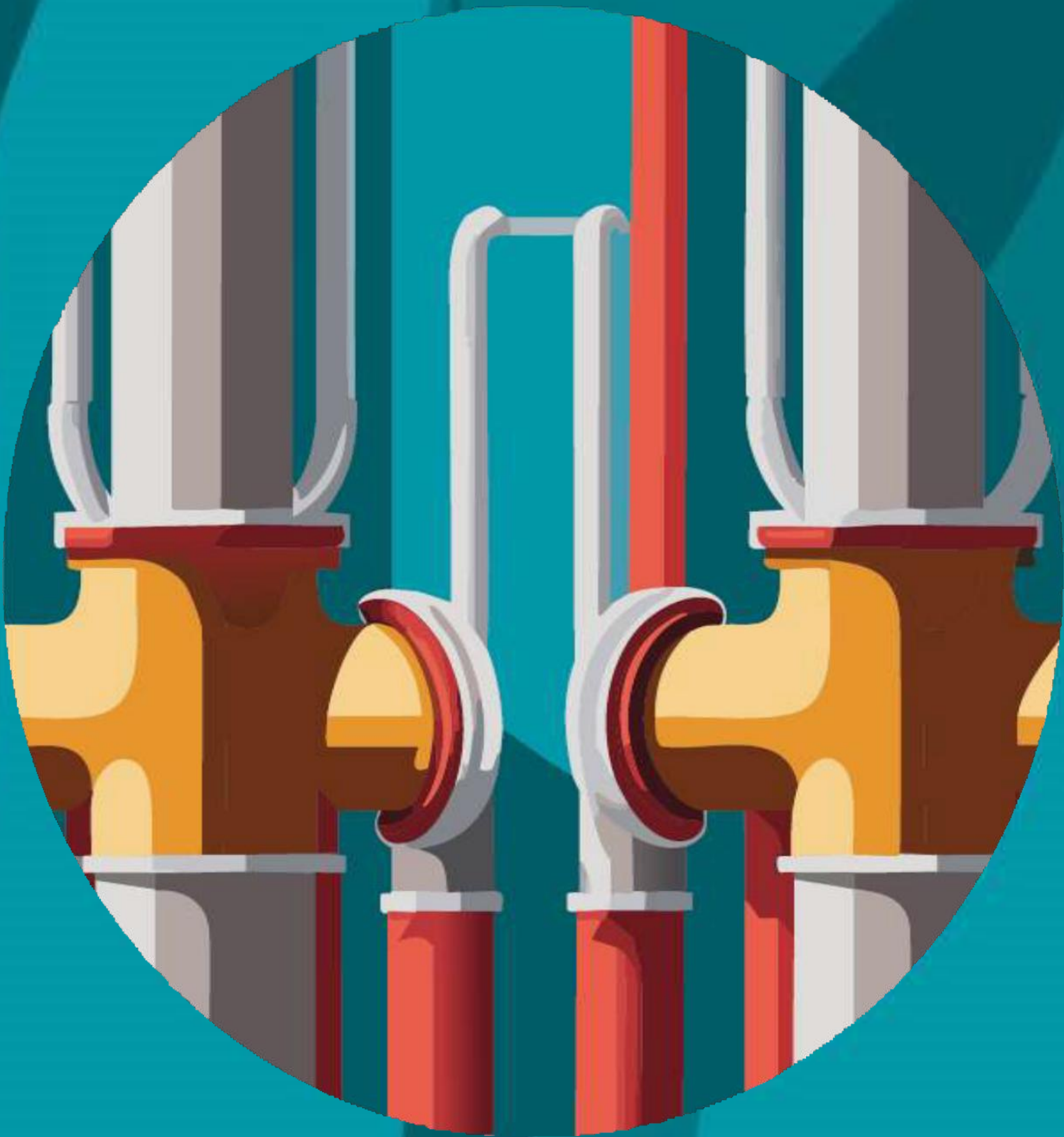
# Insights to Danish heat planning through modelling

The rationale behind the District Heating Assessment Tool



Danish Energy Agency

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# Executive summary

Municipal heat planning in Denmark plays a pivotal role in shaping the heat sector, emphasizing the sustainable development and cost-effective maintenance of comprehensive plans for heat supply. This involves approving district heating projects and follows a structured Municipal Heat Planning framework with distinct phases.

The Municipal Heat Planning phases include screening and mapping of heat demand, a scenario phase assessing multiple future heat supply options, and a planning phase detailing future heat supply in selected urban areas. The approved plan, a legally binding document, confirms the optimal alternative, ensuring compliance with legislation and outlining stakeholder responsibilities.

This is summarized into the District Heating Assessment Tool (DHAT), a pre-feasibility tool developed by the Danish Energy Agency and external consultants. DHAT allows for a comprehensive preliminary feasibility assessment of district heating, considering local factors, landscape, and climate. Its versatility enables its use across various countries and technologies.

In conclusion, the Danish approach to heat planning, shaped by historical context and evolving methodologies, exemplifies a commitment to sustainability, transparency, and effective decision-making in the heat sector. This executive summary provides a condensed overview of the comprehensive document, offering key insights into the significance of municipal heat planning and the role of modelling and scenario creation in facilitating informed decision-making.

Danish Energy Agency

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# Abbreviations

| | |
|---|---|
| [CHP] | Combined Heat and Power |
| [DH] | DH |
| [DHAT] | DH Assessment Tool |
| [DEA] | Danish Energy Agency |
| [LCOE] | Levelized Cost of Energy |

# Introduction

District heating (DH) has been one of the cornerstone of the Danish heat sector since the 1970's, but since then a lot changed. The technologies have evolved, the approach to heat planning has matured, and more versatile tools have been added to the approach.

