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Overcoming the Institutional Barriers in Relation to Meeting the 2030 Goal

An Analysis of the Danish Energy System

Authors:
Stephen Arguelles Johansen
Thuvaraahen Nagendiram

Supervisor:
Louise Krog Jensen

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AALBORG UNIVERSITY
DENMARK

Department of Planning
Sustainable Energy Planning
and Management
Rendsburggade 14
9000 Aalborg
www.en.plan.aau.dk/

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Stephen Arguelles Johansen
Thuvaraahen Nagendiram

Supervisor:
Louise Krog Jensen

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Synopsis:

The purpose of this thesis was to investigate the possibility of achieving the 2030 goal, which is a 70% reduction in CO_2 emissions compared to 1990. The complexity in achieving the 2030 goal can be defined as two fold: The first being the technical aspect of which technologies to implement, where the second being the institutional context of the Danish energy system. This lead to the following research question:
"How can the Danish 2030 goal be met through a technically feasible scenario and how can the institutional barriers of implementing be overcome?
Analyses of the Danish energy system, and the institutional context, which the Danish energy system is embedded in, were conducted. The energy system analysis investigated, if it was possible to achieve the 70% reduction in CO_2 emissions. The institutional analysis investigated and identified the barriers and challenges regarding the transition towards achieving the 2030 goal. The thesis concludes that it is technologically possible to achieve the 2030 goal, with an increased share of sector coupling between the different energy sectors. However, through the institutional analysis it was concluded, that it is necessary to change the organisational structure and the institutional context, through an increased form of networking between the stakeholders in different sectors and different levels of planning. Furthermore, it is necessary to encourage public-private partnerships in order to create a more coherent energy system in Denmark.

Preface

This thesis is made by a group of two students studying the master's program *Sustainable Energy Planning and Management* at Aalborg University. This thesis revolves around the recent change of the Danish target CO_2 emission goal by 2030, which is a 70% reduction compared to 1990 as this is highly relevant to current events in Denmark and is a prime example of the approach at Aalborg University.

The Harvard referencing method is applied throughout the project, meaning that when a reference is used in the thesis, the specific material in the thesis will be followed by a reference consisting of the author and year of publication. In some cases the authors name will be followed by: *"Et al."* meaning that the reference in question has multiple authors. In cases where multiple references are used for the same paragraph, all the references will appear following the paragraph. In other cases the authors name will be followed by *"n.d"*, meaning that no date of publication is available for the given reference. When referencing to the interview conducted throughout the thesis, these will be referenced with (A.x.x) where x is the specific number for the appendix, and the time stamp for where it is stated in the interview.

The primary language used throughout the report is English, which entails the use of English number formatting is used. This mean that commas represent thousands while periods represents decimals.

The appendix of the thesis contains:

- Interview guides used for the interviews
- Outline of the interviews
- Guides on how the scenarios are made in EnergyPLAN
- EnergyPLAN prints for the different scenarios

Additionally, external appendixes have been attached, which contains the sound files for the interviews as well as the EnergyPLAN files for the scenarios.

Finally, the group would like to thank Louise Krog Jensen for supervision throughout the thesis. Additionally the group would also like to thank the following interviewees for their contribution to the thesis by participating in interviews:

- Søren Djørup, Aalborg University
- Asger Øland, Danish Energy Agency
- Ulrich Bang, The Danish Chamber of Commerce
- Per Skrumsager Hansen, Danish Ministry of Transport
- Lars Hedegaard, North Denmark Region
- Thomas Jensen, Hjørring Municipality
- Lene Kirk Dalum, Holstebro Municipality
- Louise Carøe Foldberg, Vestforsyning

Summary

Dette speciale omhandler to specifikke grene af energiplanlægning i Danmark: Planlægning af Danmarks fremtidige energysystem og det institutionelles rolle i realisering af Danmarks mål i energisektoren. På trods af, at disse anses som to forskellige grene af energiplanlægning i Danmark, vil disse i visse sammenhæng unægteligt have indlydeslse på hinanden. Denne interaktion er hovedemnet i dette speciale og eksemplificeres gennem Danmarks nye målsætning om at reducere landets CO_2-udledninger med 70% i forhold til 1990.

Det er gennem specialets problemanalyse klargjort, at Danmarks energisystem er underlagt en række målsætninger fra både globalt, europæisk og dansk niveau. Hertil er et af de danske mål blevet revideret i 2019, hvor målsætningen om en 70% reduktion i 2030 blev sat. Grundet energisystemets konstante udvikling, er der en usikkerhed i forhold til om målsætningen er realistisk indenfor tidsrammen. Denne usikkerhed understøttes ligeledes af manglen på scenarier der påviser hvordan en 70% reduktion kan nås inden for denne tidshorisont. Dette giver anledning til en analyse af, hvorledes et scenarie hvor målsætningen imødekommes ser ud. Hertil vil en analyse følgende undersøge, hvorvidt sådan et scenarie realiseres, samt hvilke institutionelle barrierer, der foreligger en realisering af scenariet og hvordan disse håndteres.

For at udvidde specialets perspektiv er en række teorier anvendt i forbindelse med specialets analyse. Specialets teorier omfatter makro- og mikrostrukturer og Scotts Three Pillars of Institutions. Disse teorier danner hovedsageligt rammen om den institutionelle analyse. Disse teorier suppleres af en teoretisk definition af aktører og radikal tekonologisk forandring.

Udover anvendelse af specialets teorier omfatter specialets primære metode brugen af værktøjet EnergyPLAN, som muliggør en simulering af et energisystem. Gennem brugen af dette værktøj udarbejdes to scenarier der påviser den nuværende udvikling mod 2030, samt den nødvendige udvikling for at imødekomme målet i 2030. Til udarbejdelse af specialets analyser er der anvendt litteratur fra diverse kilder, samt interviews udført gennem specialet med en række aktører, som anses for relevant i omstilling frem mod 2030.

Specialets resultater påviser på baggrund af specialets analyser derfor hvordan 2030 målsætningen teknisk kan imødekommes, samt hvilke barrierer der forhindrer en implementering af de nødvendige teknologier. Hertil påviser specialets analyse ligeledes hvilke muligheder for handling, der kan bidrage til at nedbryde de forskellige barrierer.

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Introduction 1

This thesis takes departure in the ongoing transition of the Danish energy system. The problem analysis will describe the goals that Denmark have to oblige to. In order to achieve the goals, Denmark has utilised strategical energy planning through the planning hierarchy.

