AALBORG UNIVERSITY

STUDENT REPORT

DILEMMAS OF ENERGY CRISIS

FOCUS ON SHORT-TERM AND LONG-TERM ENERGY PLANNING

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Title:
Dilemmas of Energy Crisis

Theme:
Short-term and long-term planning

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Abstract:

The researched problem of this thesis has been what the influence of energy crisis is on RE development both in short-term and long-term, this has been researched to identify what knowledge from the current and previous energy crises can be utilized in future strategic energy plans to secure the RE development in Denmark.
The issue has been researched based on the theoretical understanding of energy planning. In terms of methodological choices, short-term aspects are evaluated based on calculations of Levelized Costs of Electricity and Abatement Costs where long-term aspects are measured based on EnergyPLAN modeling. These assessments take point of departure in PVs, since this technology is mentioned in the Emergency Regulation established by the EU during the current crisis.
Since the results of these investigations are based on conceptual and theoretical assessments the results are evaluated by key actors in the energy sector to identify the difference between the theoretically identified issues and solutions - and the practical experience. The results indicate that stand alone PVs are one of the cheapest RE-technologies short-term. However, if the share of PVs is significantly increased in relation to long-term needs of capacity the electricity from PVs is not utilized in the energy system. The general experience from the practical viewpoint from the actors is also that systems based on the most differentiated mix of RE-technologies have been least influenced by the crisis.
The energy crisis has been a key factor to emphasize these issues and has reopened the discussion of how to reach both the short-term goals of the energy crisis, and the long-term goals of the climate crisis with RE development.

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SUMMARY

Several dilemmas have occurred during the crisis, decisions should be based on consideration of both short-term and long-term aspects to ensure that renewable energy (RE) -projects implemented during an energy crisis does not pose a threat to reaching the long-term goals of 100% RE to meet energy demands in the future. Experience from the oil crises during the 1970s indicate that a combination of planning approaches and both short-term and long-term goals for development creates an increased RE-development.
Dilemmas during both the crises in the 1970s and the current crisis are following; energy dependency, self-sufficiency, energy infrastructure and finding alternatives to a limited fossil energy source. These elements are a part of the first phase of the energy crisis. The next part of the energy crisis if considering the crises in the 1970s is going to be the implementation of RE-projects and establishment of new goals and strategies with the opportunities the energy crisis has entailed.
However, this experience combined with events of the current energy crisis also indicates that development of RE should happen before the crisis happens, since the planning methods and tools are limited during a crisis where short-term actions are needed. Several planning approaches, methods and tools exist to ensure both short-term and long-term development. Therefore, the following years of planning are crucial to the RE-development and the structure of the future energy system in Denmark.

One example of the difference between short-term and long-term goals is that short-term the goal is to out phase natural gas from Russia, in long-term the goal is to out phase natural gas in general. However, this example also emphasizes the results of this thesis that short-term and long-term perspectives is not necessarily contradictory, despite different focuses. Specifically, one product amongst others from the current energy crisis has been the Emergency Regulation, this regulation eases the approval processes for RE technologies and specifies that Photovoltaics (PVs) are one of the technologies that should play a role in becoming independent of Russian gas.

Three critical developments during the crisis have been identified in this thesis; industries have experienced a setback to oil, district heating development happens too rapidly without national frames and goals, PVs are prioritized due to their short-term economic feasibility but are not stand-alone sustainable in long-term.

Due to delimitations of the methodological and theoretical choices in this thesis, the thesis should be a starting point to investigate the dilemmas of energy crisis even further and considered in strategic energy planning to ensure a sustainable development of RE.

TABLE OF CONTENT

PREFACE

Following preface contains an introduction to the issue of this thesis, an overview of abbreviations and definitions of terms utilized in this thesis. Moreover, the preface contains a reading guide and acknowledgement of other research. The purpose of these sections is therefore to clarify the scope and purpose of this thesis while preparing the reader for how to understand the thesis structure.

A great thanks should be granted to supervisor Henrik Lund for great supervision throughout the project period. Moreover, a thanks should be granted to the interviewees; Kim Behnke, Søren Dupont Kristensen and Karsten Capion for their time and willingness to participate in interviews and their inputs on this thesis.

ABBRIVIATIONS

RE – Renewable Energy
RES – Renewable Energy Source(s)
PV – Photovoltaics
CO_2 – Carbon Dioxide
GHG – Greenhouse Gas
EP – European Parliament
EU – European Union
LCoE – Levelized Costs of Energy
AC – Abatement Costs
NPV – Net Present Value

DEFINITIONS OF KEY TERMS

In following section an overview of how key terms are defined in this thesis is made. This is done to clarify what these terms include in this thesis and how they should be understood.

Energy Policy

In this thesis energy policy is understood as a reflection of the ambitions of society, containing specific goals, measures and/or initiatives for a certain development. Thereby energy policy influences the context of energy planning.

Energy Planning

Energy planning can be a broad term. In this thesis the understanding of energy planning is that it constitutes of methods and tools that depending on the utilization create a pathway to solve a problem. Planning works within a context which influence and is influenced by the energy planning. Therefore, energy planning often entails plans or strategies to how the political goals can be reached.

Sustainability

Sustainability is overall understood as the term is defined by (Brundtland, 1987). However, energy solutions in this thesis are investigated based on specific elements of sustainability, which is; economical sustainability, technical sustainability, and environmental sustainability. This is done with the knowledge of the existence of e.g., social, and local sustainability and different understandings of these sustainability elements (Plan og Byg, 2011). In this thesis economical sustainability is measured from a short-term perspective where it is equal to economic feasibility which in short-term often is equal to the economically cheapest alternative. Technical sustainability is in this thesis measured from a long-term perspective from an energy system perspective. This means that the technical effect a certain technology has on the energy system define its technical sustainability. The environmental sustainability is in this thesis measured by the cost-effective reduction of CO_2-equivalent a specific energy technology entail. Thereby, is the environmental sustainability equal to how significant the CO_2-reduction of implementing the technology is.

Short-term

In this thesis short-term perspectives and goals are defined within the time frame from now and around 5 years past that, since this fits with the time frame of several RE-projects processes (Kærgaard, 2023). Thereby, the short-term perspective reflect actions to be taken now and not in the future.

Long-term

In this thesis long-term perspectives and goals are defined within the time from around 5< years from now. Thereby, these perspectives and goals often reflect future development. The long-term context might therefore be different from the short-term and can thereby differentiate depending on whom the development is identified by.

READING GUIDE

The structure of this thesis is illustrated bellow in figure 1.

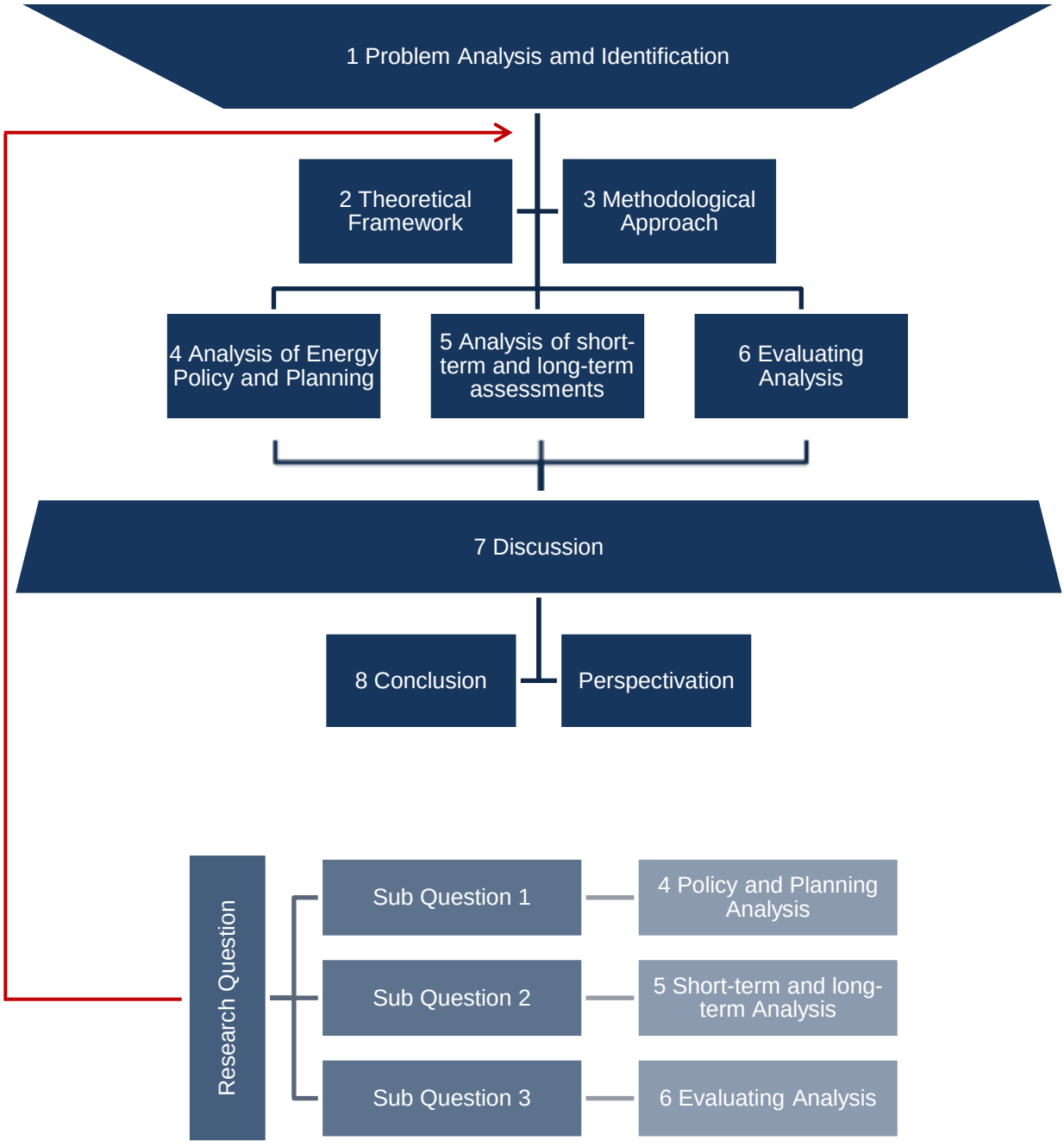


Figure 1 Overview of structure, chapters, and answer to the research question of this thesis.

It is illustrated on figure 1 that first the problem of this thesis is investigated and identified. In this relation the scope is also clarified by the problem formulation and the research question. Following this the theoretical understanding and methodological choices utilized to investigate this problem are presented. These chapters are utilized in the following analyses chapters that investigate the energy policy and planning development from 1973 until now (2023), the analysis of specific short-term and long-term measures for assessing PV technology specifically, and lastly in the evaluation of utilization of the investigations and results. Following these the results and delimitations of this thesis are discussed. The research question is answered based on the sub questions and the specific chapters that these are answered in. The conclusion is based on this and the following discussion and finally answers the research question of this thesis. The perspectivation addresses aspects that are relevant to the thesis issue but are not a part of the scope of this thesis.

References to sources in this thesis adheres to the Harvard method, literature and other sources are referred by (Surname or organization, year).

ACKNOWLEDGEMENT OF OTHER RESEARCH AND LITERATURE

Extensive research of the influence of the oil crises in the 1970s and energy crisis in general has been done, Some of these found by literature studies are ; (Williams & Alhajji, 2003) and (Coyle & Simmons, 2014). This research is acknowledged and utilized to understand the influence of energy crisis in this thesis.

Specifically in a Danish context and the Danish energy policy development after the oil crises (Rüdiger, 2011) has made one of the most specific overviews. Therefore, (Rüdiger, 2011) dominate the analytical storyline of what policy measures and initiatives were made before 1970, and between 1970 and 2011. This is key knowledge as it sheds light on the different phases of an energy crisis and has been utilized to determine what the next phase of the current energy crisis might hold.

INTRODUCTION

The latest report from (IPCC, 2023) puts into words the importance of acting on the climate crisis as soon as possible. The (IPCC, 2023) predicts a temperature increase higher and earlier than previously expected. The consequences of this development have both negative human and climate impacts. These impacts can be linked to economic costs to society, which means that improving current conditions also has a significant positive economic effect (IPCC, 2023).
The projection shows that current policies are not enough to achieve a sufficient decrease in emissions to reach a temperature increase below 2 degrees (IPCC, 2023). In general, the risks posed by increased climate change have increased because of the increased level of global warming (IPCC, 2023).
Therefore, RE-development is more important than ever and the influence the current energy crisis has on this development is crucial to address and investigate. It is clear from the IPCC report that action is needed, and that action must be taken now to change current developments. There is a need for the ambitions and objectives that have been established to be underpinned by concrete action.

Because of this global climate crisis, the long-term strategies and goals are more relevant than ever, if the human contribution to climate changes are to be minimized. It is important for these long-term goals to be reached that the short-term goals and plans constitute a pathway to reach these goals. If this is not the case a fear could be that the short-term initiatives can become a hindrance to reach the long-term goals and thereby a hindrance to minimize the climate crisis.

Currently another crisis has appeared globally – the energy crisis. During the first stage of this crisis the focus in many countries have been to find quick and cheap alternatives to the Russian gas supply that has ceased. A fear could be that because of this urgent lack of supply security, energy solutions that are not the most optimal solutions to reach the long-term goals could be implemented in a short-term period.

Therefore, the scope of this thesis is to investigate how the current and historical energy crises affects the development of RE in short-term and long-term. This is to determine what can be learned from the crisis, what elements of the crisis could be utilized in strategic energy planning and overall, what influence the current energy crisis potentially could have on the future energy system in Denmark.

CHAPTER 1: PROBLEM ANALYSIS AND IDENTIFICATION

The following chapter seeks to identify the problem and scope of this thesis, by investigating which issues the current energy crisis involves. This is done based on the initial wonder upon what the issues of the current energy crisis are and if there are any of these elements that can be problematic in long-term.

ENERGY POLICIES AND PLANNING CONCERNS DURING CRISIS

Just as oil became a political and economic weapon in the Middle Eastern conflicts of the 70s, natural gas has also become a weapon in the war that is now causing the current energy crisis (The Council of the European Union, 2022). This has caused energy policy and security policy to become closely linked during the crisis. Security of energy supply was a significant factor in first phase of the 70s and is also a significant factor today. According to (Williams & Alhajji, 2003) following objectives for security of supply can be set:

- A country's own energy production capacity
- The dependence on imported energy for the country
- The concentration of imported energy to the country
- The amount of energy reserves the country has
- The opportunities for the country to import from other energy producers

Already in 2017, when the European Parliament (EP) established the framework for the security of gas supply, security of supply in the event of an end of gas supply was a focus. Some changes have been added in the light of the current crisis;

> Quote from Regulation of gas supply security 2017:
> *"The Commission's communication of 16 October 2014 on the short-term resilience of the European gas system analysed the effects of a partial or complete disruption of gas supplies from Russia and concluded that purely national approaches are not very effective in the event of severe disruption, given their scope, which is by definition limited. The stress test showed how a more cooperative approach among Member States could significantly reduce the impact of very severe disruption scenarios in the most vulnerable Member States"* - (The European Parliament and the Council of the European Union, 2017)

Figure 2 Quote directly from (The European Parliament and the Council of the European Union, 2017), explaining the influence of complete disruption of gas from Russia.

However, the risk assessments have not ensured that Europe's security of supply was unaffected during the current crisis. It was also the conclusion by both (The European Parliament and the Council of the European Union, 2017) and (The European Parliament and the Council of the European Union, 2022) that Denmark and the rest of EU does not have effective national measures to deal with disruption of supply. According to (The European Parliament and the Council of the European Union, 2017), one way to minimize the consequences of an energy crisis is for member states to cooperate and support the particularly vulnerable countries. However, this is difficult to practice when all European countries are close to equally influenced by the crisis. According to (CEPS, 2001) the energy market in Europe and security of supply is a debated area of the European Commission. Therefore, the risks associated with ensuring security of supply in Europe have been assessed in a report by Centre for European Policy Studies (CEPS) (CEPS, 2001). According to CEPS, the responsibility for maintaining security of supply lies at the market actors, which is both energy companies, consumers, and governments (CEPS, 2001). (CEPS, 2001) sees that there are three crucial factors that define the level of security of supply. These three factors can be seen on figure 3.

Current Danish long-term goals have two milestones – 2030 and 2050 (Danish Energy Agency, n.d.). It is Denmark's vision to comply with the Paris Agreement and reduce CO_2 emissions by 70% by 2030 and to be 100% independent of gas, coal and oil by 2050 (Danish Energy Agency, n.d.).

The Danish Energy Agency states that to achieve these goals, it requires a focus on ensuring security of supply and solving the climate challenge with RE technologies (Danish Energy Agency, n.d.). Therefore, this issue is not only related to the short-term issues from the energy crisis, but also the long-term goals in relation to the climate crisis. It is an ambition that energy is produced nationally in Denmark as far as possible, but that energy cooperation with the EU continues to be strengthened and increased as well (Danish Energy Agency, n.d.). Thereby a significant amount of energy is predicted to cover the future demands (Geertsen & Dyck-Madsen, 2003). In the light of the crisis where reliability of imported energy sources has been the core of the security of supply concern, it is important that the sources for the imported energy are considered.

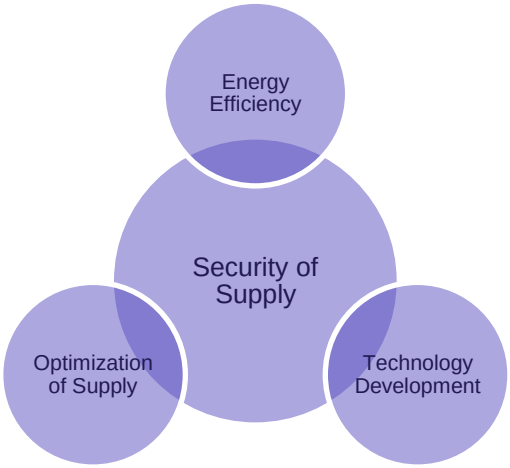


Figure 3 The three parameters (CEPS, 2001) identifies as influential to the security of supply.

According to (Moret, 2017), uncertain times lead to radical changes in countries' strategic energy planning and societal discussions for future development. Times of crisis can become drivers of policy review and the establishment of new objectives and strategies (Moret, 2017). Energy modelling and optimization plans are often the basis

for political decision-making processes, but the forecasting algorithms of these models usually do not consider the uncertainties and changes that occur in the energy field in relation to e.g., energy crises (Moret, 2017). This causes a limitation to what methods and tools decisions during energy crises can be made. It can affect the development of the RE technologies. Especially when technical stability is needed to cover energy demands that was covered by oil or natural gas, fluctuating RE-technologies can be affected by the uncertainties created by crisis.
The outcome of the policy-making processes determines the size and production profile of the RE technologies approved and established (Moret, 2017). This is crucial in terms of the short-term and long-term prioritization, since it might be different production profile and technological capacity is feasible in short-term and long-term, since it depends on how the feasibility is measured.
What the alternative to natural gas determines these needs for capacity and are politically prioritized different in each European country depending on energy potentials and availability. Before the crisis there were specific ambitions for RE-development in Danish energy policies.

DANISH ENERGY POLICY: PLANS AND STRATEGIES FOR RE DEVELOPMENT

According to the Energy Agreement from 2018, Denmark must focus on offshore wind in the future to become self-sufficient in RES (The Danish Government, 2018).
In the agreement, there is a broad consensus that Denmark's offshore wind resources should be utilized as much of the potential Denmark has geographically to produce energy from offshore wind turbines (The Danish Government, 2018). In general, (Danish Energy Agency, n.d.) identifies several energy sources that should be utilized in a Danish context. These sources can be seen on following figure 4.

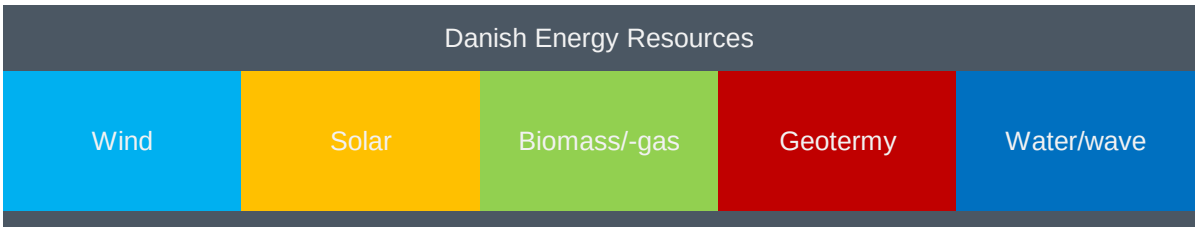


Figure 4 Overview of key energy sources for Denmark in the future, based on (Danish Energy Agency, n.d.) and (The Danish Government, 2018).

Moreover, in the agreement from 2018 the government states that market regulation in the form of technology-neutral support for RE projects should contribute to the development of RE projects in the future (The Danish Government, 2018).
All in all, an overall prioritization of focus areas to become 100% RE-based by 2030. This emphasizes that a variety of RE sources (RES) is needed to reach the long-term goals.

THE ENERGY CRISIS OF TODAY – ISSUES AND DILEMMAS

The situation of the current climate crisis is that due to the stop of natural gas supply from Russia, there has been energy shortages globally and especially in the EU (Danish Authorities, n.d.). The shortage has led to increase in energy prices and an agreement by the Danish government has been to initiate significant energy saving proposals to ensure energy security (Danish Authorities, n.d.). The crisis has been a combination of technical difficulties around Europe, less production from RE-sources than expected and the stop of natural gas supply to Europe.

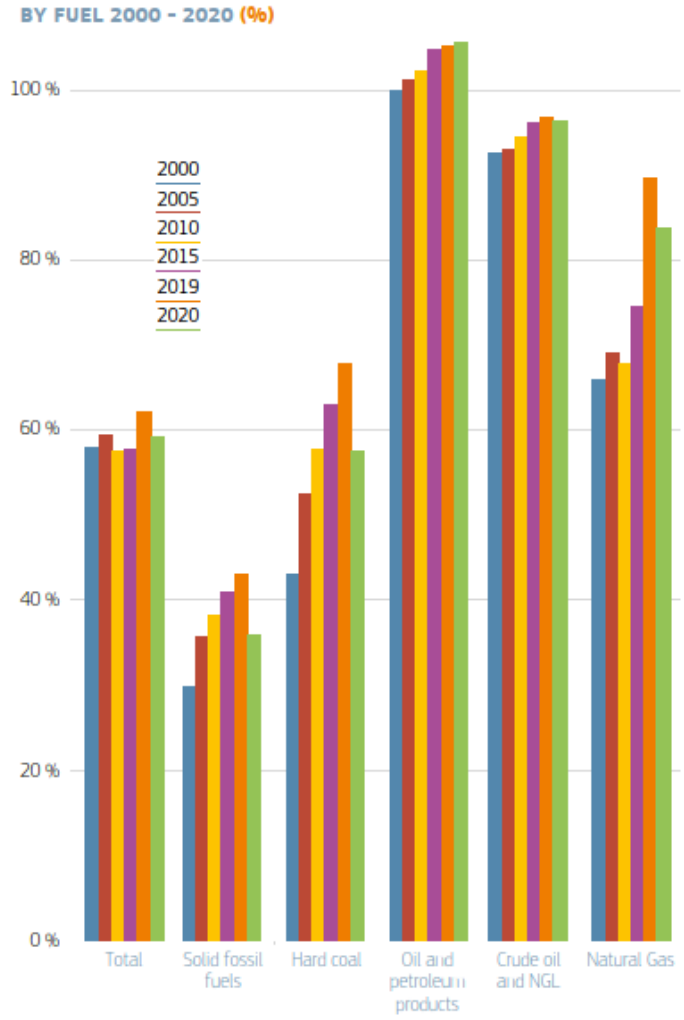


Figure 5 Overview of world energy dependency by fuel by from 2000-2020 (European Comission and ACER, 2022).