The changes over time have been influenced and mandated by the public interest, legislation and technological development. Therefore, to fully grasp the concept of Danish heat planning, it is necessary to understand the historical context and how the historical events contributed to the current Danish approach, this will be further highlighted in Section" **Fejl! Henvisningskilde ikke fundet.**".

A key element, which has been utilised since the 1970's is scenario creation. It was deemed necessary to investigate multiple solutions, in order to find the most suitable and adequate solution. This has been done in various ways. In the early stage it was done through heat zoning to define areas designated for DH or natural gas supply. This aimed to create efficient, low-emission energy systems in urban areas and prevent excessive infrastructure investments by identifying viable development areas. Afterwards it was done through socio-economic calculations, where it was mandated by law to investigate other alternatives to DH through project proposals.

In the later years, an addition to the mandated socio-economic calculations, which can be seen as a more elaborate approach were taken, modelling. Many utility companies and municipalities focus on a more holistic approach in order to secure a coherent heat sector, where the technological interplay, the economic cost, and the cumulative effects in the heat sector in total is considered.

One of the purposes of modelling in the heat sector is to secure a more transparent decision making process, which should describe the interplay with the current technologies, but also give the decision makers the necessary information to take a decision.

To help ensure heat sector stakeholders from other countries can access similar approach, the Danish Energy Agency (DEA) created a tool: the District Heating Assessment Tool (DHAT). DHAT is a simple excel-based model for DH. The model was created in 2016 by the DEA and has been developed continuously since, with the cooperation from external consultants.

The tool was created to access the preliminary feasibility of DH, while considering the local population density, landscape and climate in order to create a more realistic study. Furthermore, it was created as a multi-functional tool, which can be utilised by many different countries and access multiple technologies and scenarios simultaneously.

The analysis conducted through the tool can be utilised as a pre-feasibility study, which can be used in the initial phase of a project to determine the scope and thereby contribute to the early stages of the decision making-progress.

# Introduction to Danish Heat Planning

The current Danish approach to heat planning is rooted in experiences and methods that were used in that past 40 years. To understand the current approach to heat planning, it is necessary to examine the developments and changes in technologies and legislation that have influenced the Danish approach and shaped the current Danish heat planning methodology.

## A historic overview

In the beginning of the period, 1972-1990, Denmark like the rest of the world was hit by the oil crisis. With a high dependency on imported oil (from Middle East) Denmark was hit hard and took several initiatives to cope with the serious economic crisis it induced and reduce the dependency of imported oil.

An overall energy policy was formulated by the Government in 1976. Several initiatives to save energy were taken. Restrictions on the use of energy, subsidies and taxes were introduced. Oil and natural gas production started in the North Sea.

A Heat Supply Act was passed in 1979 with heat planning tools to ensure the introduction of natural gas and enhance the use of surplus heat from power plants.

In the 1980s, Denmark intensified its focus on domestic fuel. In 1984, Danish North Sea natural gas production commenced, and in 1985, the Danish parliament decided to exclude coal from heat planning. Additionally, in 1985, energy taxes were raised in response to a decline in oil prices to maintain a continued emphasis on energy efficiency and renewable energy. The co-generation agreement in 1986 underscored the significance of small-scale CHP plants as a major energy policy priority. The political agreement in 1990 aimed at an increased utilization of both natural gas-fired CHPs and biomass for heating in DH. Furthermore, the agreement promoted the expanded installation of wind power.

1990 was the beginning of a new era for DH and energy policy. Heat plans had been finalized for all the municipalities, laying the groundwork for a comprehensive and systematic approach to local and regional heating solutions. Additionally, there were concerted efforts to expand the supply of CHP, particularly from large CHP plants in major cities. This expansion was part of a broader strategy to optimize the use of natural gas and enhance energy efficiency. Until 1990, the 13 counties (later 5 regions) in Denmark played a pivotal role in coordinating the deployment of the nationwide natural gas system and the expansion of larger DH systems, especially those extending across municipal borders. The year 1990 marked a turning point. After 1990, the need for coordination was limited, and as a consequence thereof, the Heat Supply Act were subsequently changed. Hereafter, only the municipalities were Heat Planning Authorities at local level.

The period from 2000 to 2022 witnessed the liberalization of the electricity and natural gas sectors, a significant policy shift aiming to introduce more competition and efficiency in the market. In 2002, initiatives were taken to reduce subsidies for wind and biomass, reflecting a focus on balancing financial sustainability with renewable energy promotion. Later years (2008 and 2012), these subsidies were increased again, indicating a renewed commitment to the green transition and supporting Denmark's long-term goals for sustainable energy.

Municipalities were encouraged by the Minister of Energy in 2008 to switch from individual natural gas to DH. In 2022 with the new situation in Europe, due to the war between Ukraine and Russia, and the very high prices of natural gas, the Government encouraged once more the municipalities to enhance the switch from natural gas and build out of DH and individual electrical heat pumps.

Nowadays, the way of thinking about DH is completely different from what it was 50 years ago. In the future DH supplier shall not be dependent on large production units, but instead be flexible with several smaller green production units that can be switched on and off when it makes sense.

The historical events in this chapter highlights the various paradigm shifts that have taken place in heat planning in Denmark. It also illustrates that the Danish approach has been challenged over time, where it has subsequently been adapted to be able to meet the new needs that have been necessary after crises, technological and legislative changes.