Through the decades the approach has changed as it can be argued that in early stages of energy planning, it was not deemed as important as it is now. Due to this, the goals are continually changing based on the increased awareness of environmental impact of current energy usage. This reflects on the requirements from the international community, but also the nation itself. In Denmark, it is voluntary to compile a strategical energy strategy by municipalities, however it is recommend by the Danish Energy Agency, since it can contribute to investigate how to promote renewable energy and contribute to make the energy system more flexible. Furthermore, the strategical energy strategy is focusing on cooperation between authorities and stakeholder, which is a necessary prerequisite.

This thesis will further investigate how Denmark can oblige to reducing the CO_2 emissions by 70% in 2030 compared to 1990. In order to investigate this, it is necessary to conduct an energy system analysis of the Danish energy system as well as an institutional analysis in order to understand the institutional context that Denmark is embedded in, to give a holistic overview of how the transition towards 2030 can happen. The energy system analysis of Denmark will be based on available data and projections of the Danish energy system, while the framework of the institutional analysis is based upon views presented by various stakeholders in the Danish energy system.

Problem Analysis 2

The purpose of the problem analysis is to investigate the ongoing transition occurring in the Danish energy system, and what kind of visions and ambitions that are currently affecting the Danish energy system. Additionally, the problem analysis will investigate the hierarchy that the Danish energy planning is embedded in.

2.1 International Goals

In the last couple of decades, the international society has undergone changes and has become more aware of the climate changes, which is an occurring phenomenon. Since the beginning of the 1990's, several agreements have been passed to stabilise and reduce the CO_2 emissions in the atmosphere. An example of this is the Kyoto Protocol. The purpose of the protocol was to define six target gases and monitor their development in order to reduce the emissions level by 5.2% in the time period 2008-2012 compared to the emission levels from 1990. The Kyoto Protocol was a step in the right direction to reduce the greenhouse gas levels. However, the protocol only featured developed countries, while countries like India and China were not included at the time. Furthermore, the United States did not maintain their commitment to the Kyoto Protocol. These three countries are some of the biggest culprits when it comes to greenhouse emissions, which is supported by "Fossil CO_2 emissions of all world countries - 2018 Report" by the European Union(EU)(European Commission 2018)

The Kyoto Protocol can be defined as the first major agreement internationally. However, since many countries still had an ambition to reduce their CO_2 emissions, after the first commitment period was over, it was necessary to set new goals. This was attempted in 2013 with the Doha Amendment which would set new targets by 2020, although this was not implemented, due to the fact that not enough countries signed the agreement. (George 2008)

With the Paris Agreement in 2015, a new set of goals to reduce the CO_2 emissions were established. The purpose of the Agreement was to reduce the emissions level to pre-industrial levels, which would eventually mean a hindrance of a temperature increase of 2°C and aiming for less than 1.5°C increase. Furthermore, the Agreement also took other aspects of the changes into consideration, and states that the cash flows and food production will not be threatened to reach the goals. This indicates that the international society as a whole can experience the impact of the increased CO_2 emissions, and regards the solution as a collective solution that can have an impact on the current way of life.(United Nations Framework Convention on Climate Change; COP 2015)

The Sustainable Development Goals created by the United Nations(UN) in 2015 raises awareness of the climate changes and a perception of how sustainability is needed in order to reduce the CO_2 emissions. There is a wish to increase the share of renewable energy production and improve education, so the children of tomorrow can be more aware of the environmental changes and how to cope with them. (United Nations, 2015, n.d.)

In order for these goals and agreements to be fulfilled, it is necessary for organisations such as the EU to align with the ambitions of the international community. So each member state is obligated on multiple levels to make an effort to reduce CO_2 emissions and strive for a more renewable energy system.

2.2 European Goals

There is a common goal in the EU to maintain an affordable and stable supply of energy. Furthermore, with this goal a strategic priority is made to contribute to prevent climate change. Therefore, the following milestones have been compiled in order to lower the CO_2 emission in the future energy sector: (European Union November 2014, European Comission 2018)

- Improving energy efficiency by 32.5%
- Securing the energy supply in the EU
- Ensuring competitive energy prices in the EU
- 32% of a countries energy system should consists of renewable energy.
- Reduce the CO_2 emissions by 40% compared to 1990 (European Union November 2014, European Comission 2018)

The purpose of these milestones is to function as the fundamental groundwork for the 2020, 2030, and 2050 energy strategies, which are compiled by the EU. The purpose of having different energy strategies are to secure that the short term goals compiled in the 2020 energy strategies, align with the 2050 energy strategies, since the short term strategies are functioning as stepping stones towards the transition and a guideline for the long term strategies. However, it is up to each member state to develop their own energy system. They just need to consider the objectives of the energy strategies. Therefore, each member state has their own plan on how to align with the goals since the energy system differs from country to country. (European Commission 2014)

On the 4th of March 2020, the European Commission presented a proposal to secure political commitment to be climate neutral by 2050. This was done with the European Climate Law. Through this law a direction of how to approach the 2050 goals is set. By 2023 and every fifth year forward, the European Commission will review the trajectory for each member state to see if they are acting accordingly in relation to the climate neutral objectives. If not, they have to justify their actions, however, there are not any concrete sanctions at the moment. (European Comission 2020)

This indicates that the European society as a whole strives to be more sustainable and environmentally friendly in order to cope with the CO_2 emissions. However, the European society is currently undergoing changes in order to achieve their ambition and therefore it is up to each country to fulfill their duties and obligations to the agreements that have passed in order to reduce the CO_2 emissions.

2.3 Danish Goals

Similar to the International and European scale, Denmark has also set a number of goals for the future energy system. The long-term goal of Denmark is to become a carbon neutral country by 2050 and by extension becoming independent from fossil fuels by 2050. (Danish Ministry of Climate, Energy and Utilities n.d*a*) This means that Denmark by 2050 must produce sufficient amounts of renewable energy to supply the entire energy demand of the country. Due to this, the Danish energy system is going through a transition from an energy system utilising fossil fuels to an energy system based on renewable energy sources. (Danish Ministry of Climate, Energy and Utilities n.d*a*)

In addition to the goal of 2050, Denmark has made a few sub-goals for the period between now, 2020, and 2050. Some of the sub-goals have shown to be more ambitious compared to the corresponding European goals. In 2014, the EU adopted a climate and energy policy with a number of different binding goals. As a part of this policy, a goal was set which entails that 32% of each member states energy consumption must come from renewable energy sources in 2030. (European Comission 2018) Denmark has taken this goal a step further with the Energy Agreement of 2018, with an ambition set for 2030 with a renewable energy share of 55% (Danish Ministry of Climate, Energy and Utilities n.d*b*). Included in the Energy Agreement was funding for a number of initiatives, which will contribute to meeting the goals. These initiatives include phasing out coal from the electricity production by 2030, 90% of district heating(DH) being supplied by other means than coal, oil and gas, reduction of certain taxes, energy savings, contribute to create a flexible energy system and convert the transport sector to a more renewable one. (Danish Ministry of Climate, Energy and Utilities 2018)

2.3.1 Scenarios for the Energy System

Other than the goals set through energy planning, scenarios for the future energy system have also been developed by certain actors such as the Danish Transmission System Operator, Energinet and the Danish Society of Engineers.

