2020). It is also assessed that data centres contributed about 300 million metric tons (Mt) of carbon dioxide (CO2) emissions in 2020 (Monsalves et al., 2022).

There are different types of data centres (Monsalves et al., 2022):

Hyperscale	Large, efficient facilities designed for scalable applications, often owned by major tech corporations like Google and Microsoft, catering to substantial data-handling needs for services like search engines and cloud computing. E.g. Facebook in Odense
Co-Location	Facilities where operators rent out infrastructure to multiple companies, accommodating diverse customers responsible for setting up their own IT equipment within the data centre.
Enterprise	Dedicated data centres optimised for a single company's use, typically located on-site, operated internally, and serving as the foundation for the company's internal network.
Edge	Compact data centres strategically positioned near end users for on-demand, low-latency capacity, anticipated to play an expanding role with the growth of IoT and 5G technologies.

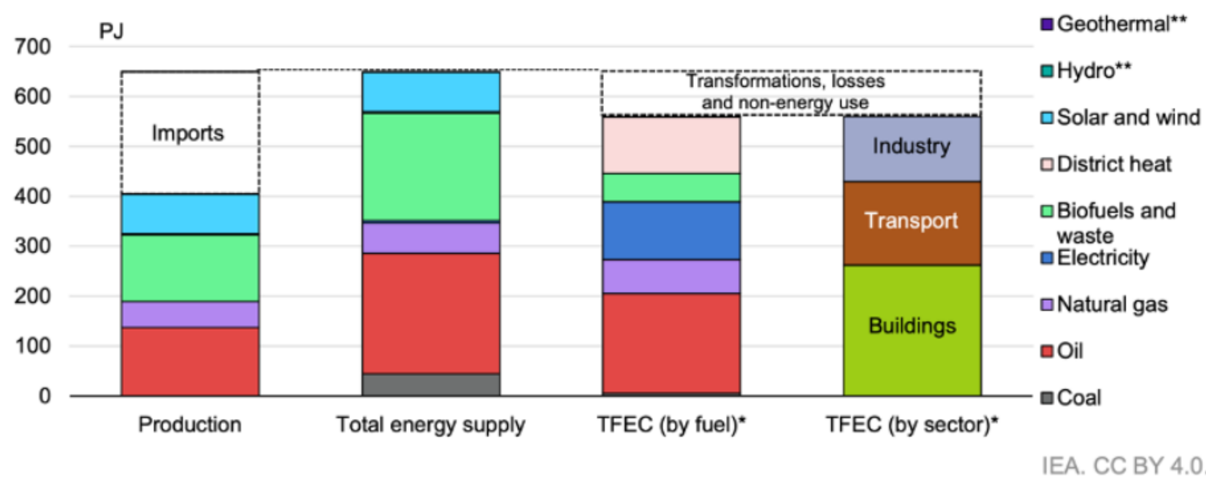
Denmark only has three hyperscale data centres in operation but with at least two more confirmed by microsoft that are planned to be in Høje Taastrup and Roskilde (Øllgaard & Sommer, 2019).

Danish data centres had a substantial surge in the electricity consumption from 0.28 to 0.88 TWh between 2019 and 2020, which will only grow. The Danish Energy Agency forecasts that data-centre electricity demand will reach 8.8 TWh by 2030, based on data centres which are already planned (Monsalves et al., 2022). In Denmark alone, electricity consumed by data centres is assumed to be 10.9 TWh in 2030, 14.5 TWh in 2040 and 15.1 TWh in 2050; thus, already in 2030, data centres will account for approximately a third of the total Danish electricity consumption in Denmark, with 2020 consumption numbers (EnergiStyrelsen, 2023).

Maybe not quite as low carbon based.

In 2022, Denmark's CO_2 emissions per unit of GDP were the fourth lowest among IEA member countries, well below the IEA average (International Energy Agency, 2023). Notwithstanding, a low-emission economy does not necessarily mean that the picture is straightforward and that the goal of reducing by 70% will be reached easily.

Over 60 % of the Danish total energy supply was covered by domestic production, primarily based on biofuels, waste and oil by the domestic production of energy, where there was a further import of fossil fuels and biomass primarily covering the remainder (Figure 1) (International Energy Agency, 2023). Meaning that although a good bit of the Danish electricity is based on solar and wind, a lot of other energy forms are not, and if the demand for energy is increased significantly and the majority of this extra energy demand which is currently covered by fossil fuels, also has to be addressed.



* TFEC (total final energy consumption) data refer to 2021.
** Hydro and geothermal represented 0.07 PJ and 0.08 PJ in production, respectively.

Figure 1: Danish total energy supply and demand from 2022 (Source: International Energy Agency, 2023)

For a long time, Denmark has been a frontrunner regarding wind turbines as a renewable energy source, and wind energy has been part of both the plans to secure its own energy production and make it sustainable. Onshore wind turbines have been established since the 1970s, and in 1991 the world's first offshore wind farm was established offshore of Lolland (Energistyrelsen, n.d.).