# The current Danish heat planning approach (2023)

The methodological approach to heat planning in Denmark is multifaceted and complicated, as it consists of several elements, which should be perceived in a holistic manner. In summary, the multifaceted approach includes:

- Principles of Choice Awareness and multiple scenario development & Transparent decision-making process
- Socio-economic assessments to complement business economic assessments
- Long-term planning & Scenario creation and design
- Levelized cost of energy (LCOE) approach

These elements highlight the essence of Danish heat planning, these elements are particularly relevant in the initial phase of a heat project, which is also reflected in the fact that District Heating Assessment Tool (DHAT) is a pre-feasibility study tool. The main purpose of this section is to elaborate the various elements and describe what they contribute to, and how it is actually reflected in the DHAT tool.

## Choice Awareness

There are numerous technological possibilities for the establishment and expansion of DH. To identify the most optimal technologies, it is necessary to map out which technologies are implementable, and then assess which are the most feasible, the purpose of this is to secure an informative and holistic decision-making process. (Not exclude better options, understand why other options are rejected).

The underlying logic of this process can be described by using the concept of Choice Awareness[1]. The concept is more than just the direct meaning of the words, Choice Awareness, which can be translated into the need and value of developing and discussing options highlighting various technological possibilities when expanding or establishing DH.

"Choice awareness" in Danish heat planning embodies a conscious and informed decision-making process, deeply rooted in the country's transition towards sustainable energy practices. This concept emerged from Denmark's significant shift in energy policy, particularly pronounced during the energy crises of the 1970s. It was during this period that Denmark pivoted from a reliance on fossil fuels to a more sustainable, environmentally-friendly approach. This shift was not just about changing energy sources; it represented a fundamental change in mindset and policy, fostering a culture of choice awareness among all stakeholders involved in the energy sector.

[1] To describe what Choice Awareness is, the starting point is the designation from "Renewable Energy Systems - A Smart Energy Systems Approach to the Choice and Modeling of 100% Renewable Solutions" by Henrik Lund.

The purpose of Choice Awareness is to promote technological alternatives in the planning and decision-making process in order to facilitate a debate about technological changes within the heat sector. This means that we have a fair and transparent discussion of multiple technologies

In order to plan effectively and reach solutions that are successfully received, it is necessary to evaluate the technology further against a variety of other options, and prevent the chances of a false choice scenario of occurring. A false choice is when only one solution is assessed and discussed, typically presented as the only alternative to the status quo. This type of discourse, characterized by to the fact that only one technology is assessed, naturally excludes other technological possibilities.

Current organizations and companies involved in the heat sector may attempt to prevent new technological solutions from being considered in the planning and decision-making processes. They do this to protect their own interest both politically and in terms of heat production. As a result these organizations and companies may strive to shape the public perception to make it seem that like there is no alternatives.

The elimination of a choice in the public debate can be done by mechanisms and strategies related to power and discourse in the existing organizations or companies to further promote their own interests and products. The elimination process takes place even before the alternative technologies are presented, by doing so the perception of a choice will not occur during any point of the public debate.

This can be further enhanced by organizations and government, who is already path dependent. This means that more steps will be taken in a direction where a path, technology, already have been implemented. This can potentially hinder other paths to be taken since the taken path is affected by positive feedback mechanisms, which is when a path has given positive feedback in the past, it is more likely that path will be followed in the future as well. Therefore it can be hard for new technologies to be part of the heat sector since it is compared to already proven and established technologies in the heat sector.

There are other aspects which also can function as a hindrance for implementation of new technologies to the heat sector such as reluctance to change, costs, and peer pressure. The reluctance to change from the current path is affected by the aforementioned positive feedback mechanisms, and will function as a barrier for up-and-coming technologies, which are not proven. The cost of the technology can also hinder the implementation of the given technology since there is willingness to implement the cheapest solution. Peer pressure is both an internal and external factor in the organization or government, that can affect the decision-making process and thereby affect which approach and which technologies that will be utilized in the heat sector.

In Denmark, we have undergone the Choice Awareness process on several occasions, and these shifts in the heating sector can be categorized as paradigm shifts, Both technological and political developments significantly contribute to these transitions. An example of such a shift occurred in the 2010s when heat pumps gained widespread adoption due to their high efficiency and competitive heat prices.

The paradigm shift could only happen due to the technological maturity of heat pumps and political willingness. This occurred with changes in the taxation of electricity-based heating production in 2019, which strengthened the business case for heat pumps. This, in turn, created a viable alternative to DH, competing not only in terms of heat prices but also highlighting the role of other stakeholders besides DH companies in installing heat-producing units in new areas not subject to mandatory connections.

All of this deviated from the previous practices in Denmark, where the primary approach was utilizing combined heat and power units for DH and where the establishment of new DH areas was heavily regulated due to mandatory connections. This created uncertainties for heat suppliers as they were challenged in areas they had not encountered before.

More recently, heat supply companies have adapted to these changes by implementing large central heat pumps, capitalizing on the new rules in this paradigm shift to their advantage.

The growing focus on Choice Awareness when conducting heat planning will increase the overall knowledge of alternative implementable technologies. This will further promote a more diverse heat sector, both in terms of knowledge and technological mix. Overall it will benefit the society by making people more aware of technological options that can enhance the heat sector, which will then lead to more true choices occurring.

Additionally, as people become more aware of these alternatives technologies, the chance of making misleading choices decreases. This will result in a more balanced discussion of different technologies in the public debates, which will then make it harder for anyone to manipulate the outcome through power or persuasion.

This phenomenon was observed when transitioning from the traditional method of supplying DH areas with centralized CHP plants to more decentralized production units with a greater focus on technological flexibility. This change allowed more users to get connected to DH-systems, and also contributed to an increased awareness of DH in the Danish society.

In hindsight, The decentralized approach has proven effective within a Danish context. However, it is essential to recognize that its success was facilitated by political willingness and the maturity of technologies, which eased its implementation. It is worth noting that this new approach diverged from the established norm and previous practices in Denmark, which meant that many stakeholders had to adapt to new practices, which broke the aforementioned path dependency.