In 2016, Energinet made an analysis consisting of four scenarios towards 2030. The primary varying factors of the scenarios are the level of European collaboration as well as the political support for the transition of the energy system. The analysis shows that the variance within these two factors can result in different energy systems with different environmental impacts. (Energinet 2016) The tendency of these scenarios is that generally, the higher the European collaboration and the political focus is, the lower the environmental impact is.

In addition to the scenarios made by Energinet, the Danish Society of Engineers has also made an energy scenario for 2030 in collaboration with Aalborg University in 2006.

Through this scenario, it is shown that it is both technically and economically feasible to transition the Danish energy system, where CO_2 emissions are reduced by 60% compared to 1990. This scenario happens through energy savings, improvement of energy efficiency, partial transition of the transport sector and replacement of fossil fuels with renewable energy sources. Along with the scenario is a list of 11 recommendations that are relevant in order to implement the energy system shown in the scenario. These recommendations include areas such as extension of energy agreements, funding for certain sectors and revision of certain taxes and market prices. (The Danish Society of Engineers 2006)

This scenario was later expanded upon in 2015 with a scenario which shows a economically and technically feasible energy system towards 2050 with a CO_2 reduction of 90%. As the CO_2 reduction is a gradual process, the reduction towards 2030 is used as a stepping stone towards reaching the 90% reduction by 2050 in this scenario. The CO_2 reduction by 2030 is similar to the scenario made in 2006 with a reduction of 60%. (Aalborg University 2015)

While these scenarios show a certain possibility for the future energy system, these are not sufficient with the new 2030 goal of Denmark.

2.4 The New 2030 Goal

In 2019, the newly formed Danish government along with the Social Democrats, the Danish Social Liberal Party, the Socialist People's Party and the Red-Green Alliance presented a new goal for 2030 which is a reduction of CO_2 emissions by 70% compared to 1990. (Energistyrelsen 2019) Denmark has already made some reductions regarding CO_2 emissions with the implementation of renewable energies such as biomass, wind and solar energy for production of primarily electricity and heat. (The Ministry of Climate, Energy and Utilities n.d) The development of emissions in Denmark is shown in Figure 2.1.

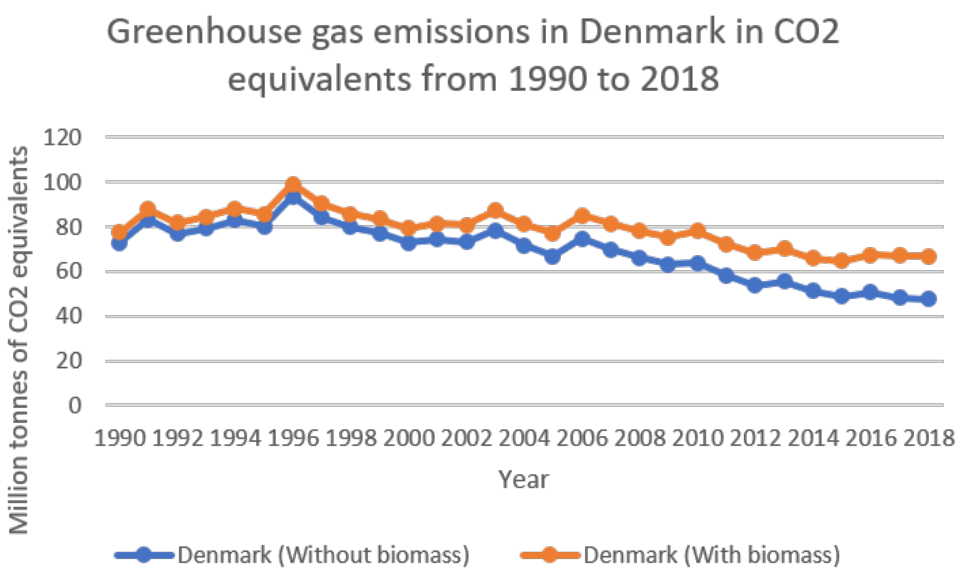

*Figure 2.1: Annual CO_2 equivalents emitted from Denmark from 1990 to 2018. Emissions from international transportation are not included. Graph based on data from (Statistics Denmark 2020*b*)

As seen in Figure 2.1, considerable efforts have been made towards reducing the emissions. However, it can also be seen that an increasing part of the reduction is due to the use of biomass, which is often regarded as a CO_2 neutral energy source. Despite these efforts towards reducing the emissions, there is still a gap between the current level and the one required with the new 2030 goal. The required reduction can be seen in Figure 2.2.