According to the EU's Agency of Cooperation of Energy Regulators (ACER), 43.3% of the EU's natural gas imports came from Russia in 2020 (European Comission and ACER, 2022). In addition, 25.7% of imported oil and 53.9% of imported coal also came from Russia in 2020 (European Comission and ACER, 2022). In general, the natural gas dependency has increased significantly since 2000 (see figure 5). In the same year, approximately 38% of the total natural gas consumption in Denmark accounted for imported natural gas (European Comission and ACER, 2022). According to (Danish Energy Agency (c), n.d.), approximately 75% of gas consumption in Denmark in 2022 was covered by imported gas. However, it is expected that this gas consumption can be covered by Denmark´s own production of biogas in 2030 (Danish Energy Agency (c), n.d.). This illustrates that both the EU and Denmark have so far been dependent on not only natural gas imported from Russia, but also coal and oil from the same source of supply (European Comission and ACER, 2022). This also means that the influence of natural gas supply stop from Russia could have been minimized if the sources of supply for both European and Danish gas consumption had been more widespread.

Because of the sudden stop of supply of natural gas, several industrial companies in Denmark have been supplied with oil as an urgent replacement for natural gas (Lynggaard, 2022). For the climate, this means that Denmark will emit more

greenhouse gases (GHG) over the coming years than have been emitted in recent years (Lynggaard, 2022). This means that Denmark can fall further behind in reaching the long-term climate goals set for 2030 and 2050 (Lynggaard, 2022). The current crisis has also influenced Denmark economically just as the crises in the 70s did (Finans Danmark, n.d.). The crisis has led to rising inflation and significant increases in energy prices (Finans Danmark, n.d.). This shows that the current energy crisis affects not only the energy sector but all sectors and actors dependent on energy economically (Finans Danmark, n.d.). Especially companies and private consumers have been financially affected by the energy crisis so far (Finans Danmark, n.d.). The consequence of the impact has led to significant corporate bankruptcies (Finans Danmark, n.d.). Moreover, several technical challenges have prevented the expected European self-generation of RE (Jørgensen, 2022).
The main causes of the energy crisis can thereby be identified as following:

- The war in Ukraine has led to a significant reduction in natural gas imports (Jørgensen, 2022).
- Hot and dry weather means that there has been a greater need for energy for cooling and that generally not as much energy has been produced in Europe as usual – i.e., we have been more dependent on fossil energy sources than usual (Jørgensen, 2022).
- Technical challenges have meant that less energy has been produced in Europe in general – e.g., the electricity market is tied to the most expensive production technologies, this has also been decisive for the electricity prices during the crisis (Jørgensen, 2022).

Right now, Denmark like the rest of Europe is facing a political decision-making process that will lay the foundation for a Danish supply policy that will ensure that Denmark gets out of the crisis (Geertsen & Dyck-Madsen, 2003). It is going to be crucial to find alternative energy supply sources to cover the future Danish energy demands (Jørgensen, 2022). However, the short-term policies must be in line with both the climate goals and transition strategies that Denmark is obliged to comply with (Jørgensen, 2022). Therefore, energy planning and policy will have to consider both short-term ways of escaping the crisis and to consider methods of ensuring that long-term strategies and goals are met.

RE PROJECTS AND -DEVELOPMENT SHORT-TERM DURING THE CRISIS?

As a political tool for Denmark to become independent of natural gas, a plan to accelerate the phase-out of natural gas was adopted (Ministry of Climate, Energy and Supply, 2022). In this connection, it became a requirement for all municipalities in Denmark to draw up a heating plan for how the municipalities' areas should transition away from natural gas as a supply fuel (Ministry of Climate, Energy and Supply, 2022). Citizens in the affected areas should be clearly informed by the end of 2022 about how the transition will take place (Ministry of Climate, Energy and Supply, 2022).
Data from the Danish gas company - Evida shows that Denmark's consumption fell by approx. 17% during the first two quarters of 2022 compared to 2021 (Evida , 2022). This illustrates that it is nevertheless possible to minimize the consumption of fossil energy sources if there is a political desire for it. The problem is that the development has happened so quickly and without an official plan that in e.g., the cases of the

industries, it has not been possible to replace natural gas with renewable alternatives immediately. For the district heating development, no clear national plan or framework to ensure the long-term sustainability of the development is done.
Another policy tool that has recently entered into force is the Emergency Regulation Plan established and approved by the EU (Kærgaard, 2023) (The European Parliament and the Council of the European Union, 2022). The regulation aims to provide a framework for accelerating RE projects as a means of improving security of supply during the energy crisis (Kærgaard, 2023). The regulation has, among other things, secured concrete changes in the definition of the permit processes required for the establishment of RE projects and a shorter processing time for specific RE-projects (The European Parliament and the Council of the European Union, 2022). Specifically, the regulation highlights PVs and heat pumps as key technologies to reach the short-term goals (The European Parliament and the Council of the European Union, 2022). This focus however does not immediately align with the Danish ambitions by (The Danish Government, 2018) to increase especially the Danish wind capacity, amongst a variety of RE-technologies and -sources.

SHORT-TERM VS. LONG-TERM PERSPECTIVES

(CEPS, 2001) defines security of supply differently for short-term supply and long-term supply. Minimizing technical and economic issues while increasing the flexibility of the energy grid are core elements in securing the future supply (CEPS, 2001). The availability and general development of the energy grid and energy infrastructure are crucial to securing supply further into the future (CEPS, 2001). Therefore, in the short-term, reserve capacity of primary energy sources plays an essential role - In the long-term, it is about storage capacity of RES (CEPS, 2001).
It is a fear that the development as mentioned, where several industries have been obliged to cover their demands by coal and oil may slow down the development and implementation of RE projects (Lynggaard, 2022). Since this not only affects the transition in short-term with increased emissions. It also affects the long-term transition goals. The current increase in oil and coal could have negative consequences in the long-term, if a plan is not drawn up to phase out the use of these fuels again (Lynggaard, 2022).
According to (Bang, 2022) who represents several larger Danish companies there is an ambition and a wish from the members of Dansk Erhverv that the development of RE is increased. According to (Bang, 2022) several Danish companies have been significantly challenged economically by the high electricity prices. This could be one of the explanations on the transition to oil by industries and can both be solved by and illustrate the need for RE development.

PROBLEM FORMULATION

Today, the current energy crisis influences energy markets and energy supply globally and thus also Denmark. The crux of the crisis lies in the fact that the European energy system so far has been dependent on natural gas from one source – Russia.
With the disruption of gas supply from Russia; energy reserves, decrease in consumption and alternative supply have been primary tools to deal with the crisis. Overall, the crisis has shown an expression of the vulnerability both the European and Danish energy systems still have to disruption of energy supply from import sources.
The energy crises in the 70s have had a major impact on the energy systems established globally today. Therefore, the current crisis may equally play a decisive role not only on current RE projects, but also equally on future RE projects and energy systems in general.
With the step back for the RE-development with several industries transitioning to oil consumption there is a risk that the short-term initiatives that has been consequences during the current crisis and new RE projects that are approved and established because of the crisis do not meet the long-term strategies and goals for Denmark's future energy system.

So, what is the problem?

What influence is the energy crisis potentially going to have on future RE development? Which aspects distinguish the short-term and long-term plans? What should be weighted in the consideration of which RE technologies should be prioritized short-term for Denmark to achieve the long-term strategies and goals? Several ways to investigate and answer these questions might exist. In this thesis, the focus is on examining what pathways have been utilized historically and what methods can assess both the short-term and long-term potentials of the RE technologies. This is based on what technologies are predicted to be a part of Denmark's future energy system. To achieve the long-term goals, it is essential that short-term goals and plans are implemented as a step towards the long-term goals. Therefore, this is what is investigated in this thesis.

RESEARCH QUESTION

"What is the influence of energy crisis on the development of RE projects short-term and long-term, and what important knowledge from the crisis should be utilized in strategic energy plans and policies for the future energy system in Denmark?"

- **Sub Question 1:** *What influence has the energy crisis made on energy planning and policy in Denmark?*
- **Sub Question 2:** *How can short-term and long-term aspects be assessed for specific RE technologies?*
- **Sub Question 3:** *Where should knowledge from the crisis and assessments be utilized in future energy plans and political decision making in Denmark in general?*

Validation of research question – why is this research problem relevant?
Since the current energy crisis is not over yet there has been limited time for other researchers to investigate the current situation and other ways to include the issues of the current crisis in future strategies. However, with the influence the energy crisis has had on the development of RE-projects in Denmark already to secure RE alternatives to the natural gas consumption, the crisis has shown the need for both short-term and long-term planning to ensure that the short-term initiatives are both feasible and sustainable in the long-term as well. It should be acknowledged that the energy crisis has entailed new challenges and therefore also new solutions that could change the development of RE radically both in short-term and long-term.

Scope on Danish electricity production
One of the outcomes of the crisis has been a plan for development of district heating in areas supplied with natural gas in Denmark (Ministry of Climate, Energy and Supply, 2022). Therefore, the scope of this thesis is the electricity system in Denmark. Another reason for this is, that to reach the current long-term goals of becoming RE-based in 2050 an essential part of the pathway is to electrify a significant share of the Danish energy system, which makes the future sources for electricity crucial (The Ministry of Climate and Energy, 2011).

CHAPTER 2: THEORETICAL FRAMEWORK – ENERGY POLICY AND PLANNING

The theoretical framework focuses primarily on explaining the ontological and epistemological understanding in this thesis explained through different theoretical understandings of, utopia of energy planning, energy policies and choice awareness. The output of this theoretical framework for further investigation is to create a theoretical understanding of the core of and solutions to the problem investigated in this thesis and to clarify how this understanding influences the respective analyses, results, and conclusions. The following chapter describes how planning, planning approach and technological choices is understood in this thesis.
The purpose of this description is therefore to create a framework for understanding how the theoretical approach from ontology and epistemology in this thesis is utilized and how it should be understood in relation to the methods and investigations done in this thesis to ensure that the research question is answered.

THEORETICAL UNDERSTANDING OF PLANNING UTOPIA IN THIS THESIS

Planning is generally understood as an approach to structure and map future developments. To understand which societal, technical, and economic considerations should be included in the planning, the context of the planning is essential. It is essential that the system in which new projects are implemented, is defined, and included in the planning that determines further development.

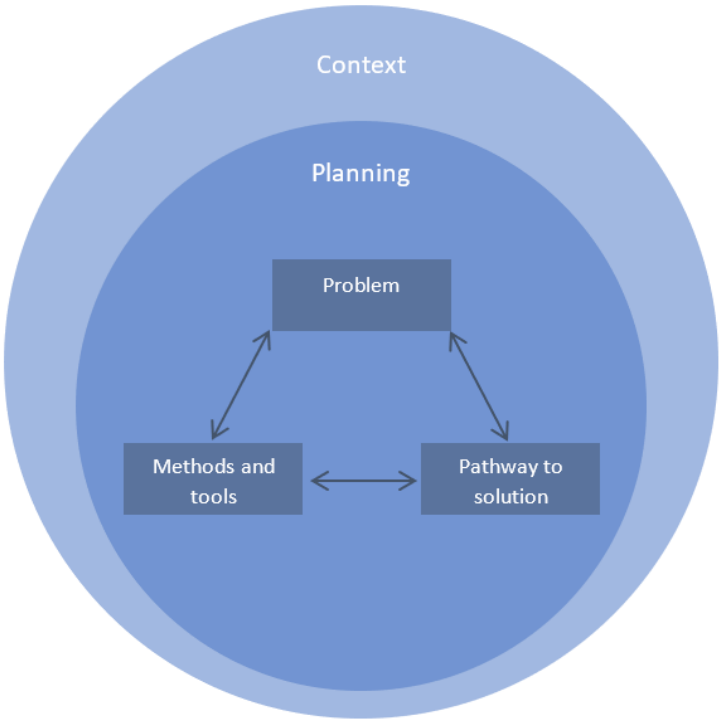


Figure 6 Illustration of the utopia of planning in this thesis.

The utopia of planning can be seen on figure 6 above and lies in the context in which it is planned. The utopian aspect of the future can therefore be a product of past trends, present challenges, or opportunities for the future. The context is thereby crucial for which problems the methods and tools of the planning are to solve.
This understanding of planning is based on the following theoretical literature.

ENERGY POLICY AND PLANNING

Planning is an instrument (Gaardmand, 1980). Planning is a prerequisite for human activity in society (Gaardmand, 1980). Planning is an expression of the priorities of the political power structure in society (Gaardmand, 1980). Therefore, planning is complex. Based on this, one could argue that planning is first a political instrument. However, it is important to remember that planning is a combination of both scientific methods and political interests (Gaardmand, 1980). The current existing social structures influence new societal changes (Gaardmand, 1980). Therefore, change will most often be conditioned by existing structures and institutions (Gaardmand, 1980). The main limitation of planning is however also the existing and established framework, since this can be challenging to change (Gaardmand, 1980).
Planning has a specific function for a specific development that is desired (Gaardmand, 1980). However, this development is linked to the social reality that is desired to be developed through planning - and in which planning therefore works (Gaardmand, 1980). In this thesis this reality is a part of the context on figure 6, where the function lies in the method and tools on figure 6. These core elements are the greatest opportunity and limitation for creating change with planning in society (Gaardmand, 1980). Planning can lead to both concrete actions and important society-related discussions (Gaardmand, 1980).
With the Planning Act reform of 1969-1974 one significant change was that the problem to be solved now is a decisive factor (Gaardmand, 1980). As a result of increased complexity of problems to be solved, spatial planning and non-spatial planning can no longer be separated to the same extent (Gaardmand, 1980). Because of the focus on the problem this factor is also included in this thesis on figure 6.

(Hvelplund, 1980) links the growth of society to energy policy. According to (Hvelplund, 1980), there is a link between the growth of society and the increase in energy consumption. The increase in energy consumption leads to an increased need for policy objectives and a new energy policy framework (Hvelplund, 1980). Therefore, (Hvelplund, 1980) puts the general development of the Danish standard of living in connection with the development of Danish energy policy.

In the same way as (Hvelplund, 1980) portray it, it can be argued that the ever-increasing energy consumption in Denmark combined with the current crisis has produced a similar effect with a similar need for new energy policy objectives and frameworks. The process of new energy policies described by (Hvelplund, 1980) is illustrated on following figure 7.

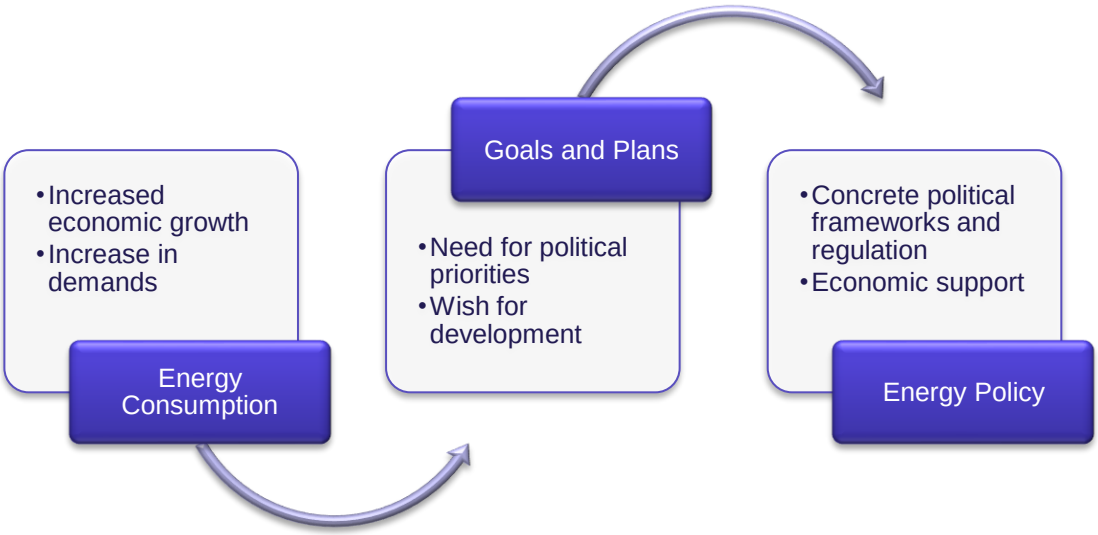


Figure 7 Overview of the driving mechanisms of energy policy and planning that (Hvelplund, 1980) identifies.

PLANNING APPROACHES AND POLITICAL PATHWAYS

One method of planning is the projection (Gaardmand, 1980). The projection attempts to predict how the future will be based on past events and developments (Gaardmand, 1980). According to (Hvelplund, 1980), many Danish energy policies over time have in common that they are based on projections that relate to previous developments (Hvelplund, 1980). This applies, among other things, to the estimation of the consumption pattern expected for the future in general and specifically future fuel consumption (Hvelplund, 1980).

The focus on projection is according to (Hvelplund, 1980) due to the influence of energy suppliers on energy policies. Their interest has not been to reduce energy consumption and they have therefore not been drivers to political changes to reduce the energy consumption (Hvelplund, 1980).

(Hvelplund, 1980) also criticizes the projection approach. Projection forecasting can provide an overview of future opportunities and challenges (Hvelplund, 1980). But projection forecasts cannot determine how the social structure and thus the propagation ground for future development and changes will be established without additional efforts (Hvelplund, 1980).

This is an essential point that can be a factor to why long-term goals can be difficult to reach. Without concrete activities or effort – a pathway of short-term goals – it can be challenging to get to the scenario the projection seeks to forecast.

The ambition of planning is to ensure changes, by analyzing alternatives the desire is that society changes for the better (Gaardmand, 1980). It is the goal that the changes

and projects that are established create added value and improvement for the context in which they are implemented (Gaardmand, 1980). For this ambition, it is important that goals for development are set. That there is significant support for achieving these goals and that the institutions and policies that are crucial for development are dominating (Gaardmand, 1980). This ambition is in this thesis described as the pathway to solve the problem in figure 6. What methods and tools are utilized to create this pathway is previously mentioned and is an essential part of the pathway as illustrated in figure 6. Energy policies are in relation to this linked to planning since policies can be utilized to coordinate which investments need to be made to achieve the objectives set and thus which instruments are to guide the desired development (Hvelplund, 1980).
(Gaardmand, 1980) identifies three main types of planning. Corrective planning which is not planning as such, things develop as they do and the framework for further development is created along the way (Gaardmand, 1980). Prognostic planning, which is planning of frameworks for future development, thereby it is more regulation based on studies of the societal development (Gaardmand, 1980). Programmatic planning which is planning of new developments that differ from previous developments and is therefore more active planning than the two other planning approaches (Gaardmand, 1980). The three approaches are illustrated on the following figure 8.

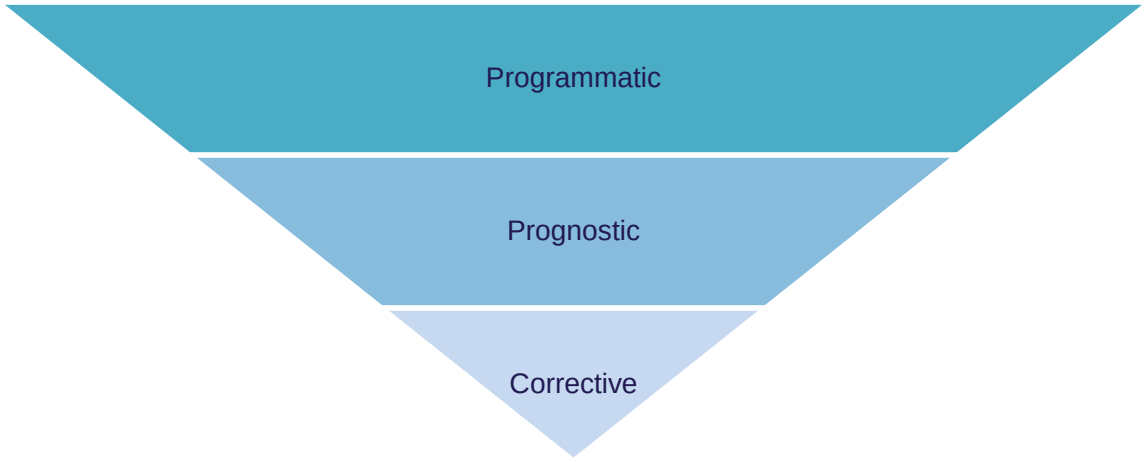


Figure 8 Illustration of the planning approach types that (Gaardmand, 1980) addresses. The approaches are placed after their influence on development where the bottom is least influence, and the top is most influence.

(Gaardmand, 1980) describes a planning dilemma. Should society adapt to the planning or should the planning adapt to society (Gaardmand, 1980). This is an essential question, since it determines the view of the context in figure 6, that the planning is implemented in. It determines what planning approach is fitting for the development.

One could argue that the answer to the question depends on whether the scope is short-term planning or long-term planning. On short-term the existing societal institutions will be dominating. Therefore, short-term planning must take existing societal structures much more into account than long-term planning where new institutions and infrastructures already have been established on the way to reach long-term goals. In terms of the planning utopia- in figure 6, the corrective planning is the approach with tools that has the least influence on the development, where the programmatic planning is the approach with the most influential tools for the development. Often the Programmatic planning is more long-term oriented, where long-term strategies and goals would be a way to define a desired development. Where the corrective and in some cases the prognostic planning is more short-term oriented, where more concrete political initiatives or regulation is implemented for the development to continue or to increase.

Planning in an energy crisis

The same planning dilemma as (Gaardmand, 1980) mentions can be described in the context of the energy crisis. Should elements of the energy crisis be considered in planning or should they not? There is no doubt that the current energy crisis can drive development faster than so many other events, and that the crisis can be the starting point for major changes. But the question is whether these are changes that benefit the development of society in the long-term, or whether decisions based on current issues risk being too hasty. The question returns to the utopia of planning as illustrated in figure 6 – the context.