2020 Climate Act, a political agreement from 2019, implements a legally binding target of reducing GHG emissions by 70% in 2030 from 1990 levels, intending to make Denmark a climate-neutral society by 2050. In 2022, the current government has proposed advancing the goal of climate neutrality to 2045 and achieving a 110% emissions reduction by 2050 compared to 1990. In the Agreement on Green Power and Heat (25 June 2022), Denmark aims to quadruple onshore wind and solar PV generation by 2030 (no split by technology is indicated) (Social Demokratisk Regeringen, 2022).

However, RE sources such as wind and sun fluctuate, as they are heavily weather-dependent. So, there are times when wind turbines produce surplus energy compared to domestic electrical consumption. They are shut down during these periods to avoid the price of running the turbines exceeding the gain, or the surplus is sold but with a far smaller yield as the energy as a lot is turned into heat (Monsalves et al., 2022).

Another of the problems RE faces related to this fluctuation is the difficulty in storing efficiently in an environmentally friendly and economically viable way and securing a steady stream of energy independent of weather (Vesborg, 2021). Denmark and other countries are looking towards green hydrogen and synthetic fuel as a solution to both use superfluous electricity and target the problem of oil being the biggest energy source (Vesborg, 2021).

A solution and another intensive electricity consumer

The fluctuating nature of RE sources, such as wind and solar, necessitates the development of devices and technologies for storing and converting the energy when there is a surplus of energy with no recipient. This is exactly what PtX is capable of. PtX, in short terms, covers technology that produces fuel for heavy traffic such as planes and ships, chemicals and materials based on green hydrogen produced by electrolysis, offering solutions for energy storage and integration across various sectors. These can be used in those sectors mentioned above that are hard to electrify and are a more flexible state of matter to be stored for longer periods and manageable for transporting (Rambøll, n.d.).

Currently, there are no operational PtX facilities in Denmark. However, numerous projects are planned for the future. According to BrintBranchen, in 2021, there were 29 PtX facilities announced in Denmark with the vision of supplying 6+ GW electrolysis capacity in 2030 (BrintBranchen, 2021). The Danish government has set a target to build up to 4-6 GW of electrolysis capacity by 2030 as part of the 2021 PtX Strategy (Klimaaftale, 2020).

The unused potential

Looking at Figure 1 again, another aspect becomes apparent: a good deal of energy loss and unused energy is currently available.

Data centre is a tangible space, structure, or facility designated for hosting IT infrastructure to construct, operate, and provide applications and services. It also serves as a repository for storing and overseeing the data linked to those applications and services (Monsalves et al., 2022). Thus, data centres operate round the clock throughout the year. There is a high need for keeping the servers cool, preventing damage to the hardware and poor performance (COWI & Energystyrelsen, 2018). Environmental control, such as temperature and humidity, is the second biggest energy consumption in data centres, representing around 40% of the overall energy consumption (Monsalves et al., 2022).

Handling the heat emissions from the IT equipment is one of the biggest challenges. The servers and other IT equipment produce heat as a side effect of their electrical activity. The common approach is to expel both the heat and the cooling air from the building, which may appear straightforward but comes with an unintended and often overlooked adverse ecological consequence (COWI & Energystyrelsen, 2018).

Like data centres, the processes in PtX produce waste heat, although, unlike data centres, the temperatures vary but some are much higher (Johansen & Werner, 2022). Even if only a fraction of these projects come to fruition, they will demand a considerable amount of energy, which, if only run in times of surplus energy, will create the needed solution but will simultaneously create an enormous amount of waste heat as the electrolysis process happens. Waste heat can be harnessed for various applications, including integration into district heating networks or industrial processes, significantly boosting overall energy efficiency. PtX facilities and data centres could thus contribute to a more sustainable and resource-efficient energy landscape by incorporating waste heat into district heating networks or industrial operations.

In the DG-RESU-LT project, the strategic placement of PtX facilities is a key concept. This involves considerations regarding wastewater sources, given the substantial water requirements of the process. The goal is to enable sector coupling and ensure that the waste heat produced by the facility can be utilised, either through collaboration with other companies or integration into the district heating network. However, there is no guarantee that this will be part of the final design and construction of all or any of the future PtX facilities.

Simply defined, a district heating system is a system that delivers heat from a central plant to multiple buildings in a network of pipes (Dansk Fjernvarme, 2023).

The establishment of Denmark's current district heating system can be traced back to the oil crises of the 70s, which prompted a significant push to conserve energy, because of oil prices. This strategic approach has facilitated the gradual transition from reliance on private natural gas and oil heat sources to a district heating infrastructure.

Heat planning during the oil crisis was a key driver for the successful implementation of district heating; the first energy policy was adopted in 1979. Simultaneously the Danish heat supply act was introduced, providing a legal framework for the large-scale collective heat infrastructure planning initiatives (Johansen & Werner, 2022). Notably, the co-production of heat and power in combined heat and power (CHP) plants has played a crucial role in these energy-saving initiatives.