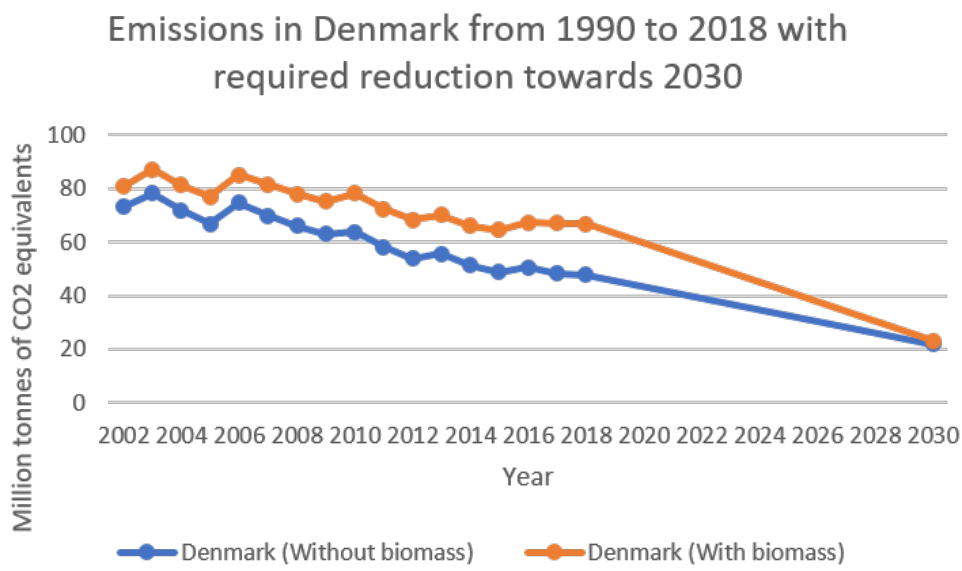

*Figure 2.2: Annual CO_2 equivalents emitted from Denmark from 1990 to 2018 along with the required reduction towards 2030. Emissions from international transportation are not included. Graph based on data from (Statistics Denmark 2020*b*)*

It can be argued, that based on Figure 2.2 and the past and required development shown in the figure, the goal of a 70% reduction in CO_2 emissions will not be met.

Depending on how biomass is considered when meeting the goal, the reduction required may change significantly. If the emission from biomass is included, the reduction has to be more drastic than if biomass is not included when considering emissions as shown in Figure 2.2. Regardless of whether biomass is considered CO_2 neutral or not, it is clear that efforts have to be made in order to meet the ambitious 2030 goal. Based upon the tendencies illustrated in Figure 2.1 and Figure 2.2, it indicates that with the current development, it is not possible to achieve the 2030 goal.

Another issue that arises when changing the goal within such a short time frame of 10 years is the lack of planning related to meeting the goal. With the change of the goal, previous planning related to the former goal may be rendered obsolete. An example of this is apparent through the various scenarios made for 2030. As mentioned with the scenario made by the Danish Society of Engineers, the scenario shows a reduction of emissions of 60%. (The Danish Society of Engineers 2006) With the addition of the new 2030 goal, this scenario can be considered obsolete as this no longer meets the goal set by the Danish government. Therefore, it can be argued that in order to achieve the 2030 goal, it is necessary to take immediate action.

A tool the municipalities of Denmark can use is strategic energy planning which focuses on long term planning of the energy system in a specific area which is often in a given municipality. Strategic energy planning also covers all energy use and production in all sectors including heat, electricity, industry and transport. (Danish Energy Agency 2013) Seeing as this is a tool that municipalities voluntarily can choose to utilise, it is not guaranteed that all municipalities utilises the tool. (Danish Energy Agency 2013) This may result in some municipalities making use of strategic energy planning while others do not, which can affect the possibility of reaching the long term goals of Denmark. As the municipalities are not obligated to conduct strategic energy planning, there is an uncertainty as to how the goal specifically will be met. In addition to this, there is no obligation to coordinate between municipalities which can cause inefficient use of resources, which can result in overuse of resources such as biomass. (PlanEnergi 2013)

2.5 Summary

Overall it can be argued that every level of planning is undergoing changes with the implementation of specific goals in the energy sector. The hierarchy of the different planning levels are shown in Figure 2.3.

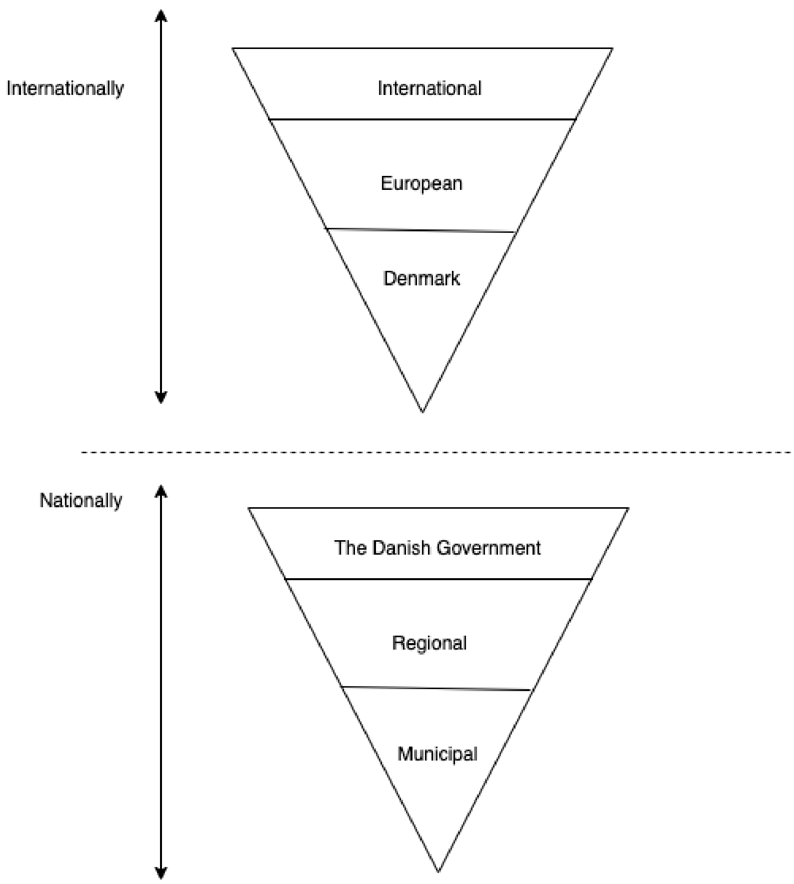

Figure 2.3: The different levels of international and national planning

Figure 2.3 illustrates the different planning levels. Currently, it can be argued that the visions and goals do not transcend through the different levels, which can hinder the development. To sum up, there are a variety of issues related to meeting the goals of both national and international levels. These issues are related to changing goals, rendering already made scenarios insufficient and a lack of coordination and obligation to conduct strategic energy planning, resulting in uncertainty regarding how the goals will be met. The consequences of these issues may result in overuse of resources or failure to meet the goals. Additionally, it is important to note that there are different levels of planning both nationally and internationally. While the levels are geographically different, they may be related in the sense that one can affect the other. The responsibility in order to reach the goals and visions can be placed on each level of the planning hierarchy. This can lead to bureaucracy, instead of taking care of the problem. Since the guidelines for the strategical energy strategies in Denmark are broad, it depends on the individual municipalities' commitment level to secure an adequate energy strategy. Therefore, it can be argued that the current tool used in Denmark is flawed due to the lack of responsibility on each authority figure through the planning hierarchy.