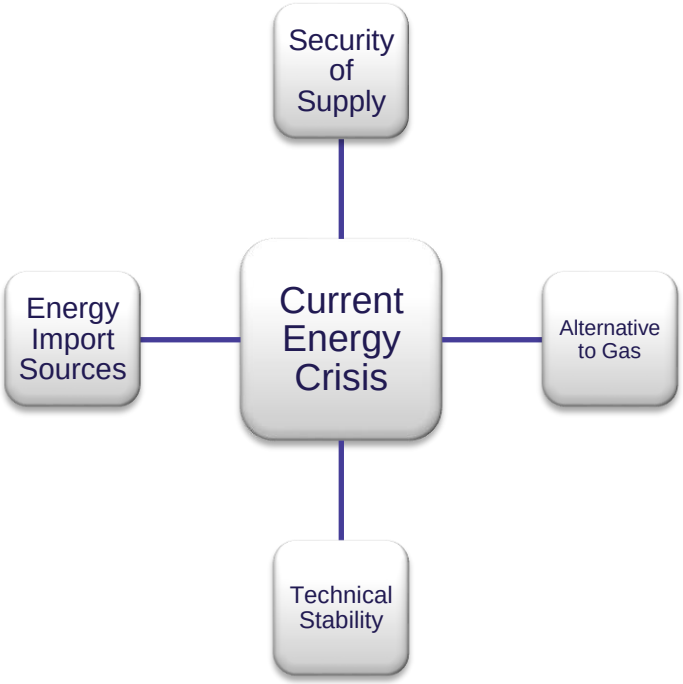


Figure 9 Overview of issues that have been discussed in the light of the current energy crisis.

The context of planning sets the planning framework for which actions and solutions are possible (Gaardmand, 1980).
This framework is determined by several societal factors, which means that, society has a significant impact on and for the results of planning and the development that occurs because of planning (Gaardmand, 1980).
The current context is crisis, uncertainty, and disagreements. That situation has existed before and will exist again in the future. But the question is whether the context can be beneficial in both the short and long term. What are the consequences of the crisis on short-term and long-term planning? And what problem out of the many displayed in the figure above does the planning seek to solve? With what methods and tools and with what solution? This is important to answer to ensure well thought

planning during a crisis. Figure 9 illustrates the issues identified in the problem analysis in chapter 1, that has dominated the energy planning during the current crisis. The existing societal structure plays a greater or lesser role, depending on the planning approach (Gaardmand, 1980). Often, adapted, and supportive planning is chosen by decision-makers because it fits into the existing social structure which can be needed on short term to e.g., get out of an urgent crisis (Gaardmand, 1980).

It is often when the problems or disagreements have occurred that planning begins (Gaardmand, 1980). In this way, planning is not preventive but becomes an attempt to regulate and correct to solve the problem dominated by the corrective planning approach (Gaardmand, 1980). In these situations, conflict mitigation is a significant part of planning as a defense of the priorities that planning entails (Gaardmand, 1980). In such situations it is important to remember that reality cannot be seen with neutral eyes - planning is therefore never neutral (Gaardmand, 1980). The perspective from which reality is viewed influence the interpretation of the world (Gaardmand, 1980). Assumptions, judgments, and norms govern how the approach to and perspective on the world is (Gaardmand, 1980). It will often be the strongest perspectives who decide the planning basis and thus the course of development chosen over the altarpieces (Gaardmand, 1980). This is especially also an important factor when planning in crisis situations. Therefore, the demand for alternative solutions plays an essential role in reducing the impact of power, as several alternatives and perspectives are forced to be considered in the planning process (Gaardmand, 1980). This uncovers new opportunities that may be valuable for future societal development (Gaardmand, 1980). Therefore, the consideration and investigation of alternatives is a key part of the choice of solutions which is core element of the planning utopia illustrated on figure 6. Dialogue in planning will also often result in priorities being reconsidered (Gaardmand, 1980). What makes sense to prioritize? What is important to prioritize? This helps to strengthen the planning principles that result from the planning process (Gaardmand, 1980). It can create the opportunity for new directions to be established and in general that the influence on societal structures is clarified (Gaardmand, 1980).

SHORT-TERM AND LONG-TERM POLITICAL GOALS

(Hvelplund, 1980) highlights some specific short-term and long-term objectives:

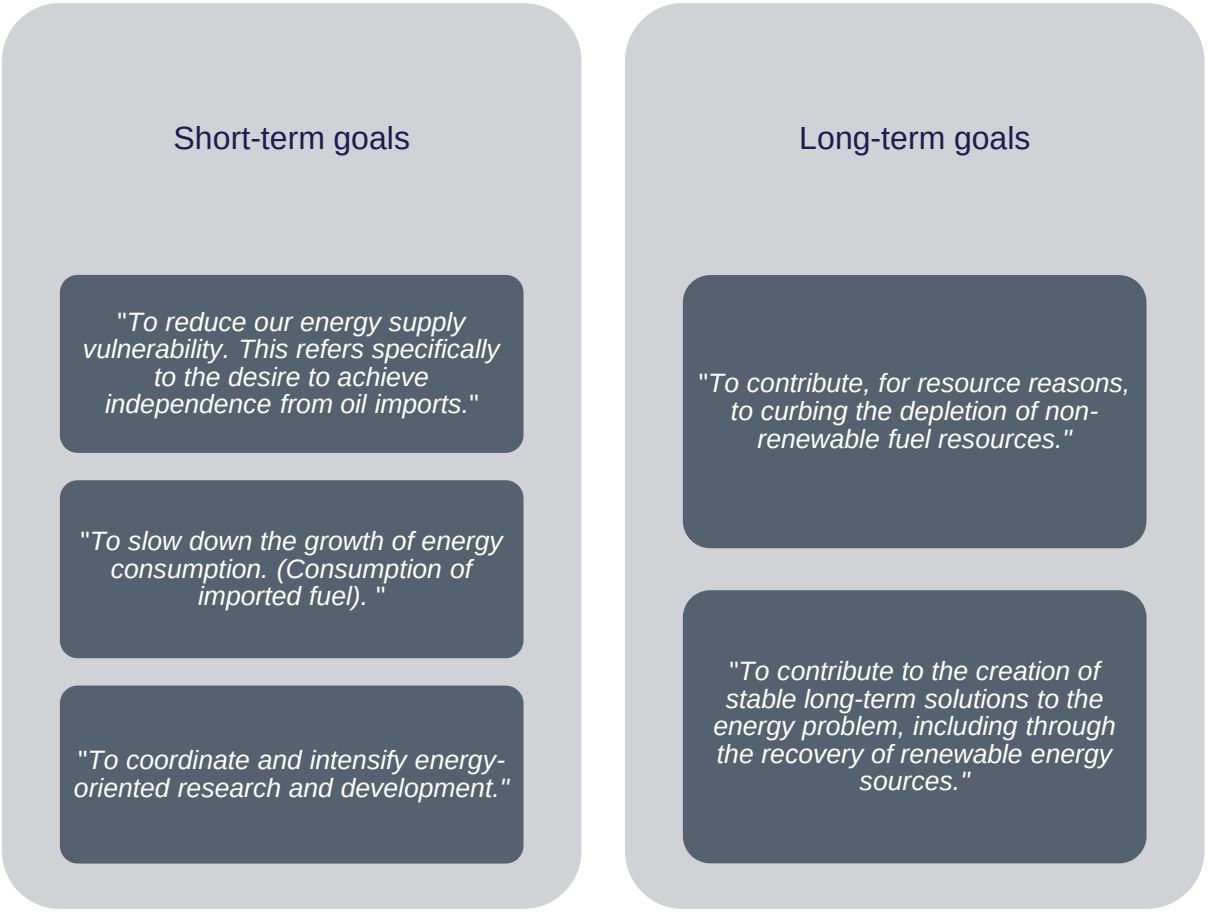


Figure 10 Quotes from (Hvelplund, 1980), who identify the essential short-term and long-term goals made because of the crises in the 70'ies.

Although these objectives were valid in 1980, when (Hvelplund, 1980) highlighted them, these objectives in several areas represent the objectives and the situation that still and especially apply today during the crisis. Both the short-term and long-term goals contain elements that have been discussed several times during the current crisis. This includes independence from imported fossil energy just natural gas instead of oil. The future energy consumption, the development and prioritization of energy technologies, and in general how stability and flexibility are ensured for the future energy system to be 100% based on renewable technologies.
As previously mentioned, (Hvelplund, 1980) questions whether projections based on previous development patterns have the possibility of including significant parameters that are important for the current context and the current issues. (Hvelplund, 1980) believes that these parameters should be investigated to map the actual underlying cause of the issues that the development seeks to solve.

(Hvelplund, 1980) identifies these parameters as following:

- Alternative energy systems
- Inflation
- Pricing policy and tax policy
- Influence from interest groups

The first parameter is also addressed by (Lund, 2014). Which precisely emphasizes the importance of being aware of the options and alternatives that exist. Which also emphasizes that new and valuable aspects are an essential part of exploring alternative solutions, which (Gaardmand, 1980) also highlights.

CHOICE AWARENESS – CHOOSING FUTURE ENERGY TECHNOLOGIES

(Lund, 2014) identifies two core aspects for achieving a future energy system based on 100% RE. The first aspect concerns which technologies based on RE are targeted to meet the energy needs of the future (Lund, 2014). The second aspect concerns how it is possible to implement the necessary radical technological changes for society to ensure the desired development (Lund, 2014).
The choice awareness thesis is important in the transition towards RE based energy systems, since this transition requires radical changes in the technologies utilized to cover the future demands and the infrastructure of the systems that these technologies is implemented in (Lund, 2014).
Choice awareness has become a part of the societal decision-making process (Lund, 2014). An important element of choice awareness is that there is a collective perception that there are valid alternative solutions to the current situation and alternatives to well-known solutions and technologies (Lund, 2014). This is important for the planning process to identify solutions to the problem as illustrated on figure 6. Choice awareness is particularly interesting in situations such as now, where the need to find alternatives to natural gas can be an opening opportunity for new institutions to be established (Lund, 2014). Thus, crisis situations can even be a driver for choice awareness and technological change with an increased implementation of RE technologies (Lund, 2014). This also includes alternative RE solutions that contribute to the development of energy systems getting closer to the long-term political objectives of the energy systems of the future (Lund, 2014).

USE OF THEORETICAL FRAMEWORK IN THE FURTHER THESIS

The theoretical understanding in this thesis as described in the beginning of this theoretical framework is to be utilized in the further investigation of the issue related to long-term and short-term planning in a crisis.
Following figure illustrates how the understanding of planning utopia is utilized in the further investigation of the issue.

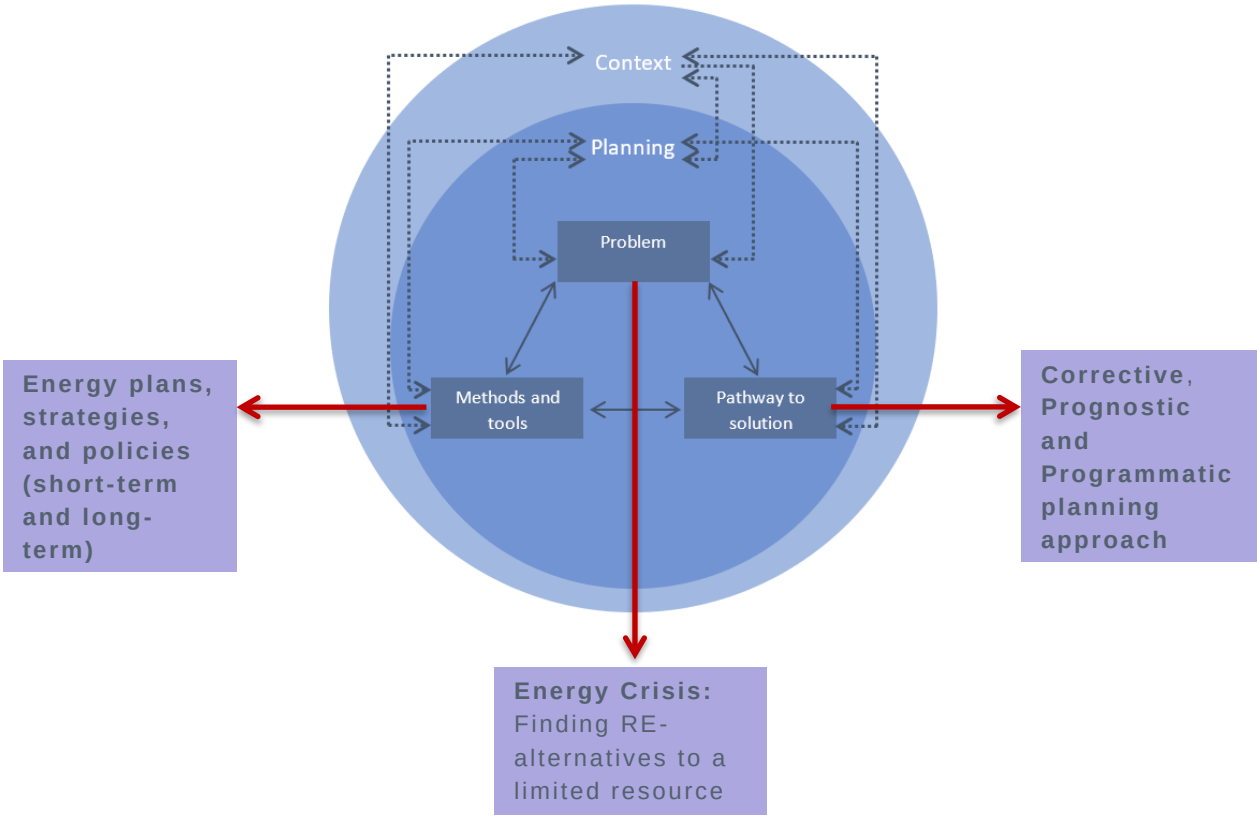


Figure 11 Illustration of how the theoretical understanding of energy planning utopia is utilized in this thesis.

Figure 11 illustrates how energy planning and the context of this influence and is influenced by the elements of energy planning. Energy Policy is not included in the figure, since it is both a part of all layers and elements on the figure and has its own process at different societal levels influencing different actors. The figure shows that all three elements of the energy planning included and investigated in this thesis are linked together. They are all linked to the energy planning (arrows) since they are all a part of the energy planning. However, they are all also linked to the context (arrows). Since these elements often depends on the context and creates the frame for a new context.
Concrete for the energy planning process the problem to be solved would be the first focus. In the case of this thesis the problem is the current energy crisis and to find alternatives to Russian gas. This has also been the focus during the crisis until now. The following steps would then be utilizing different methods and tools by establishing

concrete plans, strategies, and initiatives this would often be dominated by a certain planning approach which would then constitute a pathway to the solution of a problem. To identify the current and historical context of the Danish energy planning and policy measures made since the oil crisis in the 70'ties elements from both (Gaardmand, 1980) and (Hvelplund, 1980) are utilized. Especially elements from (Gaardmand, 1980) are utilized in the evaluation of what kind of approaches the energy political activities have followed and what strengths and limitations this have had. Both elements from (Hvelplund, 1980) and (Lund, 2014) is utilized to address the difference between short-term and long-term planning. In this depiction of planning the economic value of short-term planned energy systems and long-term planned energy systems is evaluated.
The key findings of the four analysis sections and the utopia of energy planning are also evaluated in the discussion, where this theoretical understanding is addressed in relation to other aspects from key stakeholders in the Danish energy sector.

RESEARCH DESIGN

Following research design (figure 12) illustrates an overview of how this theoretical understanding is utilized throughout this thesis together with the methodological approach. This is illustrated by specifying what chapters of the thesis the different theories and methods are utilized in and how the sub questions are answered through these chapters. Lastly, how the research question is answered based on these chapters and investigations is specified. The design thereby shows how the theoretical framework creates an overall understanding of energy planning in short-term and long-term throughout all the following chapters in the thesis. Moreover, it shows how the methods are utilized in different chapters for investigations that answers the specific sub-questions. The purpose of the research design is thereby to give an overview of how the thesis structure is designed to answer the research question.
The current energy crisis has entailed several political initiatives to find alternatives to Russian gas. Are both short-term and long-term aspects not considered in strategic energy planning for the future energy system in Denmark several issues can become a reality. A concern can be that problematic RE-development happens or alternatively, that RE-development is on a setback in sectors where RE alternatives to the natural gas has not been found. Therefore, issues and fall-pits of the current crisis, the learnings of the previous crisis and assessment of short-term and long-term aspects should be investigated.

Research Question: *"What is the influence of energy crisis on the development of RE projects short-term and long-term, and what important knowledge from the crisis should be utilized in strategic energy plans and policies for the future energy system in Denmark?"*						
Structure	**Theoretical Understanding**			**Methodology**		
	Planning Approach	Short- and long-term	Choice Awareness	Literature Review	Semi-structured interview	Comparative assessment
Energy policy analysis	x	x	x	x		
Short-term and long-term assessment		x	x			x
Evaluation	x	x	x			x
Discussion of result	x	x	x	x	x	x
Discussion of inputs from interviews		x	x	x	x	
Discussion of the future energy system	x	x	x	x	x	x

Sub question 1: *What influence has the energy crisis made on energy planning and policy in Denmark?*	**Sub question 2**: *How can short-term and long-term aspects be assessed for specific RE technologies?*	**Sub question 3**: *What solutions are optimal to be implemented in a Danish context?*
This question is primarily answered in the first analysis of the development of energy policies in Denmark. This is done by making a historical comparison of how energy crises influence energy planning and policy from 70'ies up until now.	This question is primarily answered in the second analysis of short-term and long-term evaluation. The evaluation takes point of departure in PV-technology which is a key part of the EU Emergency Regulation.	This question is primarily answered in the third analysis where the limitations and potentials for a future planning aspect for RE-development are evaluated in relation to the findings of the previous investigations.
Dominating approach to answer this question is the theoretical understanding of planning approaches, policy goals and literature review of different sources describing the events the past 50 years.	Dominating approach to answer this question is policy goals and choice awareness. The assessment methods play an essential role to quantify results to answer this sub question.	Dominating approach to answer this question a combination of all the theoretical understandings in combination with the utilized methods.
The energy crises can both challenge and drive the RE-development, depending on how the challenges and opportunities that the crisis has entailed are dealt with. Short-term goals should be a pathway to reach the long-term goals. Key knowledge from energy crises can be utilized in the debate of what RE alternatives to be prioritized.		

Figure 12 Research design illustrating how the methodology and theoretical understanding is utilized in the thesis and how the research- and sub questions are answered.

CHAPTER 3: METHODOLOGICAL APPROACH

This following methodology section addresses the methods utilized to gain information and knowledge to answer the research question of this thesis. In the section the strengths and limitations of the methods is clarified to create an understanding of what the methods contribute with and what they do not contribute with in this thesis. Following methods are included in this section; literature review, semi-structured actor interview, technical short-term and long-term assessments based on; Levelized Costs of Electricity (LCoE) calculations, Abatement Costs (AC) calculations and an EnergyPLAN investigation.

LITERATURE REVIEW

One of the purposes of the literature review is to identify the strengths and weaknesses of the literature utilized to gain knowledge and information (Booth, et al., 2022). It is most often the case with all literature that it has a purpose and therefore has something to say, but also that there are things that the literature does not say (Booth, et al., 2022). It is important in the literature review that what the literature tries to say is identified, so that the purpose of the literature is clear, and that potential bias is minimized (Booth, et al., 2022).
The literature review also provides for a higher level of transparency to what sources and background the research is based upon (Booth, et al., 2022).
The process of finding and utilizing research contains some important steps that should be done. In this thesis following steps are done, inspired by (Booth, et al., 2022):

- Literature search to find existing material addressing the focus issue.
- Selection of literature based on validity of the literature.
- Assessment of the literature based on the methodology of the literature.
- Synthesis of knowledge where key elements of the literature is identified.
- Utilization where it is clarified how the literature contributes to the thesis.

Literature for initial problem identification:

It is important to know what literature exist that already address the scope of this thesis. Therefore, this has been the purpose of the literature search for the problem analysis. Common for a significant share of the literature found that address energy crisis and the issues that arise during a crisis address the crises in 1970s.
This can be justified primarily by the fact that the current crisis is only now fully or partially over, and therefore the number of thorough studies of the situation that have yet been carried out is limited. However, these sources describe some very general issues for the crises of the 1970s, which also characterize the current crisis. Therefore, precisely these sources are chosen.
However, a few sources describe the concerns about future crisis situations that the crises in the 1970s brought about, and therefore they are also relevant to the current crisis, because they identify core parameters that can make the world's countries more exposed to future energy crises. Among these, several of the sources focus on the concept of security of supply. The sources have different methodological approaches

and therefore different ideas on how security of supply can be defined and what determines a country's security of supply.
Several sources have been identified and described in this thesis based on their focus on issues that the current crisis has caused in a Danish context. The current focus on the transition to RE has led to the Danish energy system being developed. The crisis therefore comes at a time when there is still a need for fossil energy resources to cover needs when fluctuating energy sources cannot cover energy demand. Therefore, with the need to find alternatives to natural gas, several policy frameworks have been put in place that have made it possible to speed up some RE projects. However, this has led to several issues that this literature describes based on the actors affected by this new policy framework.

Theoretical literature:
Something to acknowledge in terms of the theoretical literature is that two of the sources are written in 1980. A lot of things have happened since 1980.
However, they are for good reasons included in this thesis. This is because some of the main issues that both (Hvelplund, 1980) and (Gaardmand, 1980) address is still essential today. Even though some elements of the context have changed, some of the same problems must be solved by todays planning of future energy systems. These issues are addressed in the theoretical framework and constitute the frame for how energy planning and politics can influence the direction of the development in the future Danish energy system. An overview of the theoretical literature can be seen in following table 1.

Theme and author	***Key knowledge***	***Background for literature***	***Context of literature***	***Source in PDF***
Planning *Arne Gaardmand*	Definition of planning. Planning approaches.	Practical work with planning at Institute of roads, traffic and urban planning.	**1980**: after first oil crisis. Energy planning and planning in general have become a greater focus. The planning process has been evaluated and now includes new aspects like alternatives and focus on problem solving.	(Gaardmand, 1980)
Energy Policy *Frede Hvelplund*	Short-term and long-term planning. Energy policy goals.	Research of connection between energy consumption, economic growth, policies, and goals.	**1980**: after first oil crisis. Several energy policy initiatives have been implemented. Economic growth continues to rise after the crisis.	(Hvelplund, 1980)
Choice Awareness *Henrik Lund*	Alternative energy systems. Radical technological changes.	In the light of the establishment of several transition goals and of significant technological development.	**2014**: two years after the 2012 goals of a future energy system based on 100% RE. A situation that requires several radical technological changes to reach these goals. Still more stakeholders seek to gain influence in the transition to what technologies that should be prioritized.	(Lund, 2014)

Table 1 Overview of the background of the three main sources that the theoretical understanding is based upon.

Literature for investigation of policy analysis and technical assessment analysis:
Data collection has changed significantly during the past 50 years. Today's data collection of energy supply and – consumption has been utilized to address the context and issues of the current energy crisis. This is primarily information from different technical reports done at EU level and at a national level by the institutions authorized to collect these data. Not all energy related data was collected as detailed during the oil crises in the 1970s. However, key energy values are present in the literature utilized to investigate the oil crises. More importantly this literature is utilized since it thoroughly explains the issues of the energy oil crises and specifically creates an overview of what the development of energy planning and -policies has been up until today. This is key knowledge to compare with the current events to identify similarities and differences between the energy crises to consider in strategic energy planning.