In conventional power plants, only around 40% of the total energy input is converted into electricity, with 60% lost as heat to the surroundings, while the loss is severely cut in the CHP plants. 67.7% of the total heat distributed in 2019 was produced in CHPs, while heat-only generation plants provided the remaining (Johansen & Werner, 2022).

Regarding the district heating system's reach, it is worth noting that district heat is available to 1.7 million Danish homes, constituting 64% of the residential landscape. This extensive reach is facilitated by a network of 50 municipally owned utilities and companies responsible for supplying 70% of all district heating services (Johansen & Werner, 2022).

Additionally, approximately 340 consumer-owned cooperatives contribute to the district heating network, with many currently undergoing mergers to create larger plants (Dansk Fjernvarme, 2023).

While wind energy has traditionally been a primary method for sustainable electricity generation, there is a growing reliance on diverse sources such as geothermal heating, biomass, and solar energy, either individually for heat production or combined heat and power generation. In many urban areas, CHP plants have become instrumental, burning straw or wood to generate heat and electricity. Some plants may incorporate co-firing of gas or coal, while others exclusively rely on biomass as their sole energy source (Dansk Fjernvarme, 2023).

According to the heat supply act (varmeforsyningslov) the definition of *waste heat* is "*the unavoidable heat produced as a by-product from industrial or electricity production facilities or in the tertiary sector, which would be dissipated unused in air or water without access to a district heating system. The characteristic of waste heat is that no additional energy has been used to produce the heat*" (Klima¬, Energi¬ og Forsyningsministeriet, 2021, 4).

In Denmark it is the Danish Energy Agency that is responsible for the collective heating supply, while the municipalities have administrative authority. The municipalities are responsible for creating heat plans (varmeplaner) that denote areas expected to be supplied with district heating. The heat plans have to include the expected time frame and also areas that are expected to have individually supplied RE in the future (Plan Info, n.d.).

District heating is, at the moment, 3rd generation district heating (3GDH), which became widespread after the oil crisis in the 1970s. The main characteristics of this generation of district heating are that it operates in temperatures below 100 C, typically around 90 C and mainly uses biomass, coal, and waste as its energy source. Some 3GDH systems also use geothermal, solar and wind energy (Interreg European Union, n.d.).

The 4th generation of district heating (4GDH) is still being developed, but energy efficiency is a key feature. As buildings become more energy efficient, lowering the supply water temperature without impacting the consumer's comfort becomes possible. Whereas 3GDH needs a temperature of around 90 C, 4GDH can operate in temperatures as low as 50 C. It has a similar feature with direct cooling, where the temperature can be raised from 6 C to 12 C (Grundfos, n.d.). This means the 4th generation requires less energy to keep the temperatures of the water, which reduces both costs and CO2 emissions. There is also overall less thermal energy lost in the distribution network, and the lower temperature means that the pipes will be put under less stress, thus reducing leakages, and expanding the system's lifetime (Grundfos, n.d.). An important feature of the 4GDH is utilising waste heat because the temperature of the supply water is lowered, which enables district heating plants to draw on more energy sources, such as waste heat from industrial processes. This means that district heating plants have the ability to utilise a combination of locally available resources to support a sustainable production. Another key feature is the 4GDH ability to seasonally store waste heat in insulated pits underground so that it can be captured, e.g., solar energy in the summer and be used during the winter when the demand is higher (Grundfos, n.d.).

There is a snag with 4GDH as when you lower the supply water temperature, it risks that the consumers furthest in the distribution network cannot achieve the minimum required differential pressure without having plants increase pressure on the supply side.

However, a solution could be to use a range of smaller pumps on the way to the consumer rather than relying on one powerful one. This would result in the pumps being able to run at a lower speed, which not only saves energy but enables the system to adjust to the actual demand instead of running at full speed (Grundfos, n.d.).

The main cost in the 4GDH is the cost of transitioning from one system to another to replace infrastructures and fit buildings. However, according to a review paper from 2018, *The Status of 4th generation district heating: Research and Results* by Henrik Lund et al., this can be done without significant costs, and existing district heating grids can be changed to operate with 4GDH with minor and affordable costs (Lund et al., 2018).

Transitioning to 4GDH would allow for more and more efficient waste heat utilisation at lower costs in the system. Reducing the supply water temperature from 90 C to 50 C would mean that the waste heat created from, e.g. data centres require significantly less energy to boost the temperature as waste heat from data centres is between 15-30 C depending on the cooling method (Yuan et al., 2023).

Barriers

The potential to expand into more waste heat in the district heating network is evident, and the incentive to use more wind and solar power instead of oil, coal, imported waste and biomass is clear. Historically, Denmark has driven developments in the district heating sector with significant reforms and plans, but what does it look like today? As mentioned, a part of this study was initiated to determine what the price cap was, and that is precisely what the next section addresses. There is a need to understand which reforms form the regulatory framework for the future district heating infrastructure, and the most debated one is the price cap.