In order to fully understand the magnitude of the problem, it is necessary to examine the current system, and evaluate the current goals and barriers to give a recommendation to how to break down the barriers and evolve the system as a whole.

Problem Formulation 3

Based on the problem analysis, this project will further investigate how Denmark should achieve the new 2030-goals and how this will impact the current Danish institutional context. This have resulted in the following research question:

"How can the Danish 2030 goal be met through a technically feasible scenario and how can the institutional barriers of implementing be overcome?"

In order to answer the research question, four sub-questions have been compiled.

1. What is the current Danish energy system composed of?
2. What is the current institutional context of the Danish energy system?
3. What could the Danish energy system look like when meeting the 2030 goals?
4. What are the institutional barriers associated with meeting the 2030 goals?
5. How can the identified barriers be addressed?

Based on the research question and the sub-questions, the project includes a technical analysis which is based on an energy system analysis consisting of technical scenarios that intend to meet the 2030 target. Based upon the problem analysis, it illustrates with the current development, it is not possible to achieve the 2030 goal. However in order to evaluate how much needs to be changed, it is necessary to examine how far the current development will reduce the CO_2 emissions and how much needs to be reduced additionally.

Furthermore, this thesis contains an analysis of the institutional context surrounding possibly achieving the 2030 goal. It intends to elucidate the current actions of stakeholders within the Danish energy system and highlight various challenges they may encounter in relation to the changes that the Danish energy system is facing. In order to understand the connection between the two analyses and which influence it has on the Danish energy system in general, a theoretical framework has been constructed, which intends to act as an analytic tool to answer the research question (See Chapter 4).

3.1 Delimitation

As this thesis has a large scope that covers the entirety of the Danish energy system, a large variety of areas and subjects may be relevant to include. However, due to the limitations of the thesis, it is not possible to include every relevant subject. This section aims so address some of the subjects that may be relevant to include throughout the thesis but have been chosen not to.

The technical analyses conducted in this thesis will be evaluated based on a defined set of parameters described in Chapter 5.4. The reasoning for selecting these parameters will also be described in the chapter. The institutional analysis is compiled with the help of stakeholders from different levels of the planning hierarchy and across the different sectors. Therefore, this thesis will not consider aspects that are not pointed out by the interviewed stakeholder, given that an institutional analysis of all sectors and levels of plan hierarchy is complex and contains many aspects. Therefore, this thesis focuses on the interviewed stakeholders in order to create a holistic overview, which will describe the complexity of the Danish energy system based upon the answers of the stakeholders.

3.1.1 Institutional delimitation

The interviewees helped set the framework for how the institutional analysis is compiled. The approach used to conduct the interviews leads to interpretation of the different stakeholders' challenges in relation to meeting the 2030 goal. How the interviews were conducted can be seen in Chapter 5.

3.1.2 Technological delimitation

Seeing as the time frame of the thesis is relatively short with 10 years towards 2030, the number of potential solutions is limited. Based on this, technologies that can not be implemented within the time frame will not be considered when creating a scenario to reach the goal. Additionally, the project will primarily focus on well developed and documented technologies as there are some uncertainties related to newer and less used technologies.

Through the technological analysis, external factors may influence the energy system in Denmark as the Danish energy system is connected with neighboring countries. Despite this influence, the technological analysis will be conducted without considering the development of the neighboring countries energy systems as this would require an additional analysis of each energy system. In addition to the external factors outside of Denmark, there may be energy consuming sectors that will not be included in the energy system analysis such as the agricultural sector or international transportation. Additionally, while an analysis of the role of biomass in the transition may be relevant, biomass will be considered as a CO_2 neutral renewable energy source going forward.

Theoretical Framework 4

The purpose of constructing a theoretical framework is to develop an analytic tool to help answer the research question in Chapter 3. The theoretical framework can be utilised to analyse and describe the analysis of the Danish energy system and further investigate the institutional context of the Danish energy system, and assess potential barriers. The theoretical framework consists of: Macro and Micro Structures by Frede Hvelplund with the addition of the concept of technology by Henrik Lund and the Three Pillars of Institutions by William Robert Scott.

4.1 Macro and Micro Structures

To understand the concept of the macro and micro structure embedded in the Danish energy system, it is necessary to understand the concept of macro and micro structure.

When looking to make changes to certain aspects of society, it is relevant to be aware of the characteristics related to this part of society. This can widen the possibilities of influence as this gives an overview of the part of society one wishes to change as well as the influencing factors related to this. One approach to such an analysis is through an analysis of the macro and micro structure of a specific area as presented in *"Electricity Reforms, Democracy and Technological Change"* by Frede Hvelplund. The analytical approach is presented through the example of a bicycle trip with various elements. The specific macro and micro structures depend on the case at hand and will differ from this example in other cases. (Hvelplund 2001)

4.1.1 First and Second Order Macro Structure

With the example of the bicycle trip, the case consists of the following elements: A person (a) wants to travel to destination 2, both in time and in good health (b) from destination 1 (c) using a bicycle (d) on a road (e) among other road users (f) and without being disrupted by weather (g). (Hvelplund 2001)

When looking at the macro structure of a given case, there is a distinction between the first and the second order macro structure. The first order macro structure is made up of the underlying policies and the institutional structure of the society. While these may influence the bicycle trip, they can not be changed through decisions made throughout the bicycle trip and can instead be affected through political processes and basic societal conditions over longer term. The second order macro structure is the result of the first order macro structure and the affecting factors related to the bicycle trip. In this example the second order macro structure consists of the following:

a) A person
b) A set of goals made by the person
c) A starting point
d) A medium of transport
e) A road
f) Other users of the road
g) Weather conditions

In order for the bicycle trip to be a successful trip and reaching the goals set by the person, the person must, to some extent, be aware of the surrounding macro structure which in this case is point a-g. In this context, it is relevant to be aware of each point of the macro-structure as this can have an impact on whether or not the bicycle trip is a success. Ít is also important to note that the points presented in this example are not the only potential components of the macro structure. Other elements depending on the context may also be added to the macro structure. (Hvelplund 2001) An illustration of the first and second order macro structure can be seen in Figure 4.1, where the first macro structure in the shape of policies affect the decisions in the second order macro structure. Additionally it is also apparent that each element of the second order macro structure may affect each other. Lastly the dotted lines surrounding both the first and second order macro structure indicate that there may be other structures that could be described for the specific case.