SEMI-STRUCTURED STAKEHOLDER INTERVIEW

The stakeholder interviews follow the methodology of a semi structured interview. This method is chosen because it gives the interview a level of structure while also allowing for the interviewee to add new topics or issues that has not been thought of by the interviewer. In this thesis the interviewee holds expert knowledge and therefore holds key knowledge and information related to the issue. Therefore, it makes sense that the interviewee can express what they see as the main issues and solutions.
This methodological approach has some limitations compared to a more structured interview or a survey, which is that when more interviews are done it can be tricky to compare the response/outcome of the interview with the semi structured interview. In the more structured interview and the survey the same questions are asked to all interviewees, this makes the outcome of the interview or survey more comparable. However, the semi structured method also holds important benefits, which is why it is chosen in this thesis. These benefits are that there is a big difference between theoretical knowledge and practical knowledge. Issues and solutions are approached in this thesis from a theoretical angle and therefore interviewees practical knowledge is valuable knowledge since it might differ from the theoretical knowledge. Therefore, it makes sense to allow the interviewee to highlight what they see as main issues and solutions from this practical perspective, since the theoretical aspect of the issue is already clarified in the thesis. Another significant benefit compared to the more structured interview and especially compared to the survey is that the semi-structured structure allows the interviewer to ask follow-up questions to the answers. This makes it possible for the interviewer to gain a deeper understanding of the glasses which the interviewee sees the world through and thereby to better understand what the answers are based upon. Before the interviews the interview topics were sent to the interviewee, so any unclarity of the topics could be solved before the question and to prepare the interviewee about the purpose and scope of the interview.
The interviews were conducted the May 1st with Kim Behnke, Manager of Development at Dansk Fjernvarme, May 2nd with Søren Dupont Kristensen, CEO at Energinet, and May 9th with Karsten Capion Senior Analyst at Concito.

METHODS TO ASSESS SHORT-TERM AND LONG-TERM PERSPECTIVES

Where the LCoE measures the costs of energy production, the AC measure the ecological costs of emission related to an energy technology. Therefore, these two methodological approaches differ significantly from each other. However, it is an interesting match of measures, since the energy technologies when compared in terms of both economy of production and ecological influence is evaluated from a broader perspective. It is a way to evaluate the cost-benefits of the technologies with the purpose to evaluate the “best” technologies together in an energy system. It is important to stress that the results from this comparative analysis should not stand alone as a basis of political decision-making but rather be a starting point of discussion for the prioritization of RE-technologies short-term and long-term in a Danish context.

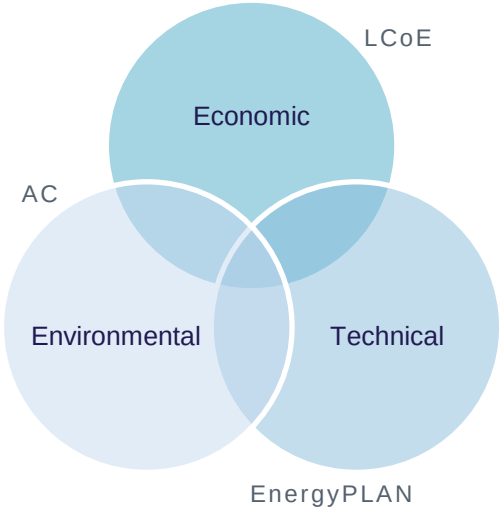


Figure 13 Three elements for assessing the sustainability of an energy technology in both short-term and long-term in this thesis.

Dominating the short-term perspective currently has been to implement the most economically feasible solution, this does not exclude the two other aspects in figure 13. However, it entails that the economic aspect of PVs are investigated from a short-term perspective in this thesis. Especially the technical feasibility dominates the long-term perspective where it is essential that the technologies implemented are compatible and thereby optimal from an energy system perspective. Again, all three aspects are a part of both the short-term and long-term perspective, however they influence the choices in short-term and long-term differently. This is linked to the theoretical understanding of planning utopia (see figure 6), where the context is influenced by the energy planning, which mean that the long-term context is different from short-term context and at a higher level is shaped by the planning than the other way around. This is more of the case for short-term where the context at a higher-level influence and shape the planning. Therefore, the context of the economic element dominates the short-term like in the Emergency Regulation by (The Council of the European Union, 2022). Where the context of the technological element dominates the long-term like in the 2050 strategy by (The Ministry of Climate and Energy, 2011). Environment is equally a part of short-term and long-term, therefore it is included in both perspectives in this thesis.

Short-term assessment method

The methodology of LCoE

The LCoE calculations is a way to compare the energy production on different energy technologies (Danish Energy Agency , n.d.). This makes it possible in a simple way to compare energy technologies and to evaluate the economic potentials of these (Danish Energy Agency , n.d.). This makes the LCoE calculation a useful tool when determining the potential of specific energy technologies (Danish Energy Agency , n.d.).

This method however has some key limitations.

- Often technologies that the LCoE is calculated for is base load technologies which means that the technologies are considered to have a high level of stability (Danish Energy Agency , n.d.). This is however not a case for all technologies that are going to play a role in the future energy system (Danish Energy Agency , n.d.). Therefore, some technologies might benefit more from this methodological approach more than others, which should be considered (Danish Energy Agency , n.d.).
- The calculations do not consider revenues, which means that a significant part of the economical case of the technologies are not included in the results (Danish Energy Agency , n.d.). This means that the revenue that could be higher for some technologies than others and thereby influence the final business-case of the technologies are not illustrated in the LCoE (Danish Energy Agency , n.d.).

Since the context and the input data of the calculations defines the output of the LCoE calculations it is important for the validity of the results that data is similar for all technologies (Danish Energy Agency , n.d.). This is to ensure that the technologies are evaluated based on the same parameters (Danish Energy Agency , n.d.).

Following formula from (Corporate Finance Institute , 2023) to calculate the LCoE for PV technology is utilized in this thesis:

$$LCoE = \frac{\sum \frac{(I_t + M_t + F_t)}{(1+r)^t}}{\sum \frac{E_t}{(1+r)^t}}$$

The LCoE calculation is a mathematical expression of the NPV of the total costs divided by the NPV of the electricity produced during the lifetime of the technology (Corporate Finance Institute , 2023). Therefore, the input values are according to (Corporate Finance Institute , 2023) following;

- I: investment
- M: O&M
- F: Fuel
- E: electricity produced
- r: discount rate
- t: lifetime

The methodology of AC

The AC are a way to illustrate the consequences of emissions from an economic perspective (Ibrahim & Kennedy, 2016). It is a way to evaluate technologies that create larger energy efficiencies or fuel consumption changes (Ibrahim & Kennedy, 2016). The method seeks like the LCoE method to evaluate the cost-effectiveness of specific technologies (Ibrahim & Kennedy, 2016). Therefore, these methods both compliment and challenge each other from a methodological point of view (Ibrahim & Kennedy, 2016). The abatement curve is a way to create an overview of the overall quantitative economic value of decreased GHG emissions (Shiping, et al., 2016). This kind of illustration thereby shows the trade-off between the environmental benefits of lowered emissions and the economic feasibility of technologies (Shiping, et al., 2016). Like the LCoE method, this method also contains some key limitations;

- Opposite of the LCoE method the AC method is complex. Especially the hybrid model of the abatement curve is complex (Shiping, et al., 2016). This entails a higher level of need for validated input data, like what one of the limitations of the LCoE method (Shiping, et al., 2016). Several approaches to the calculations can be done, and it is therefore important for the usage of the method, that the most fitting approach is chosen (Shiping, et al., 2016).
- Since this method is highly dependent on energy prices, this one parameter is important to the results of the calculations (Shiping, et al., 2016). This makes it difficult to optimally utilize this method in times with e.g., energy crisis were energy prices increase significantly and where there in general is many uncertainty factors influencing the energy markets (Shiping, et al., 2016).

The formula utilized to calculate the AC for different RE in this thesis is inspired by the formula by (Hanley, 2020):

$$AC = \frac{EP}{(E1 - E2)}$$

The inputs values are following:

- EP: LCoE/electricity price
- E1: mean ton CO_2-equvilant emissions/MWh electricity produced in Denmark
- E2: ton CO_2-equvilant emissions/MWh electricity produced by PVs

Long-term assessment method

From a long-term perspective the energy system modeling tool EnergyPLAN is utilized to assess the system effect on a specific technology in total energy system. This is done based on the IDA 2030 vision model by (Lund, et al., 2020), since this model allows for additional RE-technologies to be implemented before the system reaches 100% RE energy supply. The model in EnergyPLAN by (Lund, et al., 2020) includes a relatively low amount of electricity import/export. Therefore, it is a relatively closed system, where the energy consumption is covered solely on energy sources placed in Denmark. This is a delimiting factor if reality ends up being that there is an increase in trade of electricity in the future because the model thereby does not illustrate reality. This is especially an important factor since increase in PV capacity entails that the increased electricity production should be either utilized in the system or exported. However, EnergyPLAN as a simulation tool is a great way to qualify technical imbalances in the energy system (Lund, et al., 2020). This allows for specifically testing how PVs affects energy balances in a system based on a large share of RE to gain a larger understanding of what role PVs play in a future energy system with this larger share of RE.

COMPARISON OF THE TWO TECHNICAL METHODOLOGICAL APPROACHES IN THE ANALYSES

The short-term and long-term assessment methods vary significantly in methodology and are thereby difficult to compare one to one. This means for the results of the two analyses that the results should be viewed from the context that they are investigated in. For the short-term analysis the main parameter is economical optimal alternatives to natural gas (The Council of the European Union, 2022). Therefore, this is what is investigated in the LCoE and AC calculations in the context of short terms. In long-term it is important that the technologies implemented from a system perspective work together as technical optimal and compatible as possible (Lund, et al., 2021). Therefore, the effect of increased PV capacity on the system is investigated in energyPLAN in the context of long terms.

It is important to remember that energyPLAN as a tool also has limitations and that the 2030 vision IDA by (Lund, et al., 2020) is also limited by methodological choices.

It is debatable whether CEEP is really an issue in terms of poor integration, this depends on the goals for the future system. If the goal is for Denmark to increase its energy trade cooperation with neighboring countries and the rest of the EU in the future, CEEP is not necessarily a problem for the system, but on the contrary an opportunity to export a larger share of RE to other countries. However, if the goal is for Denmark to become more self-sufficient in RE, it can become problematic and expensive to implement a too large capacity of RE technologies that are not integrated properly into the system in the long term, as the analysis with a doubling of PV capacity showed.

THEORETICAL AND METHODOLOGICAL DISCUSSION AND SUMMARY

Theoretical and methodological choices always entail delimitations.
The theoretical framework (epistemology) of understanding is essential for how the identified problem is investigated and how the problem is generally understood (Tuli, 2010). Therefore, the theoretical framework of understanding is decisive for which methodology is chosen to investigate the problem and therefore also what type of results the investigation of the problem ends up with (Tuli, 2010). Therefore, it is important that there is transparency in what the theoretical understanding and methodology for the reader's understanding of how the problem has been investigated and how the results have been obtained.
In relation to the theoretical understanding, planning is a broad professionalism and can be understood in several ways. Therefore, it has been crucial for the studies in this thesis that planning has been understood from the three parameters identified in the theory section. In strategic planning, it is crucial which methods and tools are used to achieve the goals set (Gaardmand, 1980) (Hvelplund, 1980). Therefore, they have been crucial to identify in this thesis, as the purpose of these has been to investigate which methods and tools have been used so far in the short and long term, and which methods and tools exist today to ensure future development. The methods and tools are decisive for the direction of the planning and thus the development (Gaardmand, 1980), and therefore this factor is included in the theoretical understanding. However, the methods and tools are also crucial for the economic conditions, legal frames and for key actors, while at the same time being an expression of the resources prioritized in solving the problem (Gaardmand, 1980). These parameters have not been examined in this thesis but are also important elements in both the planning and the methods and tools used. Especially the influence on and from key actors in the energy industry in planning is of great importance in relation to solving the problems and can become part of the problem if not involved or considered in the planning (Hansen, 2016). This thesis is delimited from the importance of actors for the problem and for planning, but it does not mean that they are not a significant part of the reality being planned for and in. Therefore, their influence on the development that has occurred since the 1970s and the development that will take place in the light of this energy crisis will be essential to investigate, as this influence can put new perspectives on developments that the study in this thesis has not included.
Different actors will often have different interests, as the interviews with actors in the energy industry have shown. Therefore, to minimize this factor, surveys with several different actors, as mentioned in the methodology section, could have been prepared in this thesis to obtain more diverse inputs. However, a crucial limitation of surveys is that detailed answers are usually not included. In general, it can be difficult to assess how those who have answered the survey have perceived the questions and what they meant by the answers, since it is not possible to ask in-depth questions to both parties. Therefore, this method has not been chosen to cover the actors' views in this thesis, as the thesis deals with a complex and political issue, where it is important to be able to elaborate and explain inputs, so the point is clear.

CHAPTER 4: ENERGY POLICY AND PLANNING ANALYSIS: FROM ONE ENERGY CRISIS TO ANOTHER – 50 YEARS OF DEVELOPMENT

Following analysis seeks to investigate the key political and planning activities from the first energy crisis in the early 1970s up until today's energy crisis. The development of energy planning and – policies are investigated based upon the planning utopia described in the theoretical framework. Therefore, the context, pathways and methods of the crises are identified. This has been done to investigate and compare what influence the energy crisis 50 years ago had on Danish energy planning and RE-development and what influence the current crisis currently has. Therefore, the purpose of this chapter is to answer sub question 1:

What influence has the energy crisis made on energy planning and policy in Denmark?

CONTEXT AND PROBLEM OF THE 70S – DEVELOPMENT FROM 1800 HUNDRED UNTIL 1973

As mentioned in the theoretical framework, in chapter 2, the context and problem in this thesis is closely related why both are investigated in this section.

1800-1900

The Danish Energy Consumption and Supply

During the first Industrial Revolution, production was more mechanized and with the implementation of the steam engine, there was an increased need for energy from the industry (Rüdiger, 2011). At that time, the primary source of energy in Denmark was coal (Rüdiger, 2011). During the second Industrial Revolution after 1850, the first energy grid was established in a Danish context where gas and electricity was implemented (Rüdiger, 2011).
The first high-voltage power grid in Denmark was established in 1908 and power from Denmark's neighbor Sweden was imported shortly after (Rüdiger, 2011). This power grid and its role in the energy exchange between Denmark and other countries came to play a key role 60-70 years later and is still a key factor to the energy system that is established in Denmark today (Sperling, et al., 2011). It was an important factor in the debate of security of supply in relation to finding alternatives to the oil in the 1970s but even more so today. In general, the exchange of electricity has become increasingly more important due to the events in the 1970s, the oil crises increased the focus on energy imports especially within the EU where energy trade now plays a significant role in operations of the energy systems in the European countries (European Comission and ACER, 2022).

1950-1970

With the growing supply and demand for energy, a competitive market was created in Denmark, which meant that the smaller companies had high operating expenses compared to the larger plants and therefore had a significantly smaller financial profit (Rüdiger, 2011). Because the financial surplus ended up as part of the municipalities' finances, a significant difference was created between the Danish municipalities (Rüdiger, 2011). Therefore, the then Minister of the Interior introduced the break-even (in Danish "Hvile-i-sig-selv") principle in the late 1950s (Rüdiger, 2011). The break-even principle meant for utilities that their economic inputs and outputs had to be in balance, their turnover had to be roughly equal to 0 (The Danish Business Board , 2011). The principle should thus increase the equality of utilities and municipalities (The Danish Business Board , 2011). The principle had a significant influence on the further development of the energy sector and infrastructure. It became one of the first major and more significant political interventions in energy development. Because as a result of this, the discussion of centralized electricity generation commenced (Rüdiger, 2011) (Sperling, et al., 2011). Therefore, the basis for the electricity production that characterizes how it is today. Coal was a challenged resource during World War II, and the supply at the power plants was only stabilized when oil became the dominant fuel in the power plants (Rüdiger, 2011). Just before the oil crisis in the early 70s, Denmark's supply was based on a stable and well-functioning system, even though consumption continued to grow, there were no challenges in meeting this need because of the fossil fuels (Rüdiger, 2011) (Sperling, et al., 2011). Oil was easy to handle, cheap and generally a better alternative than coal in terms of securing the energy supply (Rüdiger, 2011). Thus, up until this time the energy development of the energy consumption and how the supply was secured had not been discussed at a political nor societal level.

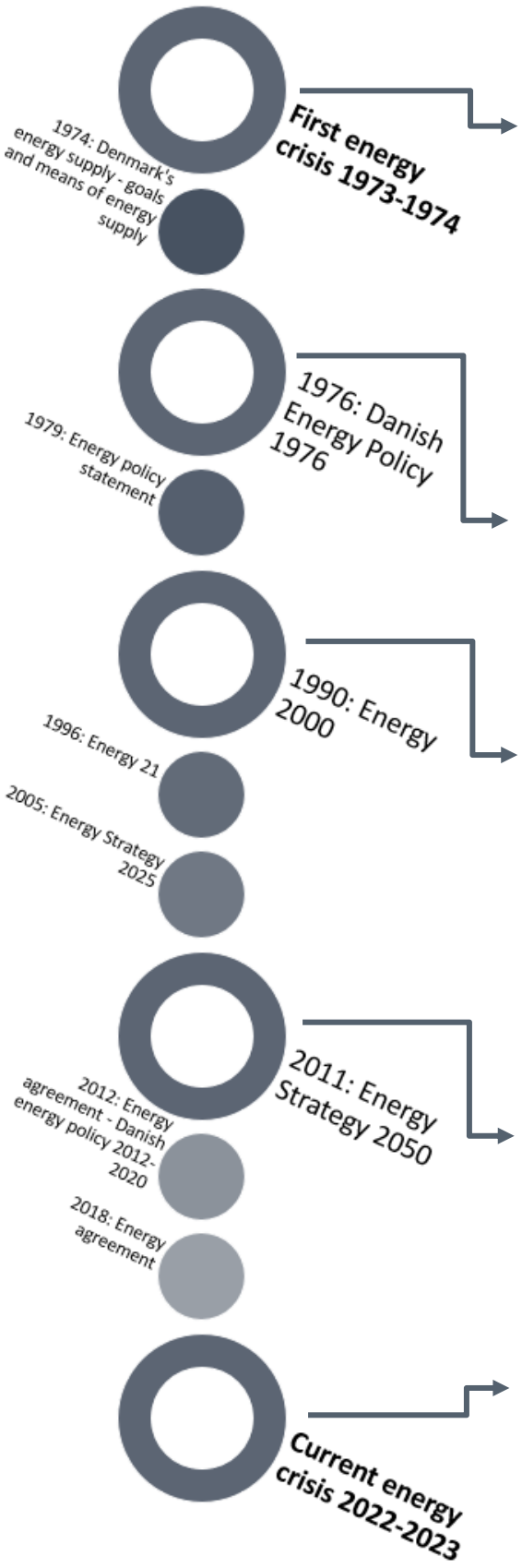
Around 1973

The main issue was that around the 1960s, about 90% of all of Denmark's energy consumption was based on oil (Rüdiger, 2011). Most of this oil was imported from the Middle East, so when their oil exports where limited due to political conflicts, the situation required political interference (Poulsen, 2017) (Farbøl, et al., 2018). So, Denmark was in the situation that most of the national energy supply was covered by one energy source – Middle Eastern oil. Denmark had no immediate back-up to replace the oil, so when the oil prices rose due to the Middle Eastern conflicts the national economy was heavily affected by this (Rüdiger, 2011). This was a vulnerable situation for Denmark to be in since the oil played an essential role to meet the Danish energy demands. The Ministry of Trade decided that Denmark should investigate the possibilities of importing natural gas as an alternative to oil (Rüdiger, 2011). However, for security of supply reasons the beginning of RE-development especially wind in a Danish context (Sperling, et al., 2011). For this reason, one could argue that the oil crises in the 1970s thereby also has played a key influence in the transition towards RES that has happened from 1973 up until today, despite the increase in natural gas consumption that it also entailed.

CONCRETE TOOLS UTILIZED DURING THE ENERGY POLICY DEVELOPMENT AFTER 1973

After 1973

The methods and tools utilized after the oil crises has been essential to the dominating planning pathways and thereby the development of RE that has evolved since 1973 up until now. The solution to the first challenge of ensuring security of supply when the crisis hit was to convert the power plants to coal and by relying on the natural gas system to cover the heating supply (Rüdiger, 2011). Thereby a setback to coal in areas previously covered by oil. The oil crisis was thus the final push for Denmark to end up in economic crisis in the 1970s that made it a primary political focus of energy policy that Denmark should become independent of oil (Rüdiger, 2011) (Farbøl, et al., 2018). With this political focus came several different campaigns directed towards the citizens to reduce energy consumption (Poulsen, 2017).
In general, the development of the energy sector was strongly influenced by political influence in the following decades (Rüdiger, 2011) (Sperling, et al., 2011). An influence that had not previously been seen when the Danish energy production was based on cheap energy sources and free market forces were therefore allowed to dominate the development of both consumption and supply of energy in Denmark (Sperling, et al., 2011). Key energy policy investigations and reports were made during the 1970s. An overview of key policies and plans between 1970 and 2023 that have had an important impact on the RE development and the Danish energy system in general. Some of the policies are highlighted in this thesis and can be seen in the following figure 14.



Oil became a limited resource. First part of the crisis was dominated by the focus on energy security and finding an alternative to the oil that could be implemented as quick as possible. In the second part of the crisis focus changed towards optimization of the energy system and implementation of RE technologies, for Denmark to become independent on oil imports. For the first time it is evaluated what alternative energy resources exist.

Quote: "The prospect of an overall shortage of energy raw materials, and of the most important energy raw material, oil, and the certainty that increasingly difficult and therefore scarcer and more expensive forms of energy will have to be used presupposes the implementation of long-term planning and management in the field of energy." (Jensen, 1976)

Quote: "How many energy resources shall we use up, and how much can we allow ourselves to disturb the climate and upset the environment? This increasingly insistent question calls for an answer now. We must ensure that generations after ours – in industrialized and developing countries – shall not look in vain for access to sufficient resources or an unharmed environment." (The Ministry of Comerce, 1990)

Quote: "The government's goal of making Denmark independent of fossil fuels by 2050 is based on a recognition that the world is facing a new age of energy policy. The 20th century was largely driven by access to cheap and abundant amounts of coal, oil, and gas. In the 21st century, other ways must be found to meet energy needs." (The Ministry of Climate and Energy, 2011)

Natural gas has become a limited resource. First part of the crisis has been dominated by the same focus on energy security like in the 1970s. Political initiatives have been established to increase the speed of current RE projects for prioritized technologies. In the current state of the crisis the political focus has also changed. Now there is a focus on what technological priorities should be made for Denmark to become independent on import of fossil fuels in long term.

Figure 14 Overview of prioritized key political initiatives based on the overview from (Rüdiger, 2011) for the past 50 years, followed by quotes of their key purpose.

Danish Energy Policy 1976 (Jensen, 1976) was the first more detailed plan for future planning and development of the Danish energy system. Integration between power and heat became part of the solution (Jensen, 1976). There were political ambitions to include both nuclear power and natural gas in Denmark's future energy supply, however, the outcome for the two energy sources was that natural gas was least complex to implement and therefore became the alternative implemented (Jensen, 1976). This political decision meant that the Danish energy demand the years after the crisis became significantly more dependent on natural gas. This was a quick way to become independent of oil and seemed at the time as the most feasible alternative to oil. It was feasible, especially economically feasible because a significant share of the natural gas was extracted in Denmark and was hence a cheap alternative and made Denmark more self-sufficient in energy production. However, today the problems of this decision has been clear from the current energy crisis based on the lack of natural gas supply.
It took more than 10 years before the natural gas system became economically feasible (Rüdiger, 2011). Thereby was the increase in natural gas utilization mainly driven by political regulation to be implemented. Which illustrates what influence political regulation has on the development of energy sources. This can become the case for RE as well in the light of the current crisis.