The transparent and informative decision-making process served as the foundation for a broad understanding of DH in Denmark. This dates back to the beginning of heat planning in the early 1980s, where the foundation was laid. Since then, there has been ongoing development in heat planning, both with the expansion DH and in recent years, with a greater implementation of heat pumps, which has increased electrification on a technical level. At the same time, it has also increased public understanding of this technological shift. The entire Danish planning hierarchy has utilized communication tools to spread this knowledge. Therefore, in Denmark, we continue to build on what began in the 1980s, which has contributed to ensuring a holistic and informative decision-making process.

## Transparent decision-making process

In Denmark, there is a focus on ensuring a transparent decision-making process. This is achieved, among other things, through public participation, engaging relevant stakeholders, and evaluating various technologies that can contribute to a competitive heat price in the area.

When it comes to ensuring a transparent decision-making process, it is essential to inform those affected at a level that is easily understandable and in less technical terms for better comprehension and acceptance. In this regard, heat supply companies play a vital role in providing information about the most relevant aspects in an easily digestible manner. Additionally, other stakeholders who may be affected need to be informed about any changes occurring in the area. This could be on an informative level, but also on some sort of participation.

This can be summarized as the need to speak the same language as the stakeholders being dealt with, as there may be different perceptions of what is essential. Therefore, it is necessary to break down barriers and clarify the extent of influence stakeholders can have on the project, rather than presenting it as if they can have a say in the entire project.

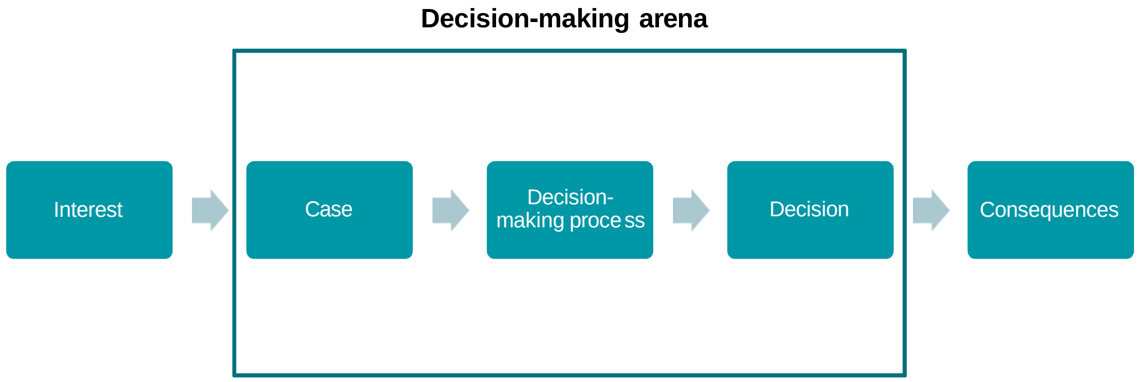


*Figure 1 - Illustration of the decision-making arena ( timeline of this process may vary depended on the given project)*

Figure 1 illustrates how a decision-making arena may appear, based on the assumptions regarding a transparent decision-making process. To gain a better understanding of Figure 1, it is necessary to break down the various elements:

- *Interest* - This refers to the motivation required to bring different technologies to the table. It can be either an economic or a political incentive to promote specific technologies. To ensure the most impartial process, it is essential to maintain technological neutrality.
- *Case* - Each technology or the overall solution must align with the specific context. Therefore, it is important to investigate what is technologically and legislatively possible in the specific case to determine the right technology or solution.
- *Decision-making process* - During the decision-making process itself, it is crucial to inform stakeholders about the technologies or solutions in consideration. To ensure transparency and fairness, it's necessary to explore multiple options and set up scenarios, which can take the form of modelling or socio-economic analyses. It is also important to emphasize the extent of influence various actors can have to ensure a legitimate process.
- *Decision* - The decision is based on what is technologically feasible and influenced by the local context.

Subsequently, it is possible to evaluate the specific decision-making process through solutions, implementation, and consensus on the relevant solution.

It should be noted that the degree of involvement and willingness to participate in energy projects depends significantly on the local context and the technology or solutions under consideration. Therefore, it is important to emphasize that one size does not fit all. Hence, a process may be transparent and legitimate in one project, but in another project following the same procedure, it may appear deficient and non-transparent. Therefore, there needs to be a degree of reflection on how different processes ensure the best form of informative and transparent decision-making process.

The Danish heat planning's holistic approach covers not only the soft elements, such as the human aspect, as highlighted in the previous sections, but also a more systematic approach to technologies and solutions in the form of modeling, scenario building, and socio-economic analyses. This will be explained in the forthcoming sections, with the aim of creating an understanding of the technical aspect and how they are applied in DHAT.

## Socio-economic assessments to complement business economic assessments

In Denmark, the Heat Supply Act obliges DH companies to promote the solution that maximizes the overall socio-economic benefit. However, what does this actually mean?

In this section, we will clarify this and explore how it truly affects heat planning in Denmark and the approaches used to achieve it and how it is applied in the DHAT tool.

When utility companies plan to change heat supply in an area, a project proposal [2]with a socio-economic analysis must be prepared. The socio-economic analysis compares the proposed project with other types of heat supply, which are relevant alternatives to the project, and the socio-economic analysis must prove that the project is the socio-economically most advantageous project, based on a concrete assessment. The concept of socio-economic analysis covers a systematic assessment of a project's advantages and disadvantages for society (socio-economic cost-benefit analysis). The result of the analysis is a statement of the socio-economic consequences calculated in precise costs.