Price cap

One of the barriers that was primarily spoken of as a huge impediment towards integrating waste heat into a district heating network throughout the internship was the new price cap.

What is the new price cap?

In January 2022, a new legislation came into effect, regulating the sale of waste heat to district heating systems (Forsyningstilsynet, 2023). This legislation encompasses price regulation, an energy efficiency scheme, and tax exemptions under specific conditions. Waste heat from electricity is tax-exempt, while waste heat from fossil fuels may be exempted if the facility is part of the energy efficiency scheme (Forsyningstilsynet, 2023). The price cap applies facilities and installations that utilise and deliver waste heat, with a capacity of at least 0.25 MW. Waste heat-based district heating from installations below 0.25 MW is exempt from price regulation. It is the heat supply company that must comply with the price cap. The waste heat supplier is exempt from price regulation (Forsyningstilsynet, 2023).

Data centres, producing waste heat through electricity consumption, are exempt from taxation, making only the price regulation applicable. The price regulation aims to provide a financial incentive for waste heat utilisation, ensure affordable heat for consumers, and prevent false waste heat production. The price cap is recalculated each year based on the district heating utilities using a minimum of 90% renewable energy as well as being within the cheapest 50%. These calculations are also based on the average theoretical investment costs for a woodchip boiler and heat pumps as well as the last two years average electricity prices and forecast electricity prices (Forsyningstilsynet, 2023).

Waste-heat suppliers and district heating companies are free to negotiate a price, but the total cost for the district heating company must not exceed a price ceiling (Forsyningstilsynet, 2023). The regulatory framework also includes a transitional scheme for suppliers with existing agreements and exemptions for facilities below 0.25 MW. The ceiling regulates the maximum price for waste heat in district heating balances, ensuring the district heating company only buys heat when the margin between the ceiling and the agreed price covers internal costs (Forsyningstilsynet, 2023).

Notably, the price ceiling's duration in agreements is not regulated. If fixed below a given ceiling, changes in the latter won't affect the agreed price. District heating companies can seek approval for individual price ceilings, demonstrating the national ceiling's irrelevance in their specific district heating area (Forsyningstilsynet, 2023).

The price cap has introduced some exceptions projects can apply for, including individual-, flexible- and locked caps that started in January 2024 (Forsyningstilsynet, 2023).

Individual Price Cap	District heating utilities may request an individual price cap in unique cases, reflecting local conditions and opportunities for sustainable heat production. The regulator sets this cap based on the application, considering additional information if needed. Multiple individual caps can be established for utilities with multiple suppliers.
Flexible Price Cap	For new or significantly modified facilities, heating utility companies can apply for a price cap increase for up to three years, followed by a corresponding reduction. This provision aims to support rapid depreciation and provide investment cost certainty.
Locked Price Cap	Waste heat providers and district heating companies can mutually agree to lock a standard, individual, or flexible price cap for a specified period. If a flexible cap is locked, it must be based on the facility's commissioning year, with a maximum lock period of three years.

As these exceptions have quite literally just been put in place, the efficacy of them is yet to be seen. However, the fact that the exceptions are only relevant as of now, did create uncertainty in existing projects or projects already invested in which was expressed at the conference about using waste heat hosted by DI Energi and the long term effects of the price cap.

Criticism on price cap

The legislation was highlighted by politicians, industry organisations and the industry itself as a game changer that could help promote waste heat projects that had previously not been economically viable (Rambøll, 2022)

However, during a conference on waste heat usage by DI Energi, it became evident that certain actors, particularly utility companies such as Dansk Fjernvarme and Fjernvarme Fyn, view the price cap as more of a hindrance than an encouragement (Rasmussen, 2023). Dansk Fjernvarme's chief consultant labelled the price cap as an impediment to waste heat utilisation, while Fjernvarme Fyn's director highlighted the adverse impact on users and the climate from the price cap (DI Energi & Dansk Fjernvarme, 2023).

Fjernvarme Fyn presentation focused on their new investment into a new waste heat facility in relation to the data centre which already is utilising waste heat to heat up 11.000 households. They have invested 400 million DKK into the project which now is in uncertainty if it can remain below the price cap (DI Energi & Dansk Fjernvarme, 2023). As mentioned above, there is the option for exceptions, determined by the Danish Utility Regulator (Forsyningstilsynet).
However, since those first went into effect this month, existing and invested projects such as Fjernvarme Fyn were left in a state of uncertainty as they could not apply for any exceptions before and therefore couldn’t insure if they could operate within the price cap. A degree of uncertainty is expected when new systems are put in place that should lessen in the years to come as the new change is integrated into the current system.