1980s

Another period in Danish energy policy came when the Danish Ministry of Energy was established in 1979 (Rüdiger, 2011). The creation of an institution to look after energy policy interests meant that after 1979 and still today there is a significantly higher level of political influence on the energy sector in general. According to (Sperling, et al., 2011) the role of political actors has increased simultaneously with the increased global focus on environmental issues. Also, with the crisis came several new planning challenges. One of these was that the development of energy consumption did no longer follow the exponential curve it followed until the crisis (Rüdiger, 2011). With the Brundtland Report in 1987 (Brundtland, 1987), the focus on the environment and sustainability was increased, which also influenced the development of the energy consumption (Rüdiger, 2011). As a result, Denmark was one of the only EU countries to introduce the CO_2-tax in 1995 (Rüdiger, 2011). With the new tax, it became necessary to draw up new long-term initiatives and plans to reduce CO_2-emissions. This was again an example of how the political influence on the energy system development secured a wider sustainable development in RE.

1990 - 2023

Energy 2000 (The Ministry of Comerce, 1990) contained as one of the first plans a concrete action plan for how Denmark should reduce CO_2-emissions. The goal was a reduction of 21% compared to the 1990 level (The Ministry of Comerce, 1990). The reduction goals of residual GHG such as SO2 was 60% and NOx was 50% (The Ministry of Comerce, 1990). This reduction required massive energy efficiency measures and energy savings in the energy system (Sperling, et al., 2011). These new requirements also opened a new opportunity for RE technologies to finally play a key role in the energy supply chain (Østergaard, 2014). This required radical changes in the energy system and institutions and became a steppingstone to the energy system structure that is established in Denmark today.
Already around 2005/2006 the first long-term strategies started to appear, the political focus changed towards climate issues and how to transition from fossil energy sources completely (Sperling, et al., 2011). However, the latest long-term strategy from (The Ministry of Climate and Energy, 2011) is the one with the longest time perspective and is one of the most specific strategic energy plans made by the Danish government currently. It was right before this strategy that strategic energy planning was considered for the first time in a Danish context (Krog & Sperling, 2019). Several approaches to achieve the goals stated in these long-term strategies have since been made and dominates the development of RE today (Sperling, et al., 2011).

PLANNING APPROACH 1970S UNTIL TODAY – PATHWAY FROM ONE CRISIS TO ANOTHER

The crisis of 1973 was a turning point in Danish energy planning and - policy (Rüdiger, 2011). An unprecedented vulnerability arose with the increased consumption covered by a primary energy source of oil, meant that there was a need for a new development in the Danish energy sector and new planning pathways to ensure the further development of the Danish energy system. This resulted in a significantly more flexible and open planning process than previously seen during the 70s (Sperling, et al., 2011). Different phases of the energy crisis and following decades have differently been dominated by the planning approaches identified in the theoretical framework in chapter 2. In following sections these are identified based on the development of energy planning methods and tools described above.

Planning approach before the oil crisis in 1973

Until the 1970s, political planning was dominated by the corrective planning approach (Gaardmand, 1980). A few policies and political initiatives were made to ensure the exponential development of both energy consumption and supply. However, there have been no further policies to steer this direction beyond when the break-even principle was introduced (Rüdiger, 2011).

Planning approach development in the light of the crisis (1980s and 1990s)

After the crises of the 1970s, several political discussions and initiatives became the starting point for a radical development of the energy sector and energy planning.

During this period, the planning progress was particularly dominated by programmatic planning (Gaardmand, 1980). The initiatives became crucial for the development and implementation of RE technologies since the development was influenced by political initiatives for the first time in a Danish context. In general, this period starting from mid 1970s up until early 2000s was a period where the very first new RE solutions in parallel with the natural gas implementation where also introduced (Østergaard, 2014). This development has since, among other things, has led to radical changes in energy infrastructures and a larger variety of energy sources (Østergaard, 2014). However, this development has also led to Denmark becoming more self-sufficient in energy, which was one of the main goals of the programmatic planning initiatives (Rüdiger, 2011) (Gaardmand, 1980).
The ambition for the energy sector was to go in the opposite direction to what it had done so far by investing in RES to supply Denmark's energy needs (Gaardmand, 1980). This development has ensured that Denmark today is much less dependent on fossil energy sources compared to before the 1970s. However, the programmatic planning conducted at the time has not yet been enough to make Denmark fossil-free. Natural gas has continued to play a key role in covering the Danish district heating demand (Ministry of Climate, Energy and Supply, 2022).
In addition to the programmatic planning approach during the 70s, several corrective measures were introduced during the 80s and 90s to ensure that the energy system followed that direction and that the prioritized energy sources were implemented (Gaardmand, 1980). These initiatives were primarily characterized by the corrective and prognostic approach, where developments were corrected to follow programmatic planning. This combination of approaches entailed the most significant influence in RE development (Rüdiger, 2011) (Sperling, et al., 2011) (Østergaard, 2014).

Planning approach during radical changes in the energy system (1990s until 2000)

With future consumption as uncertainty, the context of planning and thus the entire utopian basis for the planning process changed (Rüdiger, 2011). There was a sudden need to rethink different processes to ensure profitable investments and development for the energy sector since the context changed radically. Thus, the focus on the new initiatives with efficiency and conversion of the energy system was dominated by the prognostic planning approach in combination with the programmatic approach to the environment and CO_2-reduction (Gaardmand, 1980) (The Ministry of Comerce, 1990).New institutions where made and the programmatic planning began to dominate the planning approach (Gaardmand, 1980). This period before had showed that with all three planning approaches suddenly present with the corrective directives and regulation, the prognostic plans and the development of programmatic strategies the development of new opportunities – RE-technologies, started (Gaardmand, 1980). Mid 2000s until 2012 a gap in the planning appeared between the short-term corrective and prognostic plans and initiatives in the 1990s and the long-term programmatic strategies to be evaluated in 2012 (Rüdiger, 2011). Therefore, the RE-development and the general development of the energy system stagnated in this period (Østergaard, 2014).

Planning in the 21st century - Planning approach up until the current energy crisis

With the development from dominating corrective planning to variated planning approaches back to dominating programmatic planning the outcome of the energy planning through the 20th century was variating (Gaardmand, 1980) (Rüdiger, 2011). When sustainability and focus on climate and environment really made their mark on the political agenda the long-term goals for RE-development in the 21st century emerged (The Ministry of Climate and Energy, 2011). With the new ambitions to reduce GHG emissions and further streamline the energy sector, it became a requirement that long-term and sustainable investments were made in the energy sector.

Over the past 5 years, there has been a significant increase in the development of energy technologies. As a result, several innovative RE technologies have come into play to play a significant role in the energy system of the future (The Danish Government, 2018). The processes of implementing these technologies are often several years which has increased the need for planning in general. More than ever all types of planning approaches are needed to ensure a sustainable RE-development (Gaardmand, 1980). The current energy crisis has only enhanced this issue. RE is one of the main solutions to exit the current energy crisis (The Council of the European Union, 2022). By combining perspectives from both short-term issues and long-term with a combination of energy planning approaches, the challenges that have arisen now based on the decisions made during the 1970s will probably not arise to the same extent in the future.

However, because the current situation is also a crisis that has hit the energy sector, several decisions are again being rushed because alternatives to natural gas are urgently needed, not necessarily leaving time for proper due diligence. Thus, there is a risk that the same situation with dominant, corrective, and prognostic planning means that radical technological changes will not be implemented (Gaardmand, 1980).

RESULTS OF THE PLANNING AND POLITICAL INITIATIVES

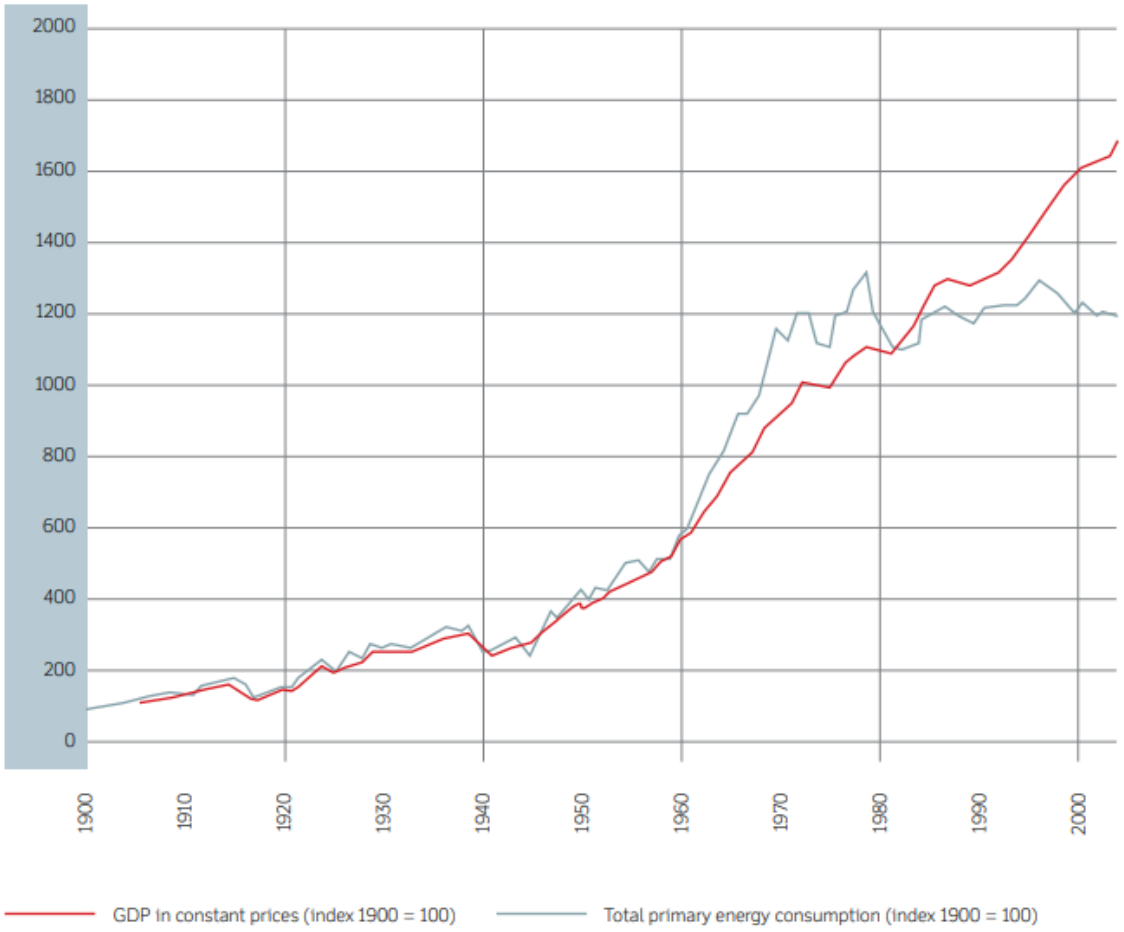


Figure 15 Overview of the development of the danish GDP and energy consumption (Rüdiger, 2011).

The results of the political initiatives set in the 70s were that the development curve of energy consumption after 1980 no longer followed the economic development of GDP (See figure 15). A separation that had not been seen before and had been criticized before (Rüdiger, 2011). One of the key reasons for the break in the consumption curve was the rising energy prices caused by the energy crisis (Farbøl, et al., 2018). In addition, the measures to introduce energy savings and optimizations in the energy system had influenced both household and industrial consumption (Rüdiger, 2011). Along with this the development, the share of RE in the Danish energy system had increased significantly from 1973 (Danish Energy Agency , 2023).

THE CONTEXT AND PROBLEM OF TODAY: TECHNOLOGICAL DEVELOPMENT AND POLITICAL AMBITIONS

With the development of long-term strategies, there has not been the same increase in short-term plans and action plans to reach the fossil free energy system ambition (Sperling, et al., 2011). Specifically, several institutions to develop the energy sector has been established since the 1970s (Rüdiger, 2011). Moreover, after the energy strategy from 2011 there has been established several energy agreements, the latest being an agreement for “green power and heat” from 2022 (The Danish Government, 2022). However, the development in energy technologies have increased rapidly during the last 5-10 years which has created political challenges or dilemmas of what technological solutions to prioritize (Madsen, 2023).

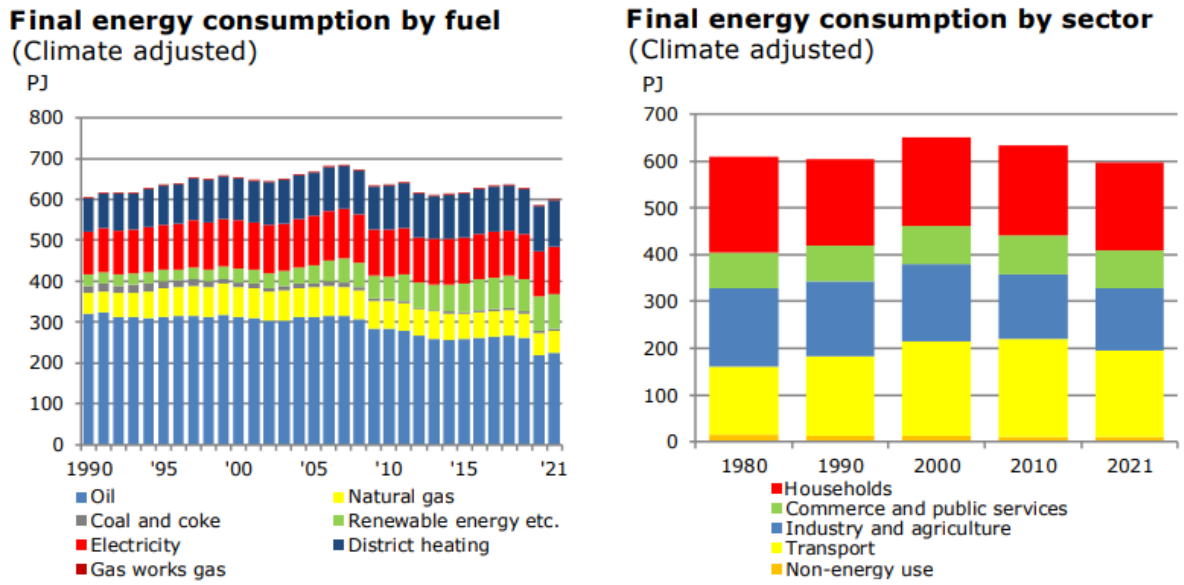


Figure 16 Overview of the development of the Danish energy consumption from 1980 until 2021. Source: (Danish Energy Agency , 2023).

Figure 16 illustrates how the share of RE has risen over the past 30 years and that the energy consumption in general has been around the same 600 PJ from 1990 until 2021 (Danish Energy Agency , 2023). Although imports of fossil energy sources still account for a significant part of energy consumption in Denmark, just as they did in the 90s, a significant proportion of RE-technologies has also been implemented over the past 30 years (Danish Energy Agency , 2023). Figure 16 shows that the amount of RE covering the Danish energy consumption has approximately doubled since 1990 until 2021 to constitute approx. 1/6 of the total energy consumption based on fuels (Danish Energy Agency , 2023).

However, still around 1/3 of the total energy consumption based on fuels was covered by oil in 2021 (Danish Energy Agency , 2023). Since the graph in figure 16 only shows fuels a larger share of RE sources can be found in the consumption covered by energy sources that are not fuel based such as wind, solar, etc. Thereby, the full effect of the strategic energy planning is not illustrated on figure 16.

Another significant difference in the context between today and the 1970s is that energy trading between countries today plays a significantly larger role in the Danish energy supply (Rüdiger, 2011) (European Comission and ACER, 2022). Following figure 18 illustrates how large the share of imports and exports were in 2021. Moreover, as previously mentioned an important difference between the 1970s and now is the share of oil in the Danish energy system around 1970 compared to the share of natural gas in the Danish energy system before the current crisis. It is obvious from figure 17 that the share of natural gas was significantly lower in 2021 than the 90% share of oil back in the beginning of the 1970s (Danish Energy Agency , 2023) (Rüdiger, 2011).

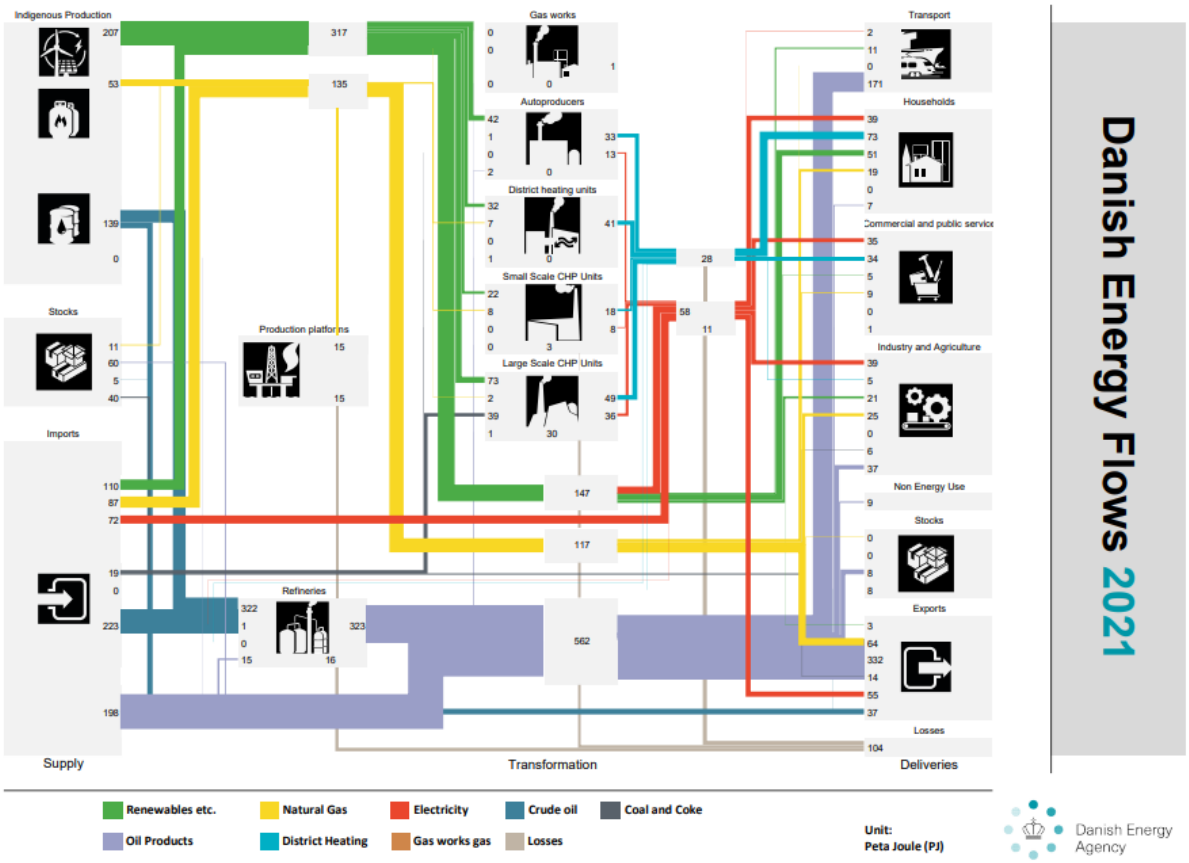


Figure 17 Overview of the Danish Energy Flow in 2021. Source: (Danish Energy Agency , 2023).

As mentioned previously during the energy crisis energy security and in that relation, self-sufficiency has been discussed. Therefore figure 17 is especially interesting, since it shows that over half of the energy utilized to cover the Danish energy demands are still covered by imported energy (Danish Energy Agency , 2023). With the political ambitions for the further development of the energy system where a decrease with 70% CO_2-emission reduction by 2030 and a 100% RE based system by 2050, figure 17 illustrates that the energy system of 2021 is still some way from reaching these goals (Danish Energy Agency , 2023) (The Ministry of Climate and Energy,

2011). It also means that half of the Danish energy sources are dependent on other countries to export energy to Denmark.

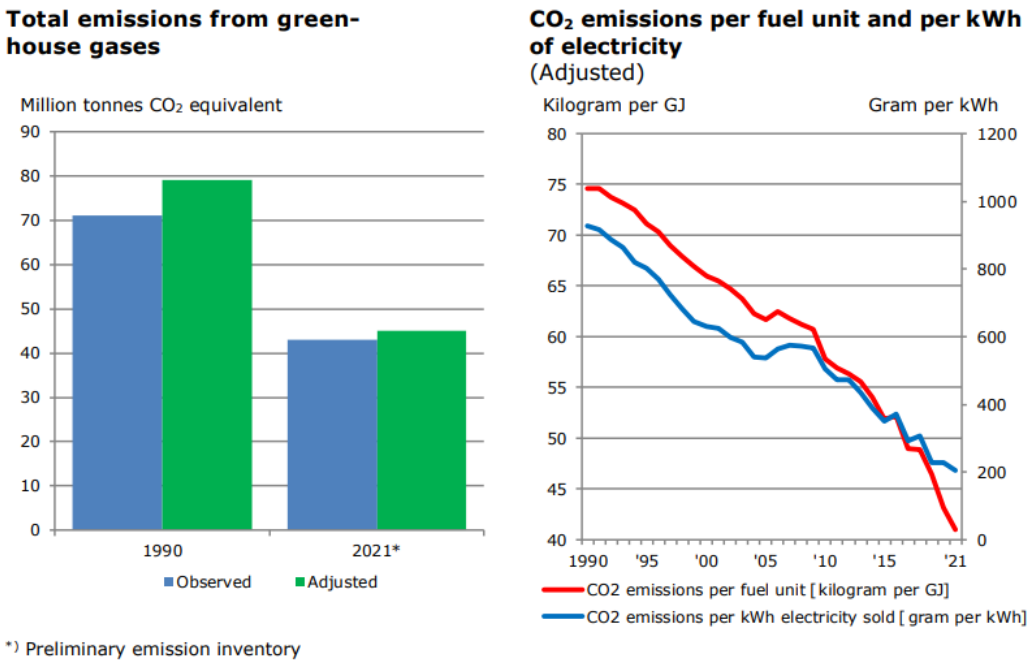


Figure 18 Overview of total emissions in Denmark from 1990 and 2021 and the concrete CO_2-emissions pr. energy source. Source: (Danish Energy Agency , 2023).

Even though the energy consumption according to figure 16 has been roughly at the same level for the past 30 to 40 years, the graphs on figure 18 shows that the overall GHG emissions have decreased to almost half of the amount of emissions around 30 years ago (Danish Energy Agency , 2023). With this development figure 18 also show that the CO_2-emissions related to the electricity production have decreased equally to almost half of the 1990 levels (Danish Energy Agency , 2023). Since the energy consumption have not changed significantly since, one explanation to this reduction in emissions could be that the effect of the RE technologies that has been implemented since 1990 due to the political initiatives and general development in RE technologies. However, it should be stated that since the energy consumption has been approximately the same, it is difficult to determine what the effect of potential energy savings and optimizations have been on the developments illustrated in figure 19. These other political tools to ensure sustainable development of the Danish energy system should be acknowledged as these tools have both technically, economically, and environmentally impact on the energy production, - consumption and – system in terms of minimizing waste of resources (Pedersen & Heller, 2001).
The problem in the current crisis has been that Denmark still rely on a significant share of fossil energy including natural gas (Danish Energy Agency , 2023). This emphasizes the need for strategic energy planning and both short-term and long-term plans, that can ensure that the RE-technologies are implemented (Sperling, et al., 2011).