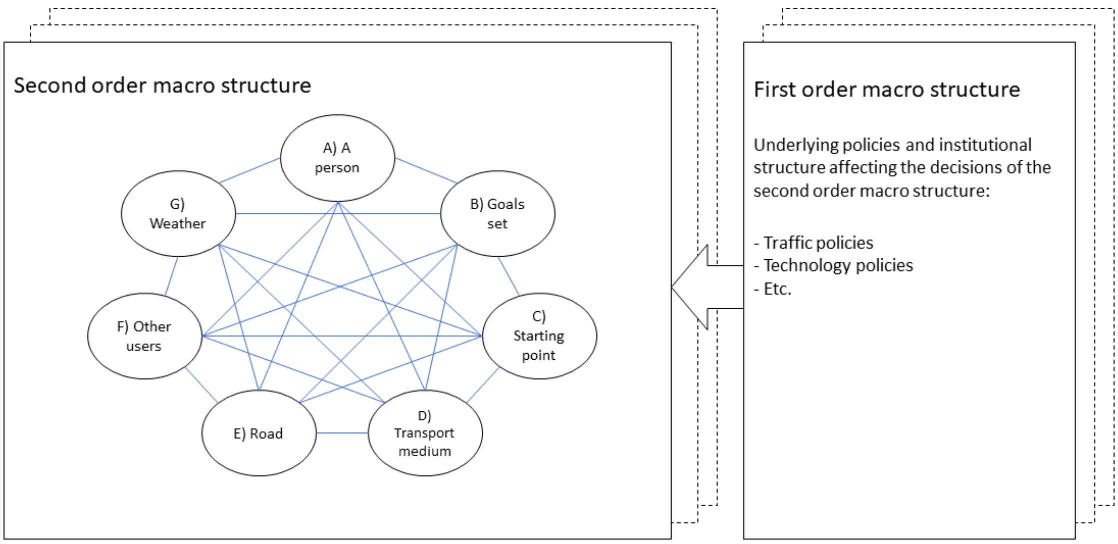

Figure 4.1: Relation between the first and second order macro structure of the bicycle trip. Inspired by (Hvelplund 2001)

4.1.2 Micro Structures

In addition to being aware of each element of the macro structure, knowledge regarding the micro structure of each component is also relevant to consider during the bicycle trip.

There is, however, a difference between relevant and irrelevant micro structures when considering the bicycle trip. Some micro structures such as how the weather may affect the road conditions are extremely relevant when looking to make a successful trip. On the other hand knowing why the weather changes or how a road is made may not be relevant when considering the success of the bicycle trip. (Hvelplund 2001)

An illustration of different micro structures within the macro structure is shown in Figure 4.2. In Figure 4.2 the same relation between the first and second order macro structure can be seen along with an illustration of different micro structures. Some of the illustrated micro structures may be relevant throughout the bicycle trip, which are indicated by the blue color, while others may not be important to take into consideration throughout the bicycle trip. These are indicated by the gray color.

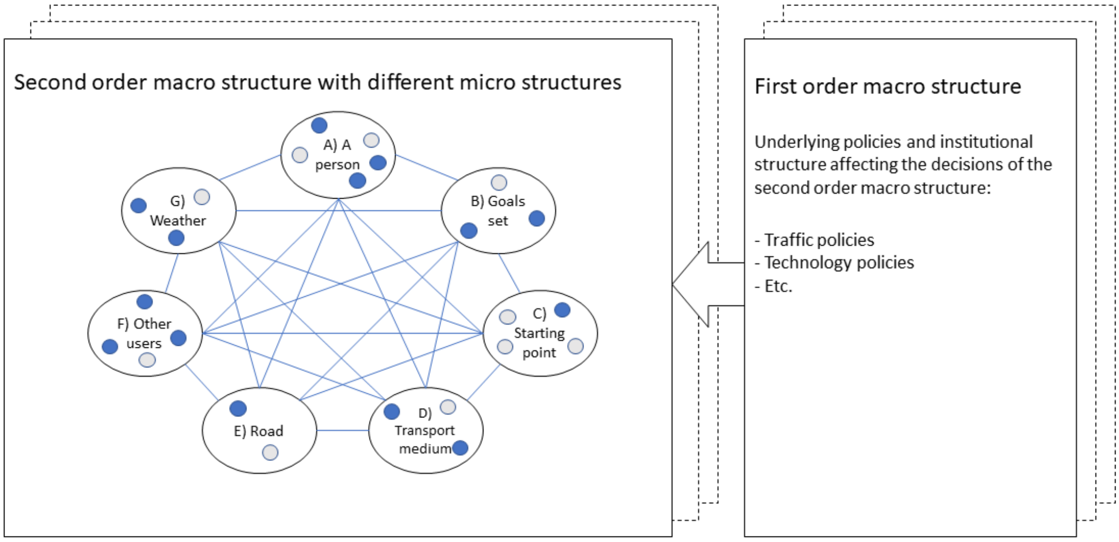

Figure 4.2: Relation between second and first order macro structure with both relevant and irrelevant micro structures. Inspired by (Hvelplund 2001)

When elaborating on the micro structures of the given macro structure, there will be an appropriate number of micro structures depending on the goals set in the macro structure. These are highly dependent on the case at hand and the given macro structure.

4.1.3 Stakeholders

It can be argued that the stakeholders who defines the macro and micro structures are also influenced by them. Regarding the Danish energy system, it can be argued that the authoritative bodies and lobbyists are affecting the macro and micro structure for the Danish energy system. This is illustrated in Figure 4.3, where the various stakeholders are represented in relation to possible changes in the structures.