When preparing a project proposal, the impact of the examined alternatives must be presented in areas of corporate economy, user economy and social-economic economy. The purpose of the corporate and user economic analyses is to inform the municipal council, as the approval

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[2] Projects which are covered by the Danish Heat Supply Act includes all projects of public interest or so-called collective heat supply, which includes:

- All projects for distribution and production of district heating, except CHP plant with a capacity above 50 MW electricity, which is approved by the Minister in accordance with the Electricity Supply Act
- Projects for production of heat-to-heat consumers with a total capacity larger than 250 kW
- All projects for distribution of gas

authority, about the financial consequences of a project proposal for companies and consumers. The purpose of the social-economic analysis is to discover which project is the most economically advantageous among the relevant alternatives. It follows from the general principle of proportionality that the municipality is obligated to choose the least intrusive but legal and sufficient means of achieving a desired result. The municipal council can thus take into account such things as corporate and user economy in connection with the municipality's processing of a project proposal in accordance with the Heat Supply Act in situations where a socio-economic assessment does not seem to clearly argue for or against a particular project proposal.

**Business economic assessment**

- Shows the overall finances of the project from the perspective of the utility company

**User economic analysis**

- Shows how the heat price that users pay varies between alternatives examined

**Social-economic analysis**

- Shows the overall sociatal consequences of the project and the alternatives compared to the reference

*Figure 2 - Overview of the different economic analysis and their purposes*

A project is typically created on the basis of a need or desire to renovate or expand an existing heating system, to establish a new heating system.

The DHAT tool is intended to be a multipurpose model, and it supports that Levelized Cost of Energy (LCOE) calculation (explained in Section ”Levelized cost of energy (LCOE) approach”), including marginal cost calculations, a feasibility study of the heat planning project and a socio economic analysis are calculated. This will be further explained in Section”Socio-economic assessments to complement business economic assessments”.

## Scenario creation & Long-term planning

"Scenario creation" during Danish heat planning is a crucial aspect of the strategic approach to managing and developing heating solutions. This process involves the development of various potential scenarios or models that represent different pathways the heating sector could take in the future. It serves multiple functions, from aiding in informed decision-making and risk management to shaping policy development and facilitating stakeholder engagement. These scenarios might include various energy source options, technological advancements, regulatory changes, and shifts in consumer preferences. The creation of these scenarios sets the stage for understanding the range of potential developments and challenges that the heating sector may face. Once scenarios are created, socioeconomic assessments come into play. This approach ensures that Denmark's heat planning is robust, forward-looking, and aligned with both current and future needs.

Scenario creation has been approached in various ways in a Danish context. Over the years, this approach has also evolved to meet the changing needs of scenario creation.

In the early years, scenario creation was primarily carried out through socio-economic analyses, where DH was compared to other relevant alternatives in accordance with Danish Heat Supply Act, which in most cases meant comparing it to natural gas. To relate this to the previous section on "Choice Awareness," one could argue that this approach to scenario creation might be seen as offering limited choices due to a lack of willingness to explore other technological alternatives, given the strong push for the adoption and implementation of DH. However, it should be noted that this scenario was a possibility, not necessarily the reality that occurred, as it might not have been technologically feasible to find an alternative that was economically competitive with DH in a socio-economic context.

In more recent times, the approach to scenario creation has significantly changed compared to the past. It is now often combined with modelling, where values and scenarios from modelling work are integrated into socio-economic analyses. It should be clarified that numerous scenarios are typically generated, not only to stress-test, i.e. test the robustness of the system, different possibilities but also to gain a better understanding of how changes in technologies and production distribution can alter the dynamics within a DH-system, e.g changing the operation strategy – which can change the capacities of production units and then eventual affect CAPEX and OPEX. Consequently, not all scenarios result in concrete feasibility studies.

However, this approach, combining modelling and socio-economics, makes it easier to identify scenarios or alternatives that are not dependent on individual user knowledge. Therefore, it can be argued that this newly developed method contributes to a more genuine occurrence of a "true choice".

## Time period

When constructing scenarios, it is essential to ensure that comparisons are made over the same time period. If this is not possible, it is necessary to account for this when calculating the Levelized Cost of Energy (LCOE).

In a Danish context, two different approaches are commonly used:

*Technological Lifetime* - In this approach, various technologies are compared based on their technological lifetimes. If there is a difference in the lifetimes, a reinvestment is made for the technology that needs an extension, as it can be argued that this financing will take place in the future anyway.

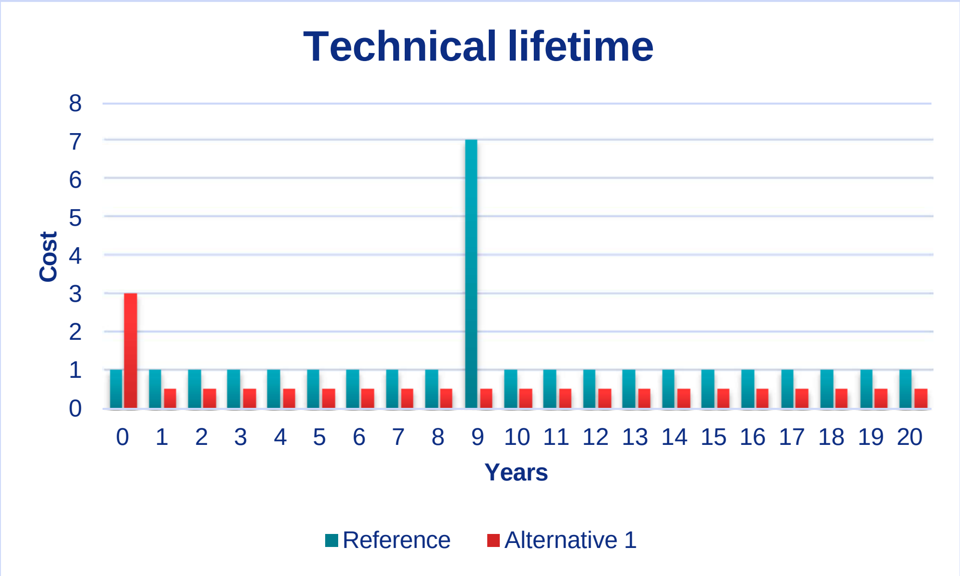


*Figure 3 - Example of comparison of cost of two technologies with different technical lifetimes*

This is attempted to be illustrated in Figure 3, where you can see reinvestment in the reference scenario in year 9. The figure only considers costs, reflected on the Y-axis, while the X-axis represents the number of years, which in this example is 20.