TOOLS TO OVERCOME THE CRISIS

With the establishment of energy sector institutions more energy planning methods and tools have been established as well. As mentioned, several agreements have been established since the first long term strategy in 2011 (The Ministry of Climate and Energy, 2011). These agreements have secured the continual development of RE projects for the past 10 years.
In the latest agreement from 2022 it is stated that the political ambition is to increase the share of RE-technologies in the Danish energy system further towards 2030 (The Danish Government, 2022). In the agreement a goal is to increase the power production from wind and solar technology four times by 2030 compared to the current production (The Danish Government, 2022).

Emergency Regulation – how to speed the RE development?

An example of a political tool that has been implemented during the crisis to speed up the development of certain technologies to replace the Russian gas is the Emergency Regulation by (The Council of the European Union, 2022). The new Emergency Regulation (ER) that was approved the 22nd of December 2022 is directly based on the regulative frame from EU to accelerate the development of RE technologies by speeding up the permit-granting process of these technologies (The Council of the European Union, 2022). Specifically, (The Council of the European Union, 2022) focus on following;

- Increasing the security of supply within EU
- Support increased development of RE technologies
- To implement short term political measures to increase the RE development
    - E.g., easing of the approval process of RE technologies, shorter approval for solar technology on existing building structures (The Council of the European Union, 2022). In general (The Council of the European Union, 2022) stresses that this should be done since RE-technologies are of societal interest.
- Ease of approval process for specific technologies
    - Specifically, to increase the development for small PV projects for private consumers and small-scale collective consumers (The Council of the European Union, 2022). Moreover, create a frame for technologies like wind turbines to increase their production of RE (The Council of the European Union, 2022). Lastly, since heat pumps are the most direct alternative in the heating sector to natural gas, the development of this technology is prioritized and eased (The Council of the European Union, 2022).
- The role that RE technologies should play to the future decarbonization
    - Especially that solar and heat pumps should play an essential role to transition from natural gas due to its cheap costs pr. Energy output (The Council of the European Union, 2022).
- Repowering of existing capacity of RE should play a role to replace Russian gas

PARTIAL CONCLUSION: WHAT CAN BE LEARNED FROM THE CRISES 50 YEARS APPART?

So, the energy crises in the 70s had a major influence on the following development of the Danish energy system. The urgent need to find and implement alternatives to the limited oil meant that for the first time since the beginning of the establishment of the Danish energy system significant political influence on the energy sector was seen. Previously some corrective energy planning initiatives where made, and thereby had the development up until the 1970s been dominated by the key actors in the energy sector. The energy system had until 1973 been stable with almost unlimited supply of goal and especially oil. Thereby the crisis forced the Danish Government and energy sector to consider the energy development and the future Danish energy system.

Since then, the political influence on the energy sector has only increased. With the political influence the development of RE began, a development that was important to get closer to the international climate goals. A development driven by political actors. With the establishment of both long-term strategies and ambitions combined with regulative initiatives like policies and directives the development of RE increased especially during the 1980s and 1990s. Therefore, the energy planning tools made after the crisis to both ensure that Denmark overcame the crisis and continued to develop had significant influence on the RE development. Since the interests in the energy sector where primarily driven by economical optimization and interests there is a possibility that RE was never established during these decades without political ambitions and influence. Moreover, there is a possibility that this political interest had not been there without the oil crises. Therefore, the crises have not only influenced the development of RE-projects from 1973 until 2023, but it has also established the foundation of the energy policies and energy planning methods and tools that exist today.

These methods and tools are going to be crucial to solve the current energy crisis and has ensured that Denmark is better placed both to tackle the crisis and to develop RE exponentially. The current crisis may become a decisive driving factor for this development, surely because Denmark is at a place in the development where the alternatives to natural gas that make sense to implement are only RE technologies and sources. Denmark is in a position where there are significantly more technological opportunities to implement RE solutions than 50 years ago. This is primarily due to the technological development that has taken place since the 1970s, but it is also due to the political prioritization of RE technologies, which has led to several of these technologies becoming economically competitive with fossil alternatives. Thus, the current energy crisis will probably have a greater impact on the actual implementation of RE projects than the crises of the 1970s ended up doing.

It is however problematic if the development of RE is based solely on short-term considerations. One of the most problematic decisions made during the crisis in the 1970s was to prioritize natural gas as the main alternative to the oil because it was the easiest and cheapest alternative from a short-term perspective. The same trend can be seen in the Emergency Regulation by the EU where specific RE-technologies are prioritized because they are easy and cheap to implement from a short-term perspective. These kinds of solutions could in worst case entail that Denmark and the rest of the EU ends up making the same mistakes that was made 50 years ago.

This is important knowledge and learning since it illustrates that with the right planning methods and tools an energy crisis can become a driver for RE-development. However, it also shows that when a crisis stands on mistakes can be made and there is not time for the long-term aspects that can ensure the optimal pathway towards a 100% RE based energy system. Therefore, the planning and policies done between crises are key to the RE-development.

CHAPTER 5: TECHNICAL SHORT-TERM AND LONG-TERM ASSESMENT ANALYSIS

The purpose of this chapter is to evaluate long-term and short-term aspects to quantify the findings of the policy analysis in the previous chapter 4. With these the economic, environmental, and technical consequences for PVs specifically is investigated. This is done by firstly calculating the economic benefits of the technology in short term based on the LCoE and the AC of the technology. The technology is then investigated from a long-term system perspective in EnergyPLAN based on the IDA Vision 2030 (Lund, et al., 2020), where the influence of a larger capacity of PVs is investigated. Therefore, the purpose of this chapter is to answer sub question 2:

How can short-term and long-term aspects be assessed for specific RE technologies?

IDAS LATEST CLIMATE RESPONSES

Researchers at Aalborg university have since 2015 developed three key climate reports; “IDAs Climate Answer: Transportation- and energy solutions 2030” (Lund, et al., 2020), “IDAs Climate Answer 2045 – how to become climate neutral” (Lund, et al., 2021), “IDAs Energy vision 2050” (Mathiesen, et al., 2015). These climate responses are important takes on what technological developments and solutions exist and how they can be utilized to reach the Danish goals for the future energy system and the increase in RE in general.

The Energy Vision 2050 was made in 2015 (Mathiesen, et al., 2015). This vision primarily focused on creating an intelligent energy system – smart energy system, where all energy sectors together should be developed for the future energy system to integrate 100% RE (Mathiesen, et al., 2015). With this vision being published in 2015 it was published only four years after the 2050 strategy (The Ministry of Climate and Energy, 2011), where some of the same ambitions for the future energy system are addressed. With the long-term focus in the report, it is stressed that as part of this long-term perspective the different energy sectors should be compatible and not considered individually but from a cross-sectorial system (Mathiesen, et al., 2015). This focus on smart energy systems has followed the research of the new visions from 2020 and 2021.

Climate Answer 2030 was made in 2020 (Lund, et al., 2020). This report describes the challenges of reaching the political 70% reduction goals (Lund, et al., 2020). The research group of this report have calculated how Denmark can become 100% based on RE sources set up in a scenario showing the technological structure of the energy system needed for Denmark to become climate neutral in 2045 (Lund, et al., 2020). The research group stresses that there is a potential for Denmark to be leading experts in transforming an energy system and implementing innovative technologies (Lund, et al., 2020).

The Climate Answer 2030 (Lund, et al., 2020) suggest a combination of following sources and technologies for Denmark to decrease GHG emission by 70%;

- Wind (both onshore and offshore)
- Solar (both PV and collector)
- Geothermal
- Biomass
- Biogas
- Wave
- Natural gas
- Oil
- Coal

Besides the last share of fossil energy sources, these sources and technologies align with the political ambitions described in the problem analysis (The Danish Government, 2018).
The purpose of the model scenario from (Lund, et al., 2020) is that the solutions in the system are the most socio-economic solutions. Especially energy conversion and energy storage play an essential role to the optimization and cross-sector smart energy system of the EnergyPLAN model (Lund, et al., 2020).
Because the Climate Response 2030 (Lund, et al., 2020) is not 100% based on RE this model is chosen to investigate in energyPLAN, since this allows for the test of an increased share of PVs in the system to see the effects of a larger development of PVs than expected.
The third and most recent vision from 2021 (Lund, et al., 2021) is in several ways more ambitious than the previous reports. In the report it is stressed that to reach the Paris Agreement goals, the 2050 ambitions are not ambitious enough (Lund, et al., 2021). The report briefly addresses the COVID19-pandemic which also showed the essential relationship between energy and society during a crisis (Lund, et al., 2021).

INVESTIGATION OF THE TECHNICAL, ECONOMIC, AND ENVIRONMENTAL IMPACT OF PVS

The following section investigates the impact of increased PV capacity from a broader sustainability perspective by including both economic, environmental, and technical aspects of the technology from a short-term and long-term perspective.

Short-term context – LCoE and AC calculations

The same context and input values is utilized for the calculation of the LCoE and AC. This context is defined as the energy system of today why prices and technical data utilized in the calculation is based on 2020-values.
These calculations are useful to determine the business case of the PVs, however it does not consider how this technology fit together with the rest of the energy system. In short-term it is important that the technologies are environmentally and economically feasible to be implemented (The Council of the European Union, 2022). However, in long-term it is essential that the technologies are also technically feasible in an energy system perspective (Lund, et al., 2020).

Table 2 Results of LCoE calculations for PVs in 2020 prices. Based on data from (The Danish Energy Agency , 2022).

LEVELIZED COST OF ELECTRICITY (PV)	VALUE	UNIT
Investment costs	166.880.000	DKK/MW
O&M costs	67.350.226	DKK/MW/year
Fuel costs	-	DKK/MW/year
Electricity generation	1.074.436	MWh/year
Discount rate	3,5	%
Lifetime	35	years
TOTAL	**218**	**DKK/MWh**

The results from the LCoE calculations are presented in table 2 The LCoE for PVs in 2020 prices are around 218 DKK/MWh. This equivalates to a little under 2/3 of the electricity price utilized in the IDA 2030 Vision of around 380 DKK/MWh (Lund, et al., 2020). Moreover, this LCoE price is somewhat equivalent with the LCoE from (Danish Energy Agency, 2018) with only around 10 DKK/MWh in difference. Therefore, the results from (Danish Energy Agency, 2018) of other RE technologies can be compared to the LCoE calculated in this thesis. The calculations from (Danish Energy Agency, 2018) show that PVs have the second lowest LCoE after onshore wind turbines. Where biomass, especially wood have a significantly higher LCoE than both wind and PV technology (Danish Energy Agency, 2018).
The results thereby indicate what is stated in the emergency regulation (The Council of the European Union, 2022). That the cost of PV technology is relatively low compared to other RE technologies and that the LCoE is thereby also lower than the average LCoE for energy technologies (Danish Energy Agency, 2018).

Table 3 Results of abatement cost of CO_2-reduction for electricity production exclusively calculations in 2020 prices. Based on data from: (Danish Energy Agency , 2023) and (The Danish Energy Agency , 2022).

ABATEMENT COSTS (PV)	VALUE	UNIT
Price for PV electricity	218	DKK/MWh
Mean **CO_2** eq/MWh	0,2	ton CO_2eq/MWh
CO_2 eq/MWh (PV)	0	ton CO_2eq/MWh
TOTAL	**1.090**	**DKK/ton CO2eq**

The results from the AC calculations are presented in table 3 and in figure 19. The results show that the CO_2-equvilant (eq) savings that PVs entails with a PV electricity price on around 218 DKK/MWh is around 1.090 DKK/ton CO_2eq.

Comparing this AC for PVs to other CO_2-saving initiatives, according to calculations from (Brøns-Petersen, 2019) the price for cheap CO_2-saving initiatives is around 377 DKK/ton CO_2eq is significantly lower than the AC for PVs. However, the price for expensive CO_2-saving initiatives is around 1.287 DKK/ton CO_2eq and thereby higher than the AC for PVs (Brøns-Petersen, 2019).

The short-term investigation thereby indicates that from an environmental and economic perspective based on energy production, PVs are a relatively cheap solution compared to other technological alternatives. Therefore, from a solely financial perspective, it makes sense that in short-term there is a political interest in developing and expanding the integration of PVs.

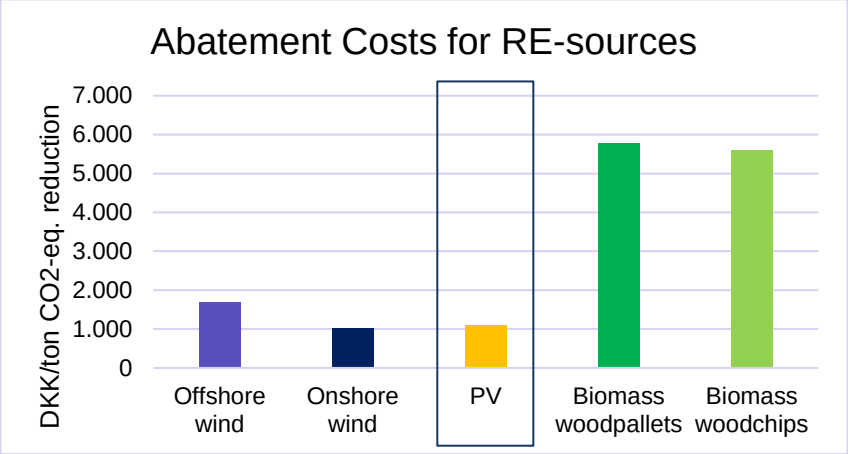


Figure 19 Overview of calculated abatement costs in DKK/ CO_2-equvilant reduction. Based on LCoE data from (Danish Energy Agency, 2018).

Long-term context – Energy System Analysis in EnergyPLAN

The technical feasibility of the RE-technologies in this case PVs is more in focus in the long-term perspective than in the short-term perspective. This technical feasibility should be investigated in a system perspective, since it is important that the technologies implemented are compatible and thereby most optimal from an energy system perspective (Lund, et al., 2021) (Lund, et al., 2020).

This long-term perspective is investigated to compare the outcome of the short-term calculations with the long-term energy system analysis to address if the short-term and long-term perspectives of the PV technology are somewhat the same, if the short-term analysis shows a better result for the PVs than the long-term analysis or vice versa. This energy system analysis is useful to determine what the effect on the energy system in long-term when the climate goals are reached, and the system is based on a significantly higher share of RE than today.

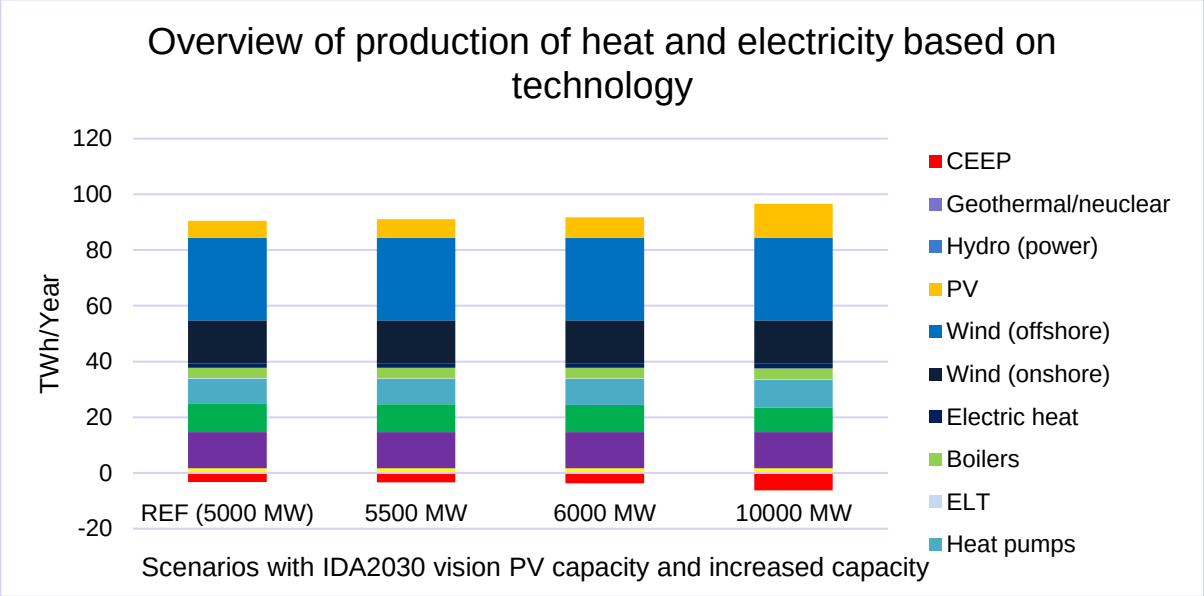


Figure 20 Overview of production and energy system balance (CEEP) for different scenarios of PV capacity. Based on the EnergyPLAN model from (Lund, et al., 2021).

Figure 20 illustrates an overview of the utilized technologies in the IDA 2030 scenario with 70% reduction of CO_2-emissions called REF scenario (first pillar) (Lund, et al., 2020). The other two pillars in the figure illustrates the effect of an increase in PV capacity of 500 MW and 1000 MW. No drastic changes appear in the system with the increased PV capacity.

However, With the increased PV capacity from 5.000 MW to 6.000 MW the CEEP (critical excess energy production) (red pilar share) increase from 3,21 TWh/year to 3,67 TWh/year. The CEEP is typically utilized to illustrate the energy system ability to integrate the RE technologies since it is a measure to how much energy is now utilized in the system and thereby instead becomes an imbalance since the transmission capacity needed increases (Lund, et al., 2020). With an increase of capacity to 10.000 MW the CEEP value increases to 6,26 TWh/year. Since this CEEP value is around double the value of the CEEP for the reference IDA Vision 2030 scenario and the PV capacity is increased to around double the CEEP value thereby indicates that the increased capacity of PVs is not integrated properly in the system (Lund, et al., 2020). If the Emergency Regulation (The Council of the European Union, 2022) entails that a significantly larger share of PVs are implemented than what would have been implemented without the regulation, the results indicates that the PVs would end up being extra unutilized RE-capacity and thereby primarily an expense in long-term. If this is the case, then the results also indicates that technologies that are feasible in short-term are not necessarily feasible in long-term. Without a tool to quantify the feasibility of the RE-technologies based on a combination of both short-term and long-term elements, a concern could be that during an energy crisis, problematic technological choices could be made to implement quick alternatives. The ambition to increase RE and phase out natural gas is a part of both the short-term and the long-

term goals, however the pathway to reach this goal might differ from a short-term perspective and from a long-term perspective.
The pathway depends on what problems are to be solved. Currently the main problem is how to become independent of natural gas – in long-term the problem is how to become independent of fossil energy. In short-term it is a problem how to increase the development of the cheapest, most optimal and least complex RE solutions to replace the supply that Russian gas covered before the crisis. In long-term it is a problem how to ensure a balance between self-sufficiency and international energy trading to optimize the energy system in terms of both technical, economical, and environmental concerns.

PARTIAL CONCLUSION: WHAT DOES THE SHORT-TERM AND LONG-TERM ASSESSMENT SHOW AND WHY?

So, with the Emergency Regulation specific RE alternatives have been prioritized in a short-term perspective for Denmark and the rest of the EU to overcome the current energy crisis. The results of the technical investigation of both short-term and long-term sustainability measures and considerations it is not without risks to implement one specific technology solely. With the increased RE shares, it is necessary to implement a flexible and smart energy system based on a broad mix of RE-technologies. One RE-technology alone, especially a fluctuating RE-technology like PVs, produce energy with a specific production profile. This production profile of PVs does not follow the consumption pattern, which entails a need for either storage of the electricity produced by the PVs or electricity export for the system to not be in imbalance if a large share of PV is implemented. In short-term the PVs are cheap and easy to implement, PVs are one of the cheapest RE-technological alternatives currently and is a well-known technology.
However, in long-term it is not feasible to implement a large share of PVs if there is no specific purpose of this other than increasing the RE share since it is then not utilized in the system. This can in worst case in long-term entail that an overcapacity of PVs is implemented which is then not utilized properly. If this ends up being the case, this could entail that PVs are not the cheapest technology in long-term due to the extra costs related to overcapacity and extra transmission needs. This then also entails that even though the share of RE is increased, if the PV generated electricity is not utilized the long-term goals of becoming 100% independent on fossil energy is not met if the electricity is just exported instead of utilized to replace the fossil energy in the Danish energy system.
The IDA climate response and other similar studies of scenarios to reach the long-term goals identify important knowledge of technological opportunities and system optimization. This kind of research include pathways to reach the long-term strategies and illustrate the importance of establishing short-term plans to implement the solutions that are already available and capable of reaching the 100% RE goal.
The results also show that the short-term and long-term solutions not necessarily work against each other. Solar and PVs are to play a role in long-term, why it is most certainly relevant to implement PV capacity in short-term. However, it is a matter of how the short-term versus the long-term considerations are prioritized since they focus on different aspects. E.g., there might be a limit for when it is no longer sustainable to

implement more PV capacity depending on what the long-term goals for PV are, this limit might be different from what is economically feasible in short-term. In this case short-term aspects solely could pose a threat to gaining an optimal system in long-term. Therefore, the future energy planning should not be based on either only on short-term aspects or only on long-term aspects. Future energy planning should be based on both and should in this regard be prioritizing aspects from both the short and long term to ensure that RE is both planned and implemented within the time frame for the global climate goals to be reached.

CHAPTER 6: EVALUATING ANALYSIS – UTILIZATION OF FINDINGS

In this following section the findings of the two analyses are identified, compared, and evaluated based on interviews conducted with key stakeholders. This is done conclude on concrete pathways for both short-term and long-term energy planning.
Therefore, the purpose of this chapter is to answer sub question 3:

Where should knowledge from the crisis and assessments be utilized in future energy plans and political decision making in Denmark in general?

IDENTIFIED KEY ENERGY PLANNING ISSUES IN THE ENERGY CRISIS

In several cases, we have ended up with the same challenges and the same approach to solving the crisis as in 1970; Among other things, natural gas was the easy solution to replace oil with back then and has not been 100% replaced yet despite political ambitions and initiatives. Therefore, a similar situation is today, with dependency of natural gas imported from Russia. However, one of the major differences between 50 years ago and today is that almost the whole energy system was based on oil before the oil crises and right before the current crisis only a smaller share of the energy system was based on natural gas (also primarily the heat sector) (Danish Energy Agency , 2023).
Many political initiatives have been set considering the oil crises in the 70s. Therefore, today several long-term strategies exist (The Ministry of Climate and Energy, 2011) (The Danish Government, 2018). However, there is not the same amount of concrete short-term plans with sub-goals for how to achieve the long-term goals. This is to not only focus on either corrective, prognostic, or programmatic planning approaches (Gaardmand, 1980). But to combine these types of approaches. The current energy crisis has helped to highlight this by showing how quickly development can happen with political priorities.
With the Emergency Regulation, the permit granting process for RE technologies has been eased – specifically for PVs and heat pumps (The Council of the European Union, 2022). This priority has been made since these technologies are cheap and simple solutions to replace Russian natural gas (The Council of the European Union, 2022). However, the technologies have not been assessed based on what role they should play in the long-term. This can in worst case lead to projects accelerated by the Emergency Regulation not being optimal in terms of achieving the long-term goals of the energy system transition. This could then lead to a similar situation like back in the 70s where natural gas was politically prioritized to implement for the same reasons (Rüdiger, 2011).