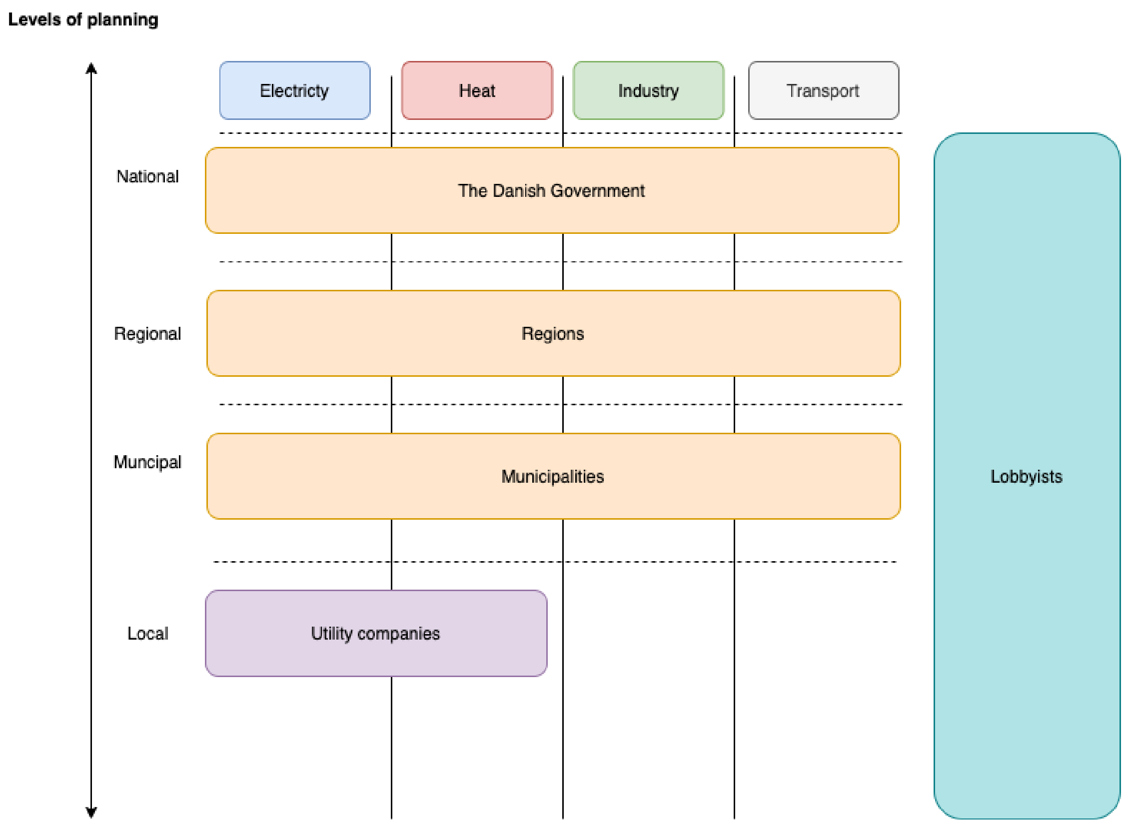

Figure 4.3: Overview of the different stakeholders who may influence the Danish energy system

The structure defined in Figure 4.3 can be defined as the organisational structure of the Danish energy system and consists of different types of stakeholders. The authorities have the opportunity to influence the outcome of the Danish energy system both in the form of direct and indirect influence. This can be in the form of a top-down oriented approach or a bottom-up oriented approach. This should be understood as the Danish government having the opportunity to implement a concrete agenda that must be followed by the regions and municipalities. The regions have the opportunity to influence how the strategic energy planning is carried out at the municipal level. Furthermore, they can contribute to increased cooperation between the municipalities among others. The municipalities with the utility companies are responsible for the specific land use for the various technologies used in the Danish energy system. (A.2.2,A.2.3) This resembles the traditional top-down oriented approach, but the broad guidelines laid out by the Danish government mean that there is an opportunity for innovative solutions from the municipalities and their partners. Another aspect is that the government is influenced with issues in the municipalities. Many municipalities have encountered resistance in relation to the implementation of wind turbines in their municipalities(A.2.3), which has resulted in an increased number of offshore wind farms instead of pushing toward implementing more wind turbines on land.

The lobbyists cannot be defined as one particular stakeholder, but as several different stakeholders across the different levels of planning and the different sectors, where the influence and importance of these actors varies. This may be based on, among other things, the economic capacity they have and what influence they have on the Danish society in general. So the components that the Danish energy system consist of are not only the government agencies that have to be taken into account, as the energy system consists of lots of actors who have the opportunity to influence the Danish energy system. In this thesis, this will contribute to identifying the current institutional context of the Danish energy system.

4.1.4 Technology

In this thesis, the macro and micro structures of the current energy system in Denmark will be examined in order to reach an understanding of the institutional context that has played a role in the development of the current energy system. Additionally, this will contribute to an understanding of how the energy system can be transitioned towards a more renewable energy system in 2030. In order to fully understand the changes in the Danish energy system it is necessary to understand when these macro and micro structures change, and what impact these structures will have on the technologies chosen in the future Danish energy system. This can be described by the concept of *radical technological change*, when a change in the macro or micro structure occur it will have an impact on the energy system and what type of technologies that are utilised in the system. In the book *Renewable Energy Systems - A Smart Energy Systems Approach to the Choice and Modelling of 100% Renewable Solutions* by Henrik Lund (Lund 2014), it is described that the concept of technology consists of five components, which is illustrated in Figure 4.4

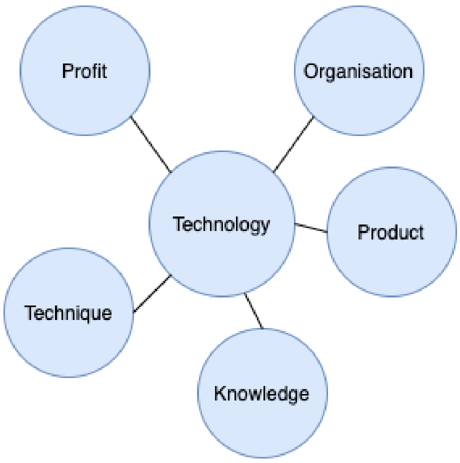

Figure 4.4: Definition of technology

The five components: Profit, Product, Knowledge, Technique, and Organisation represent different aspect of technology and is contributing to give a holistic view over the concept(Jens Müller 1984).

- *Profit* - If the given technology is profitable compared to the existing.
- *Product* - is the culmination of the approach(knowledge), the technique and the organisational structure
- *Knowledge* - of how to operate and use techniques in technology
- *Technique* - includes the physical tools of the technology, e.g machines of all kinds.
- Organisation- is defined as management and coordination in the work process.(Jens Müller 1984)

In order for a *radical technological change* to occur it is necessary for more than one of the elements to change. The concept of radical technological change can be described by using the two theories: Macro and micro structures and Three Pillars of Institutions.

In order to determine if a radical technological change must occur, it is necessary to examine the context of the Danish energy system in order to fully grasp, why it is necessary to alter the current path. This is done through defining the macro and micro structure for the Danish energy system, where the future will bring inevitable changes in the system and therefore new technologies will eventually alter the current use of technologies in the Danish energy system.