*Objectives* - The second approach involves working from a specific year, often linked to political objectives. In a Danish context, this could be 2030 and 2050, while in a Chinese context, it might be 2030 and 2060. In this approach, the lifetimes of technologies are extended until the desired year is reached.

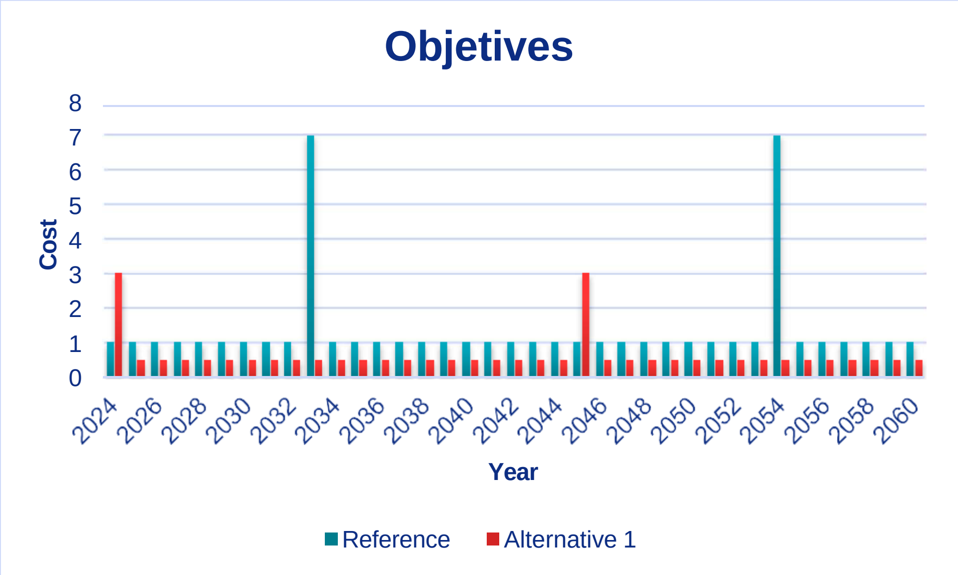


*Figure 4- The figure illustrates how reinvestments may look if the desired year is 2060. The figure only considers costs, reflected on the Y-axis, while the X-axis represents the years*

The choice between these approaches depends heavily on the intended use of the scenarios. Therefore, one approach cannot be excluded in favour of the other, and it can be argued that both approaches share many similarities. However, there are uncertainties associated with creating scenarios far into the future, as it involves dealing with many unknowns and the inability to account for political changes, technological developments, and more.

Therefore, scenarios are constructed based on assumptions, often portraying a critical approach to these assumptions to uncover their advantages and disadvantages for the scenario's purpose. Sensitivity analyses are also conducted on the main parameters such as interest rate, project evaluation time and more

In the DHAT tool it is possible to do both approaches, but it is important to emphasise that the goal of the scenario creation is important to take into consideration when choosing which approach to use.

## Methodology approach to scenario creation

The Danish approach to scenarios leads to the creation of many scenarios. This is most often done through a methodical approach where the possible scenarios are mapped based on technological developments in the DH sector and political goals. By doing it this way, one is not limited by the user's knowledge, and this also results in learning for the user who conducts the scenarios.

When creating scenarios, it is important to assess whether it involves a new DH-system or an existing system. In this section, a detailed overview of the benefits and uncertainties regarding a new DH-system is provided.


*Figure 5– Overview of the methodological approach to scenario creation*

**Demand**

Firstly, the scenario is constructed in reverse, starting with the demand, which is usually calculated based upon the prediction of connected users. Secondly, attention is given to energy savings, estimated population growth over a time span ranging from 20-40 years, and local building development, typically part of municipal planning in Denmark.

**Technologies**

After assessing which technologies are suitable to meet the demand, the focus shifts to examining short-term and long-term efficiencies, heavily linked to cost considerations. The aim is to evaluate the most cost-effective way to meet the demand. In Denmark, this is associated with striving to achieve the lowest possible heat price for consumers. While this approach may not be applicable in China, adopting a similar strategy is deemed useful, considering the most cost-effective way of producing heat.

Another key factor in Denmark is the willingness to diversify technology usages, leading to the establishment of multiple production units to fulfill the demand.

**Fuel Mix**

An assessment of the fuel mix includes determining the type of fuel to be used, exploring the potential integration of renewable energy (RE) into the system, and evaluating CO2 emissions based on the chosen fuel mix.

The methodology behind an existing DH-system is somewhat similar to the approach described with the new DH-system, but there are some key differences that should be highlighted:

When planning for existing areas, there are already connected users that need to be included, and established technologies are in place to meet the existing demand. Therefore, in terms of technologies, the goal is to find the most suitable technology based on the existing system. This provides less flexibility in choosing technologies, as consideration must be given to the technology already in use.

Avoiding sunk costs is crucial, making it essential to take a holistic view of the system and assess the interplay between new technologies and existing ones. It's important to consider the near future when existing technologies will reach the end of their technical life.