IDENTIFIED KEY ENERGY PLANNING OPPORTUNITIES OF THE ENERGY CRISIS

With the political and energy-based institutions established today, the foundation for implementing renewable and innovative technological solutions with the right political and regulatory framework has already been created. The crisis has shown that if there is a political priority, the actors are fully capable of implementing the technologies.

RE-technologies have during the crisis become of a greater interest and focus by society in general (Jørgensen, 2022). The energy crisis therefore has opened new opportunities for radical technological changes (Lund, 2014). Thereby, the opportunity to create new plans and increase the ambitions to integrate RE in the future Danish energy system with a combination of both corrective, prognostic, and programmatic planning (Gaardmand, 1980).

PARTIAL CONCLUSION: CONCRETE SUGGESTIONS BASED ON FINDINGS – PATHWAY IN THE LIGHT OF THE CURRENT CRISIS

The following three bullet points are recommendations based on the findings of this thesis. These recommendations are directed both towards the Danish Government and political decision makers, but also towards actors within the energy sector that play a key role to the RE development in Denmark.

It is important for Denmark to be based on as variated energy sources as possible

- This is both in terms of technologies, energy sources, import sources and technology material supply. This both includes the national energy production and energy imports in Denmark. Currently, more RE-technologies are available than ever before, these should be utilized and prioritized.

Future plans and strategies should be more variated in tools and methods utilized to reach the wished development and goals

- Several tools and methods have been established over the past 50 years, but if these are utilized isolated there is a risk that the same RE development as before the crisis will continue in the same speed leading to the current goals not being reached in time. This includes a stronger combination of different planning approaches.

Denmark should focus the development of RE on technologies that are most socio-economic feasible both in short-term and in long-term

- It would benefit the development of RE technologies if a tool to compare technologies based on both short-term and long-term factors would be established, so that it would be easier to enhance the implementation.

This identification of energy planning issues and opportunities have been presented to key actors in the energy sector. A discussion and evaluation of these identifications is made in the following chapter. Along this the concrete results of the analyses are discussed together with the influence of the theoretical and methodological background for these investigations. The results of the analyses and the discussion is then utilized to make concluding remarks on what the dilemmas of the energy crisis are and what challenges and solutions the crisis have entailed.

CHAPTER 7: DISCUSSION

The purpose of following chapter is to add new perspectives to the investigated scope. This is to shed a critical light and reflect on the investigation and results of this thesis. First, the results of this thesis are discussed in terms of what they indicate and the influence that the methodology and theoretical framework has had on these. In relation to these inputs from the interviews are included to evaluate the findings from a practical point of view. Secondly, other Danish political initiatives established during the crisis and their influence on the future development of the Danish energy system is discussed. Lastly, Denmark's position in a future energy crisis if the recommendations of this thesis are considered is discussed.

RESULTS OF THE DILEMMAS OF ENERGY CRISIS – DISCUSSION OF THEORETICAL SHORT-TERM AND LONG-TERM ISSUES AND SOLUTIONS

The result of the investigation of similarities and differences of the energy crises that has occurred 50 years apart showed that the context of energy planning and energy planning in it as changed rapidly since the crisis in 1973 (Sperling, et al., 2011) (Rüdiger, 2011). One of the reasons to this was exactly the event of the energy crisis that forced both political and energy sectorial actors to be aware of choices and alternatives to the import of especially oil. However, despite this development several similarities can be identified between the issues and mistakes made during the oil crisis and the current natural gas crisis. These similarities in challenges and mistakes could indicate that they are a part of a crisis. However, they are important to address since the newly arrived opportunities that the energy crisis has entailed constitute a key foundation to ensure a development of tools and knowledge to minimize the consequences of a new crisis, since there is a possibility that a future crisis might entail similar issues (Coyle & Simmons, 2014). The dilemmas of the crisis complex problems meaning that there is not only one true solution to solve them (Coyle & Simmons, 2014). Several approaches and technologies can be utilized to minimize the challenges seen both before and during the current energy crisis.

The results from the short-term and long-term assessments also indicates that single technologies are not a feasible solution in long-term stand alone. The more RE increases the more complex the system gets and relying on only few technologies or solutions does not only pose a risk in terms of reaching an optimal operation of the technology, but it also poses a threat to the energy security and to energy dependence that has been some of the main issues during both energy crises. These issues have been discussed prior to the current energy crisis but has been enhanced due to the crisis. Therefore, they are not only issues that can be solved short-term, but issues to deal with in long-term as well (CEPS, 2001).

The results of both the policy analysis and the assessments therefore does not show or define how the short-term and long-term aspects and planning methods and tools should be prioritized, weighted, or utilized. This is one of the more significant limitations of the methods utilized in this thesis. The methods utilized are conceptual and thereby constitute the foundation of an investigation of the influence of methods, tools, and aspects in short-term and long-term. A method to include the identified

aspects in this thesis a tool or matrix would be a beneficial to determine what technologies to prioritize and when to minimize the issues and utilize the solutions identified. Thereby the findings in this thesis could be starting points in innovative discussions for the pathway to not only solve the energy crisis, but also to minimize the human impact on the climate crisis. It is in this relation important to acknowledge that the delimitations entailed by the methodological and theoretical choices in this thesis influence the results. Some key dilemmas and a specific energy planning utopia identified in this thesis has been investigated based on specific methods. This does not mean that other dilemmas are not important or influential. It does not mean that energy planning utopia only contains the elements identified in this thesis. It does not mean that other methods and tools to assess and quantify the feasibility of different RE-technology does not exist. It means that alternatives to methods and theories could support or be supported by the findings in this thesis.
Uncertainties that energy crisis causes are not something to underestimate, since it plays an essential role to how the reaction and actions are during a crisis (Moret, 2017). With this uncertainty there is a limit to what can be planned beforehand of a crisis, especially since uncertainty influence the short-term context significantly more than the long-term context (Moret, 2017). Therefore, one could argue that some aspects of future crises cannot be predicted and cannot be solved by short-term nor long-term planning. With this argument mistakes will be made, and some unknown uncertainties can influence RE-development differently than expected. However, this does not make short-term and long-term planning less necessary. Especially since the foundation to deal with these uncertainties are created from the moment one crisis is over until the next crisis appears - through the methods and tools of energy planning.

INPUTS FROM INTERVIEWEES – KEY ACTORS WITH PRACTICAL KNOWLEDGE OF SHORT-TERM AND LONG-TERM ISSUES AND SOLUTIONS

Since the results of this thesis has been based on the theoretical and methodological choices described above, the results have been dominated by a principal perspective on issues and opportunities of the energy crisis. Therefore, it has been important to address and discuss these findings with key actors with knowledge in and experience with practical work in the Danish energy sector during a crisis. These key actors are identified because of their work with the main energy infrastructures in Denmark; the district heating sector, the electricity and gas sector and overall analysis of trends within the energy sector. Therefore, their opinion and experience are key factors to include and discuss in this thesis as their point of views are highly valuable. It is however important to acknowledge that the actors often act in their own interests and their identification of issues and solution therefore also reflect what would benefit themselves. E.g., it would be beneficial for Energinet, if the legal framework for establishing new infrastructure for electricity and gas was eased (Kristensen, 2023). Therefore, their interest in this is also driven by the benefits they would gain from this. However, one could argue that a development in this infrastructure also would be of a societal interest since this could minimize bottlenecks in the system and make it possible to increase the RE capacity in Denmark. Energinet holds a broad knowledge and experience in developing the Danish infrastructure because they are one of the

key actors to ensure that infrastructure problems do not occur (Kristensen, 2023). They know what the future needs for infrastructure are going to be and what processes are needed based on the long-term political goals for RE capacity (Kristensen, 2023). Because of the share of Danish households supplied by district heating in Denmark and because of the new political decision to increase this share to become independent of natural gas, the district heating sector are going to play an essential role in the future energy system and in the RE development. Dansk Fjernvarme are also interested in playing a significant larger role in the Danish energy system (Behnke, 2023). They gain influence, especially if they with the increased RE are going to work more closely with other sectors to reach the long-term goals (Behnke, 2023). However, it is also of a societal interest if the increased role of the district heating sector leads to optimized system processes and utilization of waste energy. Moreover, it is of societal interest if district heating can help reach the international long-term climate goals and can be a stabilizing factor with storage opportunities for fluctuating energy.

Thereby, these are key examples of interests from key actors that could align with societal interests why it is important that these experts in the different sectors, which the actors are, are considered in terms of their knowledge, experience, and competences valuable to reaching the political goals. The actors are as mentioned not investigated in this thesis, but the interviews indicate that these actors hold key competences and are a part of the solution for Denmark to both reach the short-term and long-term goals. The key challenges and opportunities identified by the interviewed stakeholders are displayed in following table 4.

To the statement that Denmark has been in somewhat the same position as back in the 1970s just for natural gas instead of oil, (Behnke, 2023) agrees that there are a share of similarities in the situation that is now and back in the 1970s. (Capion, 2023) somewhat disagrees, since he believes that Denmark currently is significantly less dependent on natural gas as it was the case of oil 50 years ago. (Kristensen, 2023) agrees that the EU overall is challenged on security of supply due to the dependency on natural gas, however (Kristensen, 2023) also believes that natural gas dependency is not as significant in a Danish context due to the ambitions for biogas and the backup of Danish natural gas from the North Sea.

	***Kim Behnke** – Dansk Fjernvarme*	***Søren Dupont Kristensen** – Energinet*	***Karsten Capion** – Concito*
Key challenges	To find **alternatives to natural gas** that can act as security to the supply as natural gas has done during the COVID-19 pandemic. To increase the diversity in fuels and RE-technologies, to not become dependent on certain energy sources. To reach the transition goals in the transport- and agriculture sector.	Challenges before the crisis have increased during the crisis. The establishment of necessary grid infrastructure to accommodate the RE development. To ensure the balance between electricity production and consumption with increasing future consumptions.	To find **alternatives to natural gas**. To clarify what issues are urgent and which issues are more structural. The immediate transition to LNG could lock-in new interests, which can cause new issues in long-term.
Key opportunities	To continue the transition towards RE. To utilize the resources that exist in Denmark today to reach the long-term goals in collaboration between the sectors. E.g., the power plants as **backup** to fluctuating RE sources. **Increased investments in RE technologies.** For the district heating sector to play an essential role to support other sectors to reach the climate goals.	Flexible electricity consumption. The increased engagement of citizens and municipalities. Eased implementation process for infrastructure projects. Increased EU collaboration in terms of energy trading. **Backup** of energy resources.	The increased business-case for RE compared to fossil energy, which has decreased the uncertainties of investing in RE-solutions. **Increased investments in RE technologies.** Planning should solve the climate challenges. It is important to identify what should happen in the development and when.

Table 4 Overview of identified issues and solutions based on interviews; (Behnke, 2023) (Kristensen, 2023) (Capion, 2023).

To the statement that the energy crisis has shown that with political initiatives and priorities actors are more than capable of implementing the RE-solutions needed to reach the long-term goals, (Behnke, 2023) agrees. He however adds that the crisis also has shown that new aspects need to be considered in the energy planning, e.g., that it has shown the need for backups in the existing production capacity from power plants. Moreover, (Behnke, 2023) thinks that the complexity of district heat regulation has not been clear enough from the framework described in the emergency regulation, which needs to be addressed in future plans. Both (Capion, 2023) and (Kristensen, 2023) questions this statement but for different reasons. (Kristensen, 2023) believes that not all areas of the energy system need concrete planning goals and political regulation to develop in the future. However, (Capion, 2023) believes that the political initiatives and strategies have been useful tools to increase the share of RE and find it important that concrete actions are made to fulfill the political ambitions. Moreover (Capion, 2023) believes that there still is a need for specifications of regulative frameworks for development of RE onshore and offshore.

DENMARK'S POSITION IN FUTURE ENERGY CRISES COMPARED TO THE REST OF EU

During the crisis, a major focus has been on ensuring security of supply with the acute cessation of natural gas supplies from Russia. Therefore, security of supply has been dominant in the first phase of the crisis and several solutions to restore and maintain security of supply have therefore been discussed (Madsen, 2023). The two things that have especially recurred are supply from different energy sources and a greater share of self-sufficiency. With the wind potentials in Denmark, it is not surprising that the ambition is for wind to play an increasingly important role in supplying Danish energy consumption in the future (The Danish Government, 2018).

During the current crisis, the ambition has generally been to replace natural gas with RES, which can increase Denmark's share of self-sufficiency. However, as mentioned, the emergency regulation particularly favor's PVs and heat pumps, because these solutions are cheap and relatively well-known technologies (The Council of the European Union, 2022). Another aspect of the energy development is the supply of materials and modules for the RE-technologies implemented, this would constitute a paradigm shift. For instance, China is one of the main sources for PV imports in EU, since around 67% of the total import of PV modules in 2019 was imported from China (Clean Energy Technology Observatory a, 2022). In the period between 2010 and 2021 the price of PV modules has decreased with around 92% mainly due to increase in technical efficiency (Clean Energy Technology Observatory a, 2022). For Wind turbines the primary module producing companies are in China making the Chinese market share for most of the wind energy modules over 50% (Clean Energy Technology Observatory b, 2022). This technology module import dependency is important to address in relation to the dependency on fuels, since material and module imports are becoming a larger share of the energy system as a larger share of RE-technologies are implemented.

The second aspect of greater self-sufficiency may also be a challenge in the longer term. Like Denmark, other countries in the EU could also have considered how to become more self-sufficient which could influence the future energy trade within EU.

Among other things, Norway has discussed to what extent Norway should decrease their export of hydropower to become more self-sufficient in RE (Behnke, 2023). It is to be expected, during an energy crisis, that all European countries will reconsider their energy source options and find different solutions to become independent of gas. However, it may be problematic for the EU to achieve the climate objectives and agreements reached at a European level without the systemic benefits that energy trade across countries brings. Trading surplus RE has become a major part of European energy systems (European Comission and ACER, 2022). It has become a way of utilizing the different RES available in Europe and has made European energy systems more flexible. If energy trade across European countries were not available, the transition to RE would require greater backup and storage capacities than are currently needed, because surplus RE could not be utilized to the same extent. In addition, the different energy source potentials in different countries would not be utilized in the same way if countries with high solar potentials could not export solar energy and countries with high wind potentials could not export wind energy. This is relevant to address because energy trade can bring European countries closer together and make European energy systems more flexible and independent of energy imports from outside of the EU. However, a larger amount of imported and exported energy within EU also makes European countries more dependent on each other, which the current energy crisis has shown can be problematic when all countries are influenced by the crisis and thus all are challenged on security of supply. This would be less of a problem if individual countries in Europe were experiencing energy problems. Here it would be easier for other European countries to support the country with solidarity, as has already been seen with the gas solidarity concept (Behnke, 2023).

CHAPTER 8: CONCLUSION AND PERSPECTIVATION

The scope of this thesis has been to investigate the influence of an energy crisis on the development of RE projects both in the short-term and in long-term. Moreover, which elements of the crisis should be included in strategic planning and energy policy for the future energy system in Denmark has been examined. Therefore, it has been investigated what impact the crises on planning and energy policy had on the development of RE up until the current energy crisis.
The result has shown that with varied political initiatives and planning approaches, where elements of both short-term and long-term elements of planning were present around the 90s, there was a significant increase in the development of REin Denmark. However, the RE development stagnated when a gap in the newly established plans and strategies arose. This clearly demonstrated the need for political ambition and framework both for short-term and long-term development.
Based on the short-term Emergency Regulation set by the European Union and implemented in Denmark, PV technology has been studied in relation to short-term and long-term aspects. The results indicates that even though PVs are a well-known and relatively cheap technology in short-term, PVs are stand-alone not the most optimal RE technology in a Danish context. This is because PVs primarily produce energy in the summer, when energy consumption is lowest, and that an increased production capacity of PVs in relation to IDA's 2030 Vision will not be integrated into the energy system.
Three problematic developments during the current energy crisis have been identified:

- Danish companies have been obliged to switch to oil to maintain their activities. New consumption of oil could lock-in new interests and create new markets.
- District heating as alternative to heating based on natural gas, is already being established. Development of district heating happens rapidly without a national frame or plan. There is a risk that rapidly development could result in a paradigm shift with material shortage and solutions that are not optimal for the energy system in long-term. If pitfalls like these are not addressed, they could become new problems in the future for Denmark to reach the long-term goals.
- Increased PV capacity stand alone are not feasible in long-term energy system perspective.

This thesis has been limited by the scope as well as the associated theoretical and methodological choices, which have led to limitations in relation to the studies carried out in the thesis. Therefore, this thesis should be an inspiration for the issues and opportunities identified in this thesis to be further investigated.
The investigation of the historical development of RE and energy planning from when the oil crises 50 years ago happened has shown that the initiatives that have been established in the light of the crises have been decisive for how the current energy system is structured.
With the current crisis, Denmark and the rest of the world have thus ended up at an interesting and crucial point in the development of RE, which will have an impact on the ambitions and goals set in relation to solve the climate crisis. A crisis that has not become neither a major nor a minor challenge during the current energy crisis.

PERSPECTIVATION

Following perspectivation seeks to investigate topics that is linked to the scope of this thesis and thereby to cover aspects that could be investigated in relation to the issues that are addressed in this thesis. Thereby is the purpose of this perspectivations shed light on elements of strategic energy planning that has not been investigated in this thesis.

Negative electricity prices in Denmark

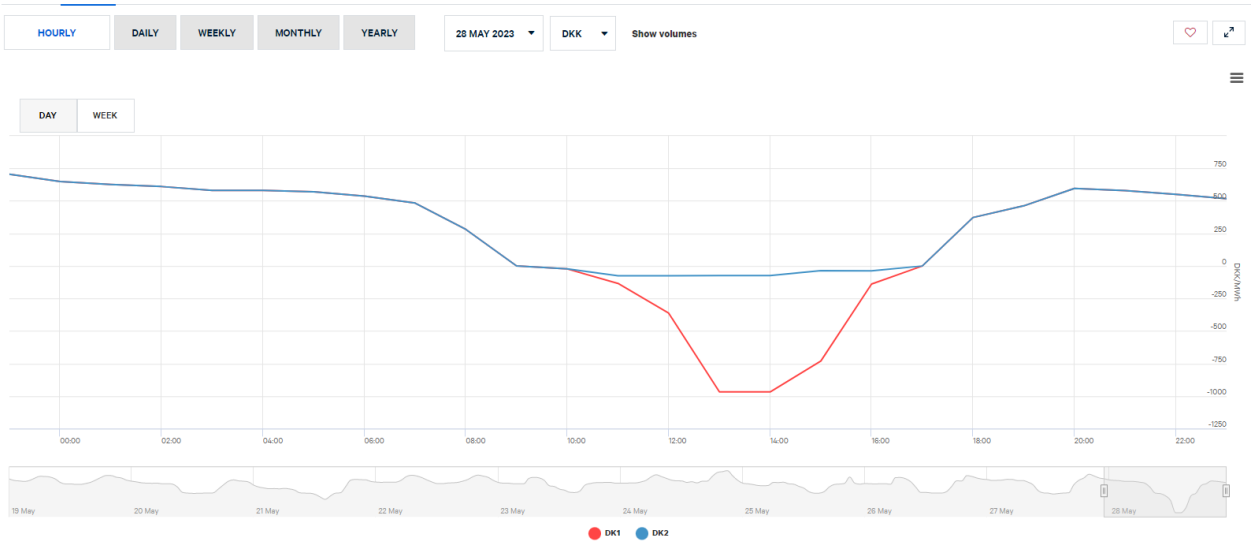


Figure 21 Overview of hourly electricity prices on May 28, 2023, from (Nord Pool, 2023). The chart shows that between 9 AM and 5 PM the electricity prices where <0 and around 1 PM the prices where negative 1000 DKK/MWh.

In May of 2023 some of the most negative electricity prices have been seen (see figure 21). One of the reasons that this describes the current situation is the implementation of PVs in 2022 (Sørensen, 2023). Negative electricity prices are caused by overload of production, from especially fluctuating RE sources like wind and solar, compared to the consumption (Strømlinet, 2022).
Consumers gain economic value from the low electricity prices, but the prices are an issue for the suppliers and the fluctuating production is an issue to the electrical infrastructure (Sørensen, 2023). If this issue is not handled it can cause the same situation for PVs that has been seen for Danish wind turbines that suppliers might be forced to shut down PVs during hours with too much electricity in the grid (Sørensen, 2023). According to (Sørensen, 2023) this can entail that the value of PVs will decrease significantly during 2023, which would pose a concern in terms of solutions addressed by (The Council of the European Union, 2022) in the Emergency Regulation. Moreover, an issue with this situation is also that a share of the certificates for “green power” that a significant share of Danish companies and industries buy is based on certificates for PV electricity which then ends up posing a threat to the Danish electricity consumption being based on RE (Sørensen, 2023).

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APPENDIX A: INTERVIEW SUMMARY

The following appendix contains summaries of the semi-structured interviews conducted in connection with the preparation of this thesis. The interviews were conducted with Kim Behnke from Dansk Fjernvarme, Søren Dupont Kristensen from Energinet and Karsten Capion from Concito. All interviews are based on the same questions, except for the last one where an additional question theme has been added. Summaries of the interviews will therefore follow the same structure.

01-05-2023: Kim Behnke

Introduction:

Kim Behnke is employed as Development Manager in Danish District Heating and has been with Danish District Heating for 8 years and before that he was 12 years in Energinet, which is TSO for electricity and gas in Denmark. In addition, he is the representative of Danish District Heating in the emergency work, which has taken place during the COVID-19 pandemic and during the current energy crisis. As Head of Development, Behnke will ensure that Danish District Heating is involved in relevant development projects so that district heating in Denmark is developed. Dansk Fjernvarme is a trade association with approx. 380 members and therefore covers approx. 99% of district heating supply in Denmark.

How do you see your workplace/industry having been affected by the energy crisis?

According to Behnke, there is no emergency law for the district heating sector yet, as it is only now being drafted. This lack of contingency legislation became a challenge already during the corona crisis, as there was no legal basis for issuing orders during the crisis. Therefore, the pandemic created an increased need for collaboration across industry organisations and with the Danish Energy Agency. This resulted in more tasks than Danish District Heating had previously handled. Among other things, lists of acute hospitals supplied with district heating and information on fuels had to be drawn up, this was necessary despite the fact that hospitals typically have their own emergency power system, as these systems only produce electricity and therefore do not produce heat. The newly established systems benefited again during the energy crisis. However, the focus during the energy crisis has been different than during the pandemic, as the crisis has also had elements of security policy and is therefore not solely about security of supply as it primarily did during the pandemic. Together with Green Power Denmark and Energinet, Danish District Heating has entered into an energy CERT (Computer Emergency Response Team) that keeps an eye on and averts potential cyberattacks against the energy sector. Behnke had not imagined just 2 years ago that someone would blow up vital supply infrastructure, but it happened with Nord Stream 1 and 2 and according to Behnke it has also helped to increase awareness of safety.