There is the possibility that the prominence of the price cap as an unnecessary hindrance for waste heat utilisation may be an attempt of certain actors to prompt legislative change. By openly and vehemently opposing the regulation, they may aim to influence its alteration or potential abolishment (Jacobsen, 2024), a task more achievable in the early stages than after it becomes ingrained in the system. Although, it is not all utility companies who cite the price cap as a decisive barrier.

During the internship I had an informal interview with an energy planner from the utility company VEKS who is a consultant to Høje Taastrup municipality regarding the new planned data centre. According to him, the new price cap wasn't a problem for them or in general and they could stay below the price cap's ceiling.

Price cap effect on facilities

When focusing on facilities like data centres and PtX facilities, it becomes apparent that the price cap minimally affects their planning and construction. The price cap is pertinent only to already established and operational facilities, and for future-oriented planning involving PtX and data centres, it plays a limited role. However, the price cap significantly impacts whether operational hyperscale data centres can integrate into the district heating network (Rasmussen, 2023).

Denmark currently has a small number of hyperscale data centres, including the one operated by Facebook in Odense, Apple in Viborg and Google in Fredericia (Øllgaard & Sommer, 2019). The Danish Energy Agency projects an increase in hyperscale data centre establishments in Denmark before 2030 (EnergiStyrelsen, 2023), this includes Microsoft's data centre in Høje Taarstrup and Roskilde municipality. The price cap has minimal sway over the construction of such facilities, given that waste heat utilisation is not a primary function or priority for operators. While it might influence considerations for waste heat recovery infrastructure or heat pump integration, it is unlikely to be a decisive factor in determining the facility's location or construction.

District Heating regulation

The regulation of the Danish district heating sector has been a subject of debate over the past decade. In this context, discussions have revolved around how district heating should be managed and regulated, and what types of regulations are best suited to address climate considerations and the green transition. District heating companies have undergone significant changes and proposed reforms that were never implemented. The debate began with a report commissioned by the Ministry of Energy, Utilities, and Climate and the Ministry of Finance in 2015, examining the efficiency potential of the utility sectors conducted by McKinsey, with a clear desire for the liberalisation of the heat supply sector.

The report concludes that to encourage an efficient utility sector, action should be taken in three specific areas: utility companies should be given sufficient economic incentive to streamline costs while maintaining investment levels to ensure future supply security. This, they argue, requires a reform of economic regulation, including:

Introduction of revenue-cap regulation with TOTEX benchmarking
Introduction of WACC regulation
Transition to agreement-based regulation (for the largest companies) (McKinsey & Company, 2016).

Facilitating the merger of utility companies should be made easier and more attractive, achieved through:

Implementation of corporate separation, including a shift from § 60 joint ventures to joint-stock companies.
Permission to build up free equity and distribute dividends in all companies.
Relaxation of offsetting rules for the sale of municipally owned companies (McKinsey & Company, 2016).

Members of the boards of utility companies should have the right skills, and a separation of policy and business operations should be ensured through:

- Introduction of competence standards for board members of utility companies, enforced (McKinsey & Company, 2016).

Another report, conducted shortly afterward by EA Energianalyse in collaboration with Deloitte and Konveks, addresses the competitive situation in the district heating sector. It provides recommendations for introducing a competitive element in the heat supply sector and evaluates whether district heating production can be competitively regulated. The report was prepared for the Ministry of Energy, Utilities, and Climate (EA Energianalyse, 2017).

Currently, when district heating companies initiate new projects, they can take out municipally guaranteed loans at low interest rates from the municipalities' and regions' credit union Kommunekredit. They have been able to do this under EU rules on state aid since it involves a 'public task,' and district heating companies have not been in 'direct competition' with other companies (EA Energianalyse, 2017).

Connection obligations mean that residents in an area designated by the municipality for district heating are obligated to pay the local district heating plant, even if their homes are heated with, for example, gas or oil. Connection obligations and/or retention obligations are meant to ensure the operation of the local district heating plant by distributing the plant's expenses among enough customers. If a municipality has imposed a connection obligation and/or retention obligation on a property, it means that fixed expenses for the district heating plant must be paid until the municipality decides otherwise. The obligation also entails that the utility company has the right to establish the technical facilities necessary to supply the property (Forbrugdk, n.d.).

From January 1st, 2019, a rule came into effect prohibiting municipalities from deciding that new areas must be connected to a district heating plant. The rules do not apply to existing connections, only to future ones. This means that as a newcomer to an "old" residential area, you still have an obligation to pay the district heating plant if the properties were subject to connection/retention obligations before January 1st, 2019 (Ministry of Energy, Utilities, and Climate, 2018).

There was also a proposal to eliminate the obligation for homeowners to remain connected to their district heating company (Energistyrelsen, 2020). This would make it more difficult for companies to plan new investments, and the interest on their loans would likely increase. However, this proposal was not adopted after the change of government in 2019.