There is also greater certainty regarding the degree of connected users in existing areas, which strengthens the business case and provides a better indication of the feasibility of the project.5.

The two methodological approaches shares the hermeneutic approach, where one continually optimizes and evaluates the results until reaching a satisfactory outcome or the scenario cannot be further optimized.

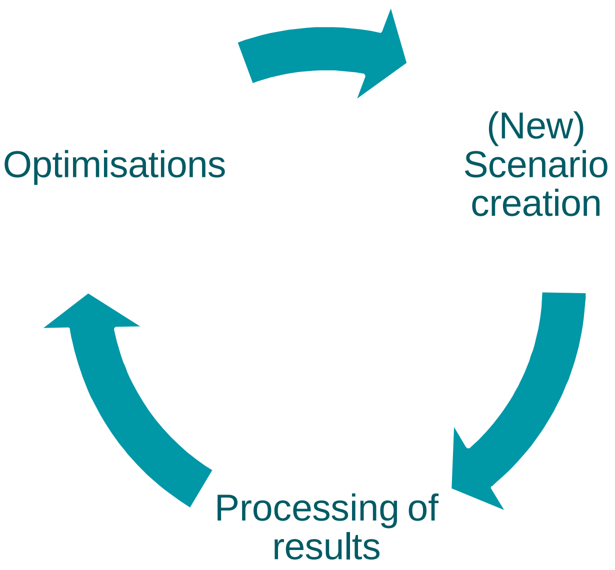


*Figure 6 – Illustration of the hermeneutic approach*

Figure 6 illustrates the hermeneutic approach, where one continually optimizes and evaluates the results until reaching a satisfactory outcome or the scenario cannot be further optimized. In the figure, "new scenario creation" is indicated, and this should be understood as the initial creation of the scenario, with the argument that every time optimisation occurs, a new scenario emerges

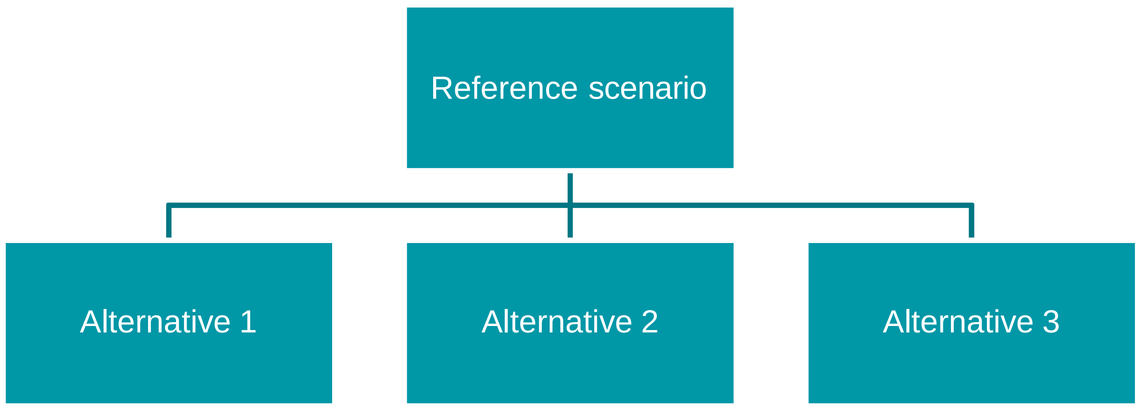


*Figure 7 - Overview of possible scenarios*

As mentioned earlier, many scenarios are created, and an overview of these can be seen in Figure 7. This is a common approach to how scenario mapping can look in a Danish context. First and foremost, there is a reference scenario, the purpose of which is to map the existing production and needs. Depending on the purpose of the scenarios, either a frozen policy approach or an approach that considers planned changes and takes into account objectives for the time period is usually used. To enhance understanding, both of these approaches are included in Figure 8.

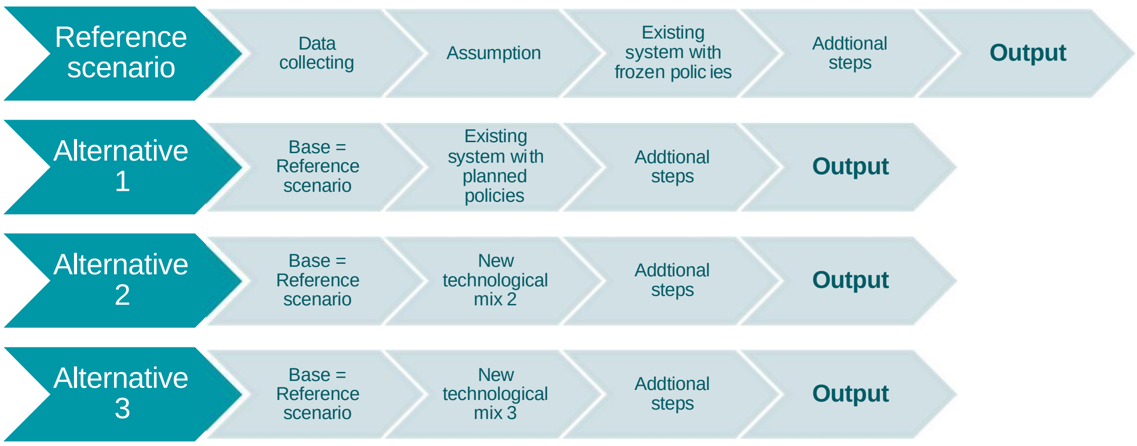


*Figure 8 – Overview of the structure of the different scenarios*

In Figure 8, an attempt has been made to illustrate how the construction of the various scenarios takes place. It is a simplified version to promote understanding, but essentially, it starts with the reference scenario and how it is actually created. Under "Additional steps," sensitivity analyses are performed on relevant parameters, capacity optimizations, and more. Therefore, it is important that these elements are given priority, and the right amount of resources is allocated to them.