What core challenges have you seen in your industry during the crisis?

During the pandemic, Behnke says that there was a certainty for Danish District Heating and the Danish Energy Agency that the district heating sector still had access to natural gas, as the infrastructure in pipes at that time was a more secure source of supply in relation to corona sick leave than, for example, biomass, which primarily must be transported by trucks. Therefore, those who could were converted to natural gas during the pandemic. This affected several combined heat and power plants. Therefore, during the pandemic, the Danish Energy Agency recognised that there is still a need for access to gas in the Danish energy sector. The disruption of the supply of natural gas therefore became a problem for the security created by gas during the pandemic, especially as gas prices therefore increased by a factor of 30, leading to significant district heating price increases. Therefore, according to Behnke, these challenges have meant that the focus on fuel diversity has once again increased. Behnke cites

the oil crises in the 70s as an example of how a lack of fuel diversity was also a challenge back then. Behnke believes that the most important lesson that the crises have taught us is that we should not be dependent on specific energy sources or technologies. One of the people who have weathered the crises best are those who have had a wide range of fuels that they have been able to switch between.

What happens if the issues are not resolved? What challenges do you think this may have on the energy system in the short term and long term?

According to Behnke, this will mean that Danes will be introduced to Brownouts if the issues are not resolved. Blackouts are technical faults in the energy system that cause it to shut down. According to Behnke, they are therefore often unplanned and sudden interruptions of, for example, electricity supply. Brownouts, on the other hand, are planned supply interruptions where consumers are notified in advance when the supply will be interrupted – typically no later than 20 hours before. According to Behnke, brownouts were a fear during the crisis during the fall and winter, but fortunately did not materialize. According to Behnke, brownouts are practiced in several places in the United States, but are not something we have seen in Denmark yet. Behnke emphasizes that the increased prices that have been seen could be another ten times as high in the days leading up to a brownout, and therefore you will probably also see a minor or major economic crisis in this connection. According to Behnke, the population often reacts to brownouts by buying emergency power systems, which almost no one has in Denmark because we have had a high security of supply for a long time. However, according to Behnke, it is not good for a society that everyone invests in an emergency power system, it is fine that, for example, hospitals have some, but ordinary customers should not have emergency power systems. Instead, we should focus on a wide variety of energy sources that complement each other well. So that you do not end up, for example, having to switch back to other fossil alternatives such as gas oil, which, according to Behnke, some had to do during the crisis as a remedy for the rising heating prices.

"Many political initiatives have been prepared in light of the oil crises in the 70s. However, the energy crisis has highlighted the lack of framework, among other things by showing how quickly development can go with regulatory policy priorities. " What is your position on this?

Behnke agrees that the recital is a major challenge. Abroad, according to Behnke, there is a picture of Denmark with power plants and combined heat and power plants as being a picture of the perfect electricity and heating system. But they want to close it, and according to Behnke, the crisis has shown to be a bad idea. In this connection, Behnke highlights the energy trade to our neighbouring countries – we have seen that while Denmark has been in crisis, our neighbours have also been at the same time. Therefore, according to Behnke, the continued need for existing CHP capacity has been a very valuable lesson from the crisis. According to Behnke, this learning will be a shift in Danish energy policy, because power and combined heat and power will therefore probably instead be standby for the fluctuating RES. Another political aspect is REPower EU, which contributes with a new framework for district heating and cooling. Behnke highlights three things about the directive; that district heating must be modernised – primarily in countries in Eastern Europe, that municipalities are obliged to provide district heating for multi-storey buildings where district heating has the least losses, that companies producing surplus heat are obliged to supply this for district heating purposes. According to Behnke, it is expected that there will be an EU directive for surplus heat in the near future, which Behnke believes will open up new opportunities for energy optimization by not emitting the heat but instead utilising it. According to Behnke, this is an option that Danish District Heating is very much in favour of. According to Behnke, there are

therefore some areas where energy policy will change after the crisis. In continuation of the potentials for surplus heat, Behnke mentions the energy islands as an example of an area where, according to Behnke, it is important that surplus heat potentials are exploited and not discharged into the sea. Especially in the case of electrolysis, where about half of the supplied energy is converted into surplus heat, Behnke believes that there is no reason why the surplus heat is not used for district heating.

What is your experience with the Emergency Regulation, what do you think it has contributed and do you see any shortcomings in it that could have been included?

According to Behnke, the biggest challenge for the district heating sector is that the regulation is primarily written based on the possibilities of the electricity system. Behnke believes that the difference between the complexity between district heating and electricity has been overlooked in the regulation. Behnke mentions, among other things, that one of the differences is that individual consumers cannot be disconnected from the district heating network as they can for the electricity grid. So, for example, when hospitals need to be prioritised, the district heating supply cannot be interrupted for other customers on the grid at the hospital. These challenges have needed to be coordinated with the Danish Energy Agency.

"To ensure that we do not end up in the same situation if another crisis should hit Denmark, there is a need for sub-goals for how the long-term goals are to be achieved. " What is your position on this?

Behnke agrees with the above statement, adding that a good example of this is the consumption of natural gas. In Denmark, natural gas consumption was reduced by 25% against the EU target of a 15% reduction. According to Behnke, one of the main reasons for this reduction is the price increases for gas, among other things, that came during the crisis. According to Behnke, this meant that companies and district heating companies saved on their gas consumption by themselves because it became too expensive. According to Behnke, this example illustrates the importance of price if fuel consumption is to be reduced. Therefore, Behnke also believes that fuel prices should be allowed to rise during a crisis situation, as the relief schemes made in the EU shielded the population from the price increases and thus led to not as many households reducing their gas consumption to the same extent. Instead, Behnke believes that it makes more regulatory sense to introduce economic stimulus packages to pay gas bills so that people are aware of the price increases. Behnke also believes that the example of reducing gas consumption has shown that when there is an interest in achieving the targets, they are also achieved. Which is positive because the development has led to an acceleration of the green transition. Behnke generally believes that the ambition for the green transition has increased during the crisis. Among other things, Behnke highlights that a Danish company has invested billions in an ammonia factory and that significant investment capital has generally been freed up during the crisis. Behnke therefore shares the European Commission's ambition to reach a target of 45% RE by 2030.

With the political and energy-based institutions established today, the foundation for RE development has already been created. The crisis has shown that if there is a political priority, the actors are fully capable of implementing the technologies. What is your position on this?

Behnke agrees with the recital, adding that the reference price of green gas compared to fossil gas has now improved with the price increases, especially of fossil gas, that have occurred. He believes that customers have become accustomed to the high gas prices and are

therefore more willing to switch to green gas. Behnke adds that with the rising CO_2 quota price, the business case for green solutions has improved.

What solutions to the problems do you see?

According to Behnke, one of the primary solutions is that we continue with the green transition. Behnke believes that it is realistic to reach the goal of the latest statement from the government, both when it comes to electricity, gas, and the heating sector. However, Behnke believes that there is a challenge in achieving the goals for the transport and agriculture sectors. Here, however, Behnke believes that the district heating sector, among others, can play a role in these sectors achieving the objectives as well. Among other things, by ensuring sales of biogas from the agricultural sector, as well as by utilizing surplus heat from PtX to produce liquid fuels for the transport sector. According to Behnke, it does not make sense to invest in technologies such as nuclear power. He believes that a choice was made in the 70s after the oil crises, and that this choice has meant that we in Denmark today therefore have neither research education nor other professional or technical skills to develop the technology in Denmark. Therefore, Behnke believes that it is about utilising the resources we have in Denmark now, in that we have three well-functioning infrastructures for electricity, gas and heat and thus also the possibility of sector coupling, to achieve the goals.

Are collaborations in connection with. Sector coupling and similar part of the solution?

Behnke clearly believes that it is and adds that it is one of Denmark's strengths. Among other things, Behnke highlights carbon capture plants and in general the development of e.g. PtX as good examples of what cooperation can result in with e.g. negative CO_2 emissions. Behnke believes that with PtX it will be possible for Denmark to develop an energy cycle to achieve negative CO_2 emissions; a cycle where biogas is supplied as fuel to the district heating sector that supplies heat and CO_2, CO_2 is used to produce PtX products for transport, e.g. in connection with biogas production. Behnke mentions the ambition to achieve a 110% reduction of CO_2 by 2050 and believes that Denmark is ideal to achieve this goal. Behnke believes, however, that the biggest challenge for creating collaborations is that part of the regulation and the Danish authorities are used to thinking in silos. Among other things, Behnke mentions the previous tax on surplus heat, which the Ministry of Taxation was opposed to removing because they were worried that companies might produce "false" surplus heat if the tax was not there. Behnke believes that considerations for the energy sector should have been given greater weight and that the process of getting the tax repealed takes too long if each step towards the green transition will take just as long. Behnke therefore hopes that changes will be madein this area.

02-05-2023: Søren Dupont Kristensen

Introduction:
Søren Dupont Kristensen started 20 years ago in the TSO in Western Denmark, before Energinet was established and the TSOs in Denmark were merged. Kristensen's educational background is cand. Oecon. And was associated with the energy sector through his master's thesis on economic regulation of the electricity sector, which is also what he works with today. In addition, Kristensen is part of Energinet's overall Group Management. Since 2011, Kristensen has been Director and is today Director of System Responsibility at Energinet.

Do you see that your work and the industry you are in have evolved during the crisis?

Kristensen highlights the development of RE since 1980 until today. According to Kristensen, Denmark has become one of the leading countries, including periods of supply covered by 100% wind power. With the projections that currently exist for the future development of RE, Kristensen believes that the next 17 years up to 2040 will be even higher characterized by a development of RE. Among other things, because there will be a quadrupling of solar and wind over the next 7 years, which will thus be a quadrupling of the development that has occurred with the RES over the past 40 years. Kristensen believes that the crisis has affected these objectives, as the crisis has led to an increased focus on RE, energy saving and energy supply from non-imported energy sources. Among other things, Kristensen believes that the focus on the implementation tasks, which is an important focus that has come during the crisis and which he believes can lead to important political agreements, they can help increase the speed of the green transition. In general, Kristensen has experienced that there has been an increased desire to accelerate the speed of the green transition during the crisis, especially to ensure security of supply with non-imported sources in an EU perspective.

What are the core challenges you have seen during the crisis that you think could be a challenge to solve?

According to Kristensen, some of the challenges that existed before the crisis have become greater during the crisis and are therefore still relevant to solve. In this context, Kristensen highlights two challenges; establishment of infrastructure to transport electricity from RES, and balance between consumption and production. Kristensen believes that there has generally been greater support but has also experienced during the crisis that prices and delivery times have been affected by the crisis. In connection with the balance between consumption and production, Kristensen mentions, among other things, fluctuating RES such as PVs, where production is dependent on weather conditions that do not follow consumption patterns. Thus, according to Kristensen, the transition to RE entails new balancing challenges. According to Kristensen, these are issues that are relevant in both the short and long term, especially since the expansion of infrastructure is a time-consuming process. According to Kristensen, while RE projects often take about a year to implement from the time the permit is granted, it takes rather 10 years to implement a 400 kV overhead line. According to Kristensen, this difference in time entails challenges if the infrastructure is not considered at the forefront. In this connection, Kristensen highlights the challenge experienced in Germany, where RE capacity has been established in northern Germany, while consumption is in southern Germany without corresponding infrastructure between north and south. According to Kristensen, the potential for renewable technologies is often not in the same place as the need. In this connection, Kristensen mentions that there has been talk of, among other things, exploiting solar closer to consumers, but believes that for solar alone, the contribution will be too low to contribute significantly to security of supply. According to Kristensen, the challenge

for larger RE plants located further from consumers will be to expand and strengthen the infrastructure between production and consumption. According to Kristensen, the consequence of not doing this is that the system must be downregulated and that there will be a need to stop production from wind turbines and PVs. According to Kristensen, there are already challenges in maintaining the balance between production and consumption for periods, and this is an issue that may be exacerbated by increased electricity demand in the future, and which may thus create a greater imbalance between consumption and production.

Do you see anywhere because of the energy crisis that we have made some wrong choices or investments both in the short term, but also in relation to the longer term and the green transition?

Kristensen cites the decommissioning of nuclear power plants in Germany as an example of a measure that has led to an increased production of coal and gas, and which in this way has led to a step in the wrong direction in relation to the political climate objectives. Kristensen does not believe that they in Germany would have closed their nuclear power plants if they had known that there would be an energy crisis like the current one. In a Danish context, Kristensen believes that despite proper processes with neighboring countries in terms of infrastructure, the crisis has shown that it is also important to have emergency supplies available. In addition, Kristensen believes that there is a need for case processing processes for infrastructure projects to be faster so that investment in infrastructure can also be accelerated. Kristensen believes that during the crisis it has become clearer that some administrative practices and procedures have been created that do not support the speed of RE development.

"In several cases, we have ended up with the same challenges and the same approach to solving the crisis as in 1970." What is your position on this?

Kristensen immediately agrees with the consideration, adding that European dependence on Russian gas has been a part of the supply crisis. However, Kristensen does not believe that the consideration is fair in a Danish context alone, partly because the Danish natural gas has been under reconstruction and is expected to be restored to also be able to export natural gas already during this year. In addition, Kristensen believes that with the Danish ambitions to phase out natural gas consumption, there are opportunities for Denmark to become frontrunners for e.g. biogas, which according to Kristensen can become an alternative to imported energy in the future. However, Kristensen can see a problem in the fact that other European countries during the crisis have begun to import liquefied natural gas (LNG) and establish new fossil agreements with countries such as Qatar. In this connection, Kristensen adds that there is a need for closer European cooperation, especially since some of the European energy technologies complement each other well across Europe. According to Kristensen, most European countries benefit from European cooperation.

"Many political initiatives have been prepared in light of the oil crises in the 70s. However, the energy crisis has highlighted the lack of framework, among other things by showing how quickly development can go with regulatory policy priorities. " What is your position on this?

Kristensen partially agrees with the consideration and adds that it is crucial which areas the sub-goals are intended to cover, as some markets function fine without it. According to Kristensen, technologies such as solar, wind and biogas do not require direct government

subsidies. Thus, Kristensen also believes that with infrastructure opportunities, e.g. through Energinet, development will happen faster than planning government tenders will entail. Kristensen therefore does not believe that political objectives should be set for e.g. the amount of electric cars, PVs or wind turbines. Kristensen believes that the need for political decisions has changed as the context for RE has changed since RE is now the cheapest form of energy.

What is your experience or experience in Energinet with the emergency claim, and what do you think it has contributed and possibly also what it lacks?

Kristensen believes that this regulation is most relevant to the issue of implementing the necessary infrastructure as quickly as possible.

With the political and energy-based institutions established today, the foundation for RE development has already been created. The crisis has shown that if there is a political priority, the actors are fully capable of implementing the technologies. What is your position on this?

Kristensen immediately agrees with the recital. Kristensen highlights the new program that the government has presented to set up an energy crisis staff, NEKST inspired by NOST (National Operational Staff). According to Kristensen, this is a product of the crisis and an opportunity to bring together national competences and authorities, where there is an increased focus on solving the challenges and issues that exist. Kristensen believes that the group can help accelerate the development of RE precisely because of the focus on solving the obstacles that may exist for it, and that the issues are solved for the entire value chain as efficiently as possible.

What options and solutions have you seen considering the crisis in your industry?

Kristensen believes that there are many opportunities that have arisen during the crisis. However, Kristensen emphasizes consumer engagement in relation to flexible consumption in relation to when there is a lot of RE in the system. During the crisis, Kristensen has observed that more and more consumers have shifted their consumption according to when electricity prices have been low and where there has been more RE in the system. According to Kristensen, Energinet's aggregated data has shown energy savings due to this trend. Therefore, Kristensen believes that there has been both a mental and physical boost in consumer engagement, which will be important in the future as well. Kristensen also hopes that in the future there will be a greater willingness to make unpopular decisions in relation to solving the challenges highlighted by the crisis. Kristensen believes that there is a need for proper and respectful processes for the affected citizens, but also believes that there must be a balance between when these processes should take place and when there is not the same need for involvement. According to Kristensen, the primary solution to the infrastructure problem is faster case processing. In this context, Kristensen highlights a specific project that the Danish Energy Agency has had in the regulatory approval process for 9 years, and which they themselves expect to spend 2 years implementing if the project is approved. Here, Kristensen emphasizes that the Baltic Pipe project is a good example of how quickly a project can be established without administrative hurdles. Kristensen believes it is about the principle of proportionality and that it should be considered in relation to some of the Danish processes whether there is disproportionality present in them.

09-05-2023: Karsten Capion

Introduction:
Karsten Capion is educated at DTU, specialized in energy systems. Since then, Capion has worked with district heating planning at Ramboll and worked for about 7-8 years at Dansk energi (now called Green Power Denmark) as an analyst for expected development of the energy system of the future. In addition, Capion has worked in the Danish Council on Climate Change and most recently in Concito, where his tasks are broader in relation to climate and politics and therefore work more indirectly with energy.

How do you think your work has been affected by the energy crisis?

Capion does not believe that his work as such has changed in relation to the content of his work. However, Capion has observed that the developments that have occurred have occurred at an increased speed during the crisis, because there has been a need for urgent solutions. Capion believes this is especially special in the energy industry, because the solutions that are implemented frequently are long-term. Capion believes that there is a need to plan efforts correctly so that Denmark does not burn out before the solutions are implemented. Especially because the renewable technologies to be implemented require investments, Capion does not believe that they can be established "Over Night", but that they are solutions that must be implemented continuously. Capion adds that the pace accelerated during the crisis may also be due to the 2025 targets, which need to be achieved in a very short time and therefore also require urgent action.

What have you seen as core challenges during the crisis in general?

Capion believes that one of the main issues during the crisis has been how to reduce dependence on imported Russian gas. He adds that it has therefore led to a need to reduce gas consumption. Capion believes that the timescale of when alternatives to natural gas are to be implemented has been a source of confusion and thus what it has taken to get the right processes started. Capion adds that there has been a discussion about whether Russian natural gas should be replaced with gas from the North Sea as a short-term measure, or whether the area should be reserved for offshore wind turbines instead as a longer-term measure. Therefore, Capion has missed a clearer division of acute and structural aspects.

With the challenges that have been here during the crisis, how do you see that in the short and long term they can affect the energy system if they are not solved?

In the short term, Capion believes that we are urgently facing a supply crisis and economically risk that people cannot afford to heat their houses with the acute cessation of Russian gas. Among other things, this issue has led to several companies switching their consumption to oil, which is a decline in terms of GHG emissions in the short term. Therefore, Capion believes that if the problem is not addressed in the long term, where a phase-out of fossil energy sources must take place, the problem could become even bigger. According to Capion, the crisis has been a "wake up call" for many companies, which has aroused an interest among more people in relation to their consumption. With rising prices, Capion's impression is that more plans for how companies can be converted faster are being established. Capion believes that to promote this development, there is, among other things, a need for renewable electricity-based power to become cheaper.

Do you see in some places that due to the energy crisis, we have made some wrong choices or investments in the short term, which can also affect us in the long run in the green transition?

Capion says that Germany has invested in LNG (liquefied natural gas). Capion's concern in relation to this is that with such a type of infrastructure, there may be a risk that society binds itself to such energy sources and that strong interests are created there, working against the green transition. In a Danish context, Capion highlights the potential for biomass, which has emerged during the crisis and which has been a cheaper alternative with the high gas prices. However, this does not change the fact that in the long term, biomass should not play a major role in the energy system, among other things, says Capion that it has been discussed whether a climate tax should be imposed on biomass. According to Capion, such a tax could have been implemented as early as last year, but because the economy for biomass has been good during the crisis, such measures have been postponed. In this context, Capion believes that it has seen a tendency for the technologies and energy sources that work to be prioritized and that it is difficult to implement solutions that are expensive.

"In several cases, we have ended up with the same challenges and the same approach to solving the crisis as in 1970." What is your position on this?

Capion believes that it is important to distinguish between the situation in the 70s and now, when a larger proportion of Danish society at that time was based on oil and that the crises therefore affected the economy in Denmark broadly. Before the current crisis, according to Capion, about 400,000 households were heated with natural gas, and therefore he believes that the cessation of natural gas supply has been a relatively isolated problem. In this connection, Capion adds that several other energy sources have not risen as significantly in price, and therefore, according to Capion, the crisis has not affected the economy as broadly. If the crisis has nevertheless affected the energy market, it is because a share of electricity production is still based on gas, which has meant that the most expensive power plants have defined the entire price of electricity on the market. According to Capion, it is positive that they do not switch from one fuel to another as they did after the crises in the 70s, but instead switch to RE instead.

"Many political initiatives have been prepared in light of the oil crises in the 70s. However, the energy crisis has highlighted the lack of framework, among other things by showing how quickly development can go with regulatory policy priorities. " What is your position on this?

According to Capion, there are currently. Many frameworks especially in relation to climate policy and to a lesser extent in relation to energy policy. Among other things, in relation to the goals set for Denmark to become CO_2 neutral by 2050 at the latest and preferably by 2045. Capion believes that the 2025 target has been a guide to these policy objectives and has been a good way to reduce fossil fuel consumption. Capion also believes that the energy crisis has helped push the phase-out of gas and thus contributed to more plans being established. However, Capion believes that it is paradoxical that we are now in a period where climate goals have never been higher, while less RE has never been established. Capion adds that, among other things, no onshore wind turbines have been installed this year. Capion sees that the paradox is that the ambitions for rapid development have become too strong to really get started. Therefore, Capion hopes that there will be some tenders that can help clarify the

regulatory framework for the expansion of RE both on land and water. Capion believes that the ambitions are right, but that concrete action has not materialized.

What options and solutions have you seen during the crisis that you think are important to take forward in future energy planning?

According to Capion, one of the main opportunities created by the crisis is the focus on the business case of RES versus fossil fuels. Among other things, Capion has observed that in the past there has been some fear of investing in RES because there has been fluctuation in price and supply. According to Capion, this fear has diminished because the crisis has shown that the otherwise stable fossil fuels can also fluctuate in price and supply, just like the RES. Capion believes that it has been important that the fluctuating RE sources are primarily fluctuating and uncertain in the short term in relation to the weather, then fossil sources are uncertain in the long term and may risk disappearing. Capion believes that this has helped to loosen up investments in RE and that the understanding of the need for transition to RE in general has become greater among consumers, so it is no longer solely about the business case for the transition. In general, Capion believes that climate challenges must be solved with planning and thinking about what should happen and when it should happen.

After interviews with industry organizations, it has become clear that the different organizations see different challenges and opportunities, is this something you at Concito have also seen?

Capion believes that it is natural that the players in the industry have different interests and attitudes to what are challenges and opportunities. In relation to the long-term answers, according to Capion, it is to a large extent the cost-effective answers that are brought into play, because these solutions are often run by companies with an interest in making money. What is of highest public interest is not necessarily the same. According to Capion, it is rare that the solutions that are implemented are not a business for the players who implement them.

What influence do you see these different actors having on energy planning and do you think they will have more or less influence after the crisis than they have had before?

According to Capion, the actors have obvious influence in that the civil service and the rapporteur continuously influence the dialogueabout challenges and solutions in the area. Capion adds that some elements of how central government is organized and how politics works well could change considering the crisis without basing this consideration on concrete data.