With the price cap, there is an attempt to protect citizens from a sector that operates as a monopoly. The Energy Agency ensures consumer rights by implementing a price cap, preventing the price of green heat from becoming significantly higher than it is today, without the ability for people to opt out (Forsyningstilsynet, 2023).

Criticism from both utility companies and industries is that it reduces the economic incentives to make the necessary initial investments, creating greater uncertainty about whether they will be allowed to build and sell energy (Dansk Fjernvarme, 2023). There is preparation for a disposition scheme where the investments to establish the connection may become more expensive than previously decided for up to a year, which may help alleviate some of the uncertainty described by industries and utility companies.

Utility companies are either owned by shareholders or municipalities, and they operate as nonprofit entities by law (Johansen & Werner, 2022). This means the price cap is clearly not implemented to prevent utility companies from making money, but rather to prevent firms from earning substantial profits from what is essentially a by-product and, therefore, a side income. As the regulation stands today, district heating is, in a way, a free choice for new district heating establishments, and at the same time, a massive investment for both district heating companies, municipalities, and industries that want to connect (e.g., data centres). However, it is still operated in many ways as a monopoly, especially for established networks, which can make it very uncertain for consumers if district heating is regulated on market terms.

Location/Placement

The purpose of this analysis was, in a way, to understand the price cap and, in addition, comprehend the impact this regulation would have on the future use of waste heat. The price cap was only implemented in 2022, so it is, in many ways, equally relevant to consider what factors have made biomass and waste the primary energy sources for the district heating network instead of waste heat.

As previously mentioned, one recurring point of discussion was the challenge that energy-intensive industries such as data centres were not located in areas were connecting to the district heating network made sense. In the following section, I will, therefore, address the placement of industries for district heating connection, with a specific focus on the municipalities' role as both heating planning and spatial planning authorities.

Several local areas supply district heating, as heat cannot be transported cost-effectively over long distances. Within each area, heat is produced by a set of generating facilities and then fed into a distribution network that transports it to the final consumers. Approximately two-thirds of district heating is distributed by close to fifty municipal companies, whereas the remaining supply is covered predominantly by consumer cooperatives (Dansk Fjernvarme, 2023). The municipalities and utility companies are the central actors in collective heat supply. The municipalities carry out heat planning and are responsible for the expansion of heating and the delineation between various collective supply forms, ensuring compliance with the regulations of the heat supply law (Johansen & Werner, 2022). District heating, combined heat and power, and natural gas companies have the operational responsibility for delivering heat to consumers. The municipality can engage in initiatives as a business, as an authority, as an owner of utility companies, and as a facilitator for district heating. As owners, they can promote green transition in collaboration with companies, especially in district heating, district cooling, and waste management (Johansen & Werner, 2022). District heating is legally bound by the self-sufficiency principle, meaning that district heating companies are not allowed to make a profit. In other words, district heating is non-profit (Johansen & Werner, 2022). According to the purpose clause of the heat supply law, the municipal council, in collaboration with the companies, must plan the heat supply in the municipality (varmeplaner) (Klima-, Energi- og Forsyningsministeriet, 2020). Usually, district heating companies propose projects, but the municipal council can also instruct them to create one, for example, regarding a specific area requiring district heating or a transition to renewable energy. The project announcement specifies that the municipality must Plan heat supply and ensure that it happens with environmentally friendly fuels. Review project proposals and ensure positive societal, corporate, and user economics before the municipal council approves the project. Through heat planning, the municipality can initiate a transition in heat supply, and municipalities are responsible for approving project proposals under the heat supply law (Klima-, Energi- og Forsyningsministeriet, 2020).

According to numbers from Rambøl, presented at the Conference of Usage of Waste Heat hosted by DI Energi, there is an enormous potential for utilising waste heat from Business and Industry in Denmark, with around 3.000 GWh/year (Rambøll, 2022).

In an analysis by COWI in 2018, they outlined the importance of location when dealing with data centres, especially if there is a goal of heat recovery (COWI & Energystyrelsen, 2018). When utilising waste heat, the location is a crucial factor due to the need for a heat recipient. If the waste heat is to be used in district heating, the data centre and PtX facility must lie close enough to such facilities so they can be coupled to the pipes; otherwise, the water will not cool down.

Another option could be more along the lines of the Kalundborg Symbiosis, in which a network of industries shares each other's waste resources, in which location is still vital (Kalundborg Symbiosis, n.d.).

Unfortunately, currently, the many data centres are placed or are planned to be placed in places that are inopportune for such potential (Nisgaard et al., 2022). The location is of enormous importance for potentially using waste heat from facilities such as data centres and PtX. As Table 1 indicates, it is especially the hyperscale data centres that are often placed away from cities and thus also oftentimes from district heating networks. If there is no recipient, such as the district heating network, it would mean that the heat must be transported via vehicles, or a piping system must be built over such a long distance that it does not make economic sense. Furthermore, even if the pipes are laid, the longer the heat has to "travel," the more energy it loses along the way, necessitating heat pumps for a 'boost.'