After all the scenarios have been created, it is crucial to present the results to decision-makers and explain what they actually mean, which can be linked back to Section ”Choice Awareness & Transparent decision-making process”. Additionally, scenarios have also been created to enhance user understanding and curiosity. These scenarios may not necessarily be used in the decision-making process but can serve as important elements in the holistic approach.

Regarding how to assess whether a scenario is good or not, the LCOE (Levelized Cost of Electricity) is used, which will be described in the next section.

## Levelized cost of energy (LCOE) approach

The levelized cost of energy (LCOE) methodology discounts all projected expenditures and revenues to their net present value in a specific year – equivalent to the average expected price for consumers in order to repay all costs. This concept is used in DHAT tool.

In Danish heat planning, the Levelized Cost of Energy (LCOE) approach is a critical analytical tool used to assess the cost-effectiveness of different heating solutions. LCOE represents the average cost per unit of energy produced, calculated over the lifetime of an energy-producing asset. The main function of the LCOE in Danish heat planning is to provide a standardized and comprehensive method for comparing the economic feasibility of various heating options, including conventional fossil fuel-based systems and renewable energy alternatives. By evaluating the long-term costs associated with different energy sources and technologies, LCOE helps decision-makers identify the most cost-effective and sustainable solutions for meeting the country's heating needs.

Net present value, on the other hand, is a financial concept that discounts future cash flows to their current value, allowing for the comparison of projects with differing timelines and cash flow profiles. When applied to energy projects, net present value helps to understand the net economic benefit or cost over the project's life, considering the time value of money.

Together, LCOE approach and present valve form a comprehensive approach to evaluating the long-term financial feasibility of energy projects, which is crucial for effective decision-making in energy planning.

The methodology is useful from a societal perspective comparing alternative heat generation technologies. The LCOE calculation use the same technology data and costs estimates, as the remaining calculations in the model. Therefore, the LCOE results will automatically be adjusted to local conditions, when changing the cost estimates and price projections. For comparison of the cost structure, the LCOE is calculated for all technologies with 5000 full-load hours and 200 full-load hours by default, representing base-load plants and peak-load plants respectively. Still, the user can specify the number of full load hours. In this way, the user can easily see the difference in cost composition of plants with high investment costs and low marginal costs, typically base-load plants, and plants with low investment costs and high marginal costs, which are typically peak-load plants.

Moreover, the user can develop ideas about which technologies to promote, and thereby, create a political incentive to change the framework conditions to ensure private investors select the best technologies from a societal perspective. Usually, the optimal societal decisions differ from the private entities optimal decision. The socio economic marginal cost and private economic marginal cost are also calculated, but excludes the annualized investment costs and fixed operation and maintenance costs. A marginal cost comparison showing the societal benefits of CHP (combined heat and power) plants in favour of condensing power plants and boilers is furthermore calculated following the feasibility study approach, which follows the standard cost-benefit analysis evaluation method. The cost of the reference, continuation of individual supply including reinvestments in new individual heat production technologies, is compared to the project, which is establishing district heating with its associated production technologies and district heating network. The development of the district heating network will take place over a couple of years. In that time, individual technologies will still produce heat to some households, which is also included in the project.

## Conclusion

In conclusion, the evolution of DH in Denmark has been a dynamic journey influenced by public interest, legislative changes, and technological advancements since its establishment. The approach to heat planning has matured over the years, incorporating more versatile tools and methodologies to address the complexities of the heat sector.

Key to this evolution has been scenario creation, a practice to explore diverse solutions and identify the most suitable options. Initially focused on zoning and socio-economic calculations, recent years have seen a shift towards more holistic approaches, incorporating modeling to consider the technological interplay, economic feasibility, and other cumulative effects within the entire heat sector.

The introduction of modeling serves as a crucial purpose to the development of a transparent decision-making process. Decision makers are provided with comprehensive information on current technologies and the interplay between, based upon that they can make informed choices. In this context. The DHAT tool tries to capture of all this and make it implementable in an international context, DHAT serves as a versatile model for assessing different supply alternatives for DH.

DHAT's creation was driven by the need to ensure a preliminary feasibility assessment of DH, considering local factors such as population density, landscape, and climate for a more realistic study. Importantly, it is designed as a multi-functional tool accessible to various countries, accommodating multiple technologies and scenarios concurrently.

The tool's analytical capabilities extend to pre-feasibility studies, contributing significantly to the early phases of decision-making in project development. In essence, the Danish approach to heat planning, shaped by historical context and evolving methodologies, illustrates a commitment to sustainability, transparency, and effective decision-making in the heat sector.

Danish Energy Agency

# References

# Appendix

Terminology Explanations

- The principle of proportionality
  The principle of proportionality, in law and ethics, advises that actions by authorities should be balanced and not excessive relative to the situation or intended harm prevention. It is commonly applied in human rights, constitutional, and administrative law to prevent unnecessary infringement of individual rights.

- Frozen policy
  Frozen policy means a long-standing government or organizational policy that remains unchanged, despite changing external conditions. It implies policy stagnation, resistance to updates, and reluctance to make necessary changes. This can be due to bureaucracy or political factors. The term can have positive or negative connotations based on the policy's relevance."

- Sunk costs
  Sunk costs are past expenses or investments that cannot be recovered. They are irrelevant to future decisions in business and economics. Decisions should focus on prospective costs and benefits. Sunk costs, being unchangeable, should not affect whether to continue or abandon a project.