Tabel 1: Typical energy characteristics and locations of different types of data centre (COWI, 2021).

	Hyperscale	Co-location	Enterprise	Edge
Electricity demand	50 – 300 MW	below 50 MW	below 2 MW	50 – 400 kW
Connection to the electricity grid	Transmission (400/150/132 kV)	Distribution (50-60 kV)	Distribution (10 kV)	Distribution (10 kV)
Typical location	Rural areas, large footprint	In or near major cities	In the premises of the owner entity	Decentralised collection, close to end-users

Regarding location, wastewater treatment plants are already ensured to be close to the population due to specific regulations regarding the number and placement of such facilities (Miljøministeret, 2019). Data centres and PtX, on the other hand, have different regulations, and there is more uncertainty from the citizens about a hydrogen plant near them than data centres. Data centres are often poorly located concerning district heating; however, the idea, at least as I have come to understand it through the DG-RESU-LT project, is to place PtX facilities so that it makes sense in terms of proximity to the wastewater source but also in relation to other industries, hoping for symbiosis and waste heat utilisation (district heating).

The municipality is the planning authority for heat supply, waste planning, and physical urban planning. Despite this, they have no regulatory mandate to decide where facilities such as PtX or data centres are situated. As planning authorities, municipalities can coordinate and formulate local plans (lokal planner) (Post, 2018). The local plan can be characterised as a 'local law' specifying the permissible uses and construction regulations for specific properties. It thus serves as a crucial tool for municipal councils to shape the physical development of the municipality. The local plan has a direct, legally binding force on owners and users of real estate. Notwithstanding, they do not have the right to place the facilities anywhere specific, only the right to deny them permission to be somewhere (Post, 2018).

In the informal interview with the energy planner from VEKS, the planned Microsoft hyperscale data centre in Roskilde was discussed and it was expressed that the location was ill-chosen regarding utilising resources such as waste heat. The location is already determined to be in Gadestrup, a small town in the south part of the municipality, consisting of around 800 buildings.

There is no district heating there, and their primary heat source is natural gas and some heat pumps (EnergyMaps, n.d.).

The lack of a district heating distribution network is cited as the reason for waste heat recovery being unrealistic by Microsoft's adviser (Roskilde Kommune, 2021). According to the assessment from 2021, Microsoft has agreed to continue the dialogue on future heat recovery (Roskilde Kommune, 2021). In the Roskilde case, heat recovery might be possible in the future as, like every other municipality, Roskilde is investigating other types of heat sources to replace natural gas because of the obligation to phase out the current natural gas and oil burner before 2030. As of December 2023, Gadestrup was approved for the expansion of the district heat network, which means that the data centre could become part of the district heat network (Fors, 2023). However, implementing the waste heat recovery will likely be more expensive as it was not planned into the building's infrastructure and thus needs to be fitted afterwards, which often costs more.

As there is no national legislation mandating the utilisation and integration of waste heat from facilities, municipalities are heavily dependent on the goodwill of the data centres operators (Rambøll, 2023). They rely on the operators' cooperation to join the district heating network, possibly involving compromises to secure suitable locations for such integration.

It is also important to consider that facilities such as data centres and PtX isn't just a source of heat for municipalities, but also a source of tax revenue, workplaces, and the possibility of attracting more companies and industry to the area. Data centres and PtX can act as a magnet as more industry means more workplaces which in turn can mean more people moving to the municipality. Municipality actors, thus have to take their overall municipal plans into account when allocating areas for energy intensive industries, and as such could risk the operators moving the plans to another municipality, if they choose to make demands of the location.

Discussion

This brings us back to the realm of regulatory frameworks and the underlying plans for district heat systems and possibly the general idea of how we think about waste heat. Currently, within

EU Directives and Danish policy, the emphasis lies on encouragement and best practices regarding the harnessing of waste heat (Rambøll, 2023). The directives and legislative provisions suggest the need for assessments to determine the economic viability of utilising waste heat from facilities, such as Article 26.6 from the EU Directive of the European Parliament and of the Council on energy efficiency and amending regulation from 2023 (European Union, 2023).

This article states, "*Member States shall ensure that data centres with a total rated energy input exceeding 1 MW utilise the waste heat or other waste heat recovery applications unless they can show that it is not technically or economically feasible in accordance with the assessment referred to in paragraph*" (European Union, 2023).

Directives like these can easily be manoeuvred, allowing facilities to locate themselves in areas where utilising waste heat may not be economically justified.

There is a visible interest in promoting the use of waste heat, but the absence of robust legislative backing turns the implementation into a quasi-voluntary endeavour, primarily left to the discretion of facility owners (Klima-, Energi- og Forsyningsministeriet, 2020). While there is positive encouragement from utility companies and municipalities, the effectiveness of this approach is evidently limited, given that by 2022, only around four of the 54 bigger data centres in Denmark are connected to district heating (Nisgaard et al., 2022).

When delving into regulatory considerations, diverse approaches can be envisioned. One regulatory path might involve stipulations on how industries with high electricity consumption should be strategically located in proximity to district heating networks.

Alternatively, regulatory frameworks could pivot towards optimising resource utilisation, conceptualising waste heat as a valuable resource when repurposed, and conversely, as a form of pollution when left untapped. The exploration of regulatory avenues offers the potential to instigate meaningful change in the integration of waste heat, aligning it more closely with sustainable practices and resource efficiency objectives.

It appears that the energy agency does not view waste heat generated from more regulated public entities as strictly. As already described, a significant portion of district heating is created by combined heat and power plants.

Similarly, waste heat from wastewater treatment plants is viewed differently than fully private industries. Section 1a, no. 2 of the Heat Supply Act contains the following definition of surplus waste: "*Surplus heat: Inevitable heat produced as a byproduct from industrial electricity production plants or in the tertiary sector that would be discharged unused into the air or water without access to a district heating system*" (Klima-, Energi- og Forsyningsministeriet, 2020).

It is the assessment of the Energy Agency that heat from wastewater should not be considered inevitable heat produced as a byproduct from an industrial plant. Thus, it is assessed that heat from wastewater is not covered by the Heat Supply Act's definition of waste heat and therefore not subject to the price cap regulation on waste heat (Klima-, Energi og Forsyningsudvalget, 2023). The Energy Agency has particularly emphasised that, after the completion of the purification process, the temperature of the wastewater will mainly be the same as it was at the inlet, and thus, the heat already exists in the wastewater before it is treated at the wastewater treatment plant (Klima-, Energi og Forsyningsudvalget, 2023). Therefore, the assessment is that the heat cannot be considered produced as a byproduct from the wastewater treatment plant. The assessment is made based on the existing regulation. Just like utilities are owned or controlled by regulations to operate economically but not for profit, public wastewater treatment plants are operated in the same way (Klima-, Energi og Forsyningsudvalget, 2023). This means that the government has not felt the need to create a safeguard for consumers in the same way.

It could be interesting to consider the influence environmental considerations could have to create an incentive for other industries to connect to district heating to avoid costs rather than profit from it. The 'division of labour' between the Planning Act and the Environmental Protection Act is, in simplified terms, that through municipal and local planning, land allocation is made for various uses and types of business activities that can be placed in different commercial areas (Post, 2018). The specific limits for noise and air emissions (particles/dust and odour, etc.) are determined in environmental permits or regulated by orders under the Environmental Protection Act. According to the purpose clause of the Planning Act, environmental considerations must generally be included in planning and administration of cases related to physical planning (Miljøministeriet, 2019). The Environmental Protection Act aims to prevent and combat pollution of air, water, soil, and underground, as well as vibration and noise nuisances, and to limit the use and waste of raw materials and other resources, promote the use of cleaner technology, and encourage the recycling of resources (Miljøministeriet, 2019).

If waste heat were more established in the Environmental Protection Act as a source of air and water pollution, even at lower temperatures, as well as a resource when used, it could potentially create a more robust framework for waste heat integration and align it with environmental and resource efficiency goals.

Conclusion

In conclusion, the exploration of waste heat utilisation in Denmark reveals a complex landscape shaped by both positive encouragement and regulatory challenges. While EU Directives and Danish policies encourage best practices for harnessing waste heat, the absence of robust legislative backing leaves the implementation largely voluntary, subject to the discretion of facility owners. The legislative emphasis on waste heat utilization, particularly in facilities like data centres and PtX, is evident, with directives such as the one requiring waste heat usage for those with energy inputs exceeding 1 MW.

However, the challenges lie in the manoeuvrability of such directives, allowing facilities to choose locations where waste heat utilisation might not be economically justified. The new price cap legislation, effective since January 2022, further complicates the scenario, creating a perceived barrier to integrating waste heat into district heating networks. The price cap, designed to ensure consumer's security for relatively cheap heat and provide financial incentives for waste heat utilization, has faced criticism from utility companies and industries, labelling it more of a hindrance than an encouragement. Although it had little bearing on the planning of facilities such as data centres and PtX.

Moreover, the importance of location in waste heat utilisation cannot be overstated. The placement of energy-intensive industries, such as data centres and PtX, plays a pivotal role in determining the feasibility of waste heat integration. Current trends indicate that data centres are often poorly located concerning district heating networks, posing a challenge to effective waste heat utilisation.

As the regulatory frameworks evolve, the discussion must extend beyond encouragement to more stringent measures. Regulatory frameworks should consider stipulations on the strategic location of industries with high electricity consumption in proximity to district heating networks. Additionally, incorporating waste heat considerations into environmental protection legislation could create a more robust framework, aligning waste heat integration with broader environmental and resource efficiency goals. Overall, addressing these regulatory considerations is crucial to unlocking the full potential of waste heat utilisation in Denmark's district heating systems.

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