The organisational part of the technology can be defined as the part, which influences the macro and micro structure. It contains the stakeholders described in Figure 4.3, this will for future references be referred to as the organisational structure. It is illustrated with Figure 4.5.

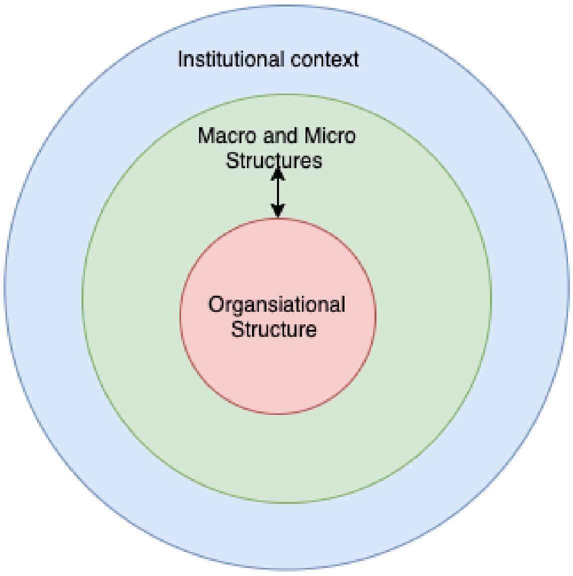

Figure 4.5: Definition of the institutional context of the Danish energy system

The organisational structure and the macro and micro structure are influenced by one and another, since the organisational structure is defining the macro and micro structures and parts of the organisational structure are subject to the defined macro and micro structure. This is illustrated with the arrows in Figure 4.5 and can be defined as the institutional context.

The Three Pillars of Institutions will be used to examine the organisation aspect of technology in order to understand, how the institution, Denmark, is affecting the technology used in the Danish energy system.

4.2 Three Pillars of Institutions

The Three Pillars of Institutions theory is applied since it can be used to describe different aspects of the current institutional context that Denmark is embedded in. Furthermore, it can be used to identify possible legislative and cultural barriers in the current Danish energy system and how it will affect the transition to a more renewable energy system.

Institutions can be defined into three categories: rules, routines, and norms. In the theory, Three Pillars of Institutions, they are defined as the regulative pillar, which describes the rules and laws, which states *how we must behave*. The routines are defined as the cultural-cognitive and state *how we usually behave* and the final pillar, the normative pillar, consists of the norms and dictates *how we should behave*. The three pillars should not be viewed as three separate pillars, which can be observed in Figure 4.6. (Scott 2001)

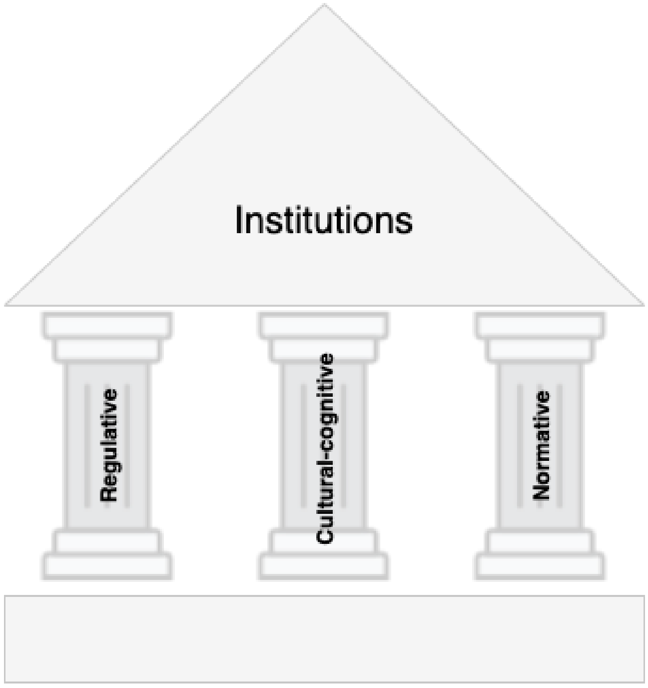

Figure 4.6: Illustration of The Three Pillars of Institutions

The three pillars work coherently with each other. This means that when a change happens in a certain pillar, it affects the other two as well. This affects the institutions, since it is required by the actors to change their behavior, which will ultimately alter the current institution into a new direction and thereby change the institution. However to alter the institution the current path must change. This phenomenon is called path dependency. This phenomenon should be understood as when a given path taken, it is more likely that more steps will be taken in that direction. This can potentially hinder other paths to be taken since the taken path is affected by positive feedback mechanisms which is when a path has given positive feedback in the past, it is more likely that path will be followed in the future as well.(Scott 2001) Therefore it can be hard for new technologies to be part of the energy system since it is compared to already proven and established technologies in the Danish energy system.

There are other aspects which also can function as a hindrance for implementation of new technologies to the Danish energy system such as reluctance to change, costs, and peer pressure. The reluctance to change from the current path is affected by the aforementioned positive feedback mechanisms, and will function as a barrier for up-and-coming technologies, which are not proven in a Danish context. The cost of the technology can also hinder the implementation of the given technology since there is willingness to implement the cheapest solution. Peer pressure is both an internal and external factor in the institution, that can affect the decision-making process and thereby affect which approach and which technologies that will be utilised in the Danish energy system.(Scott 2001)

With the ongoing transition from a fossil-fuel based energy system to a more renewable energy system, the different pillars will certainly be affected. However, it is up to the different stakeholders to actually shape the energy system of tomorrow, which will be further investigated in Chapter 8. The changes that occur through the regulative pillar will define the cultural-cognitive pillar and normative pillar, however it may also be the other way around. (Scott 2001)

The theory by Frede Hvelplund on Macro and Mictro Structures identifies the current institutional context which Denmark is embedded in, and gives an overview of the interplay between current policies and legislation and how it shapes the current energy system in Denmark. The Three Pillars of Institutions identifies the specific legalisation and policies in every sector, through the regulative pillar as it describes *how we must behave.* Furthermore, it investigates how each sector function based on the cultural-cognitive pillar, which can be described as *how we usually behave.* The normative pillar describes *how we should behave* and will function as a recommendation on how to change the Danish energy system in order to fulfill the 2030 goals.

Methodology 5

The purpose of this chapter is to give an overview of the different methods used throughout this thesis, both in terms of theoretical knowledge and how they are applied in this thesis. The methods used in this thesis are data collection, in form of interviews and literature study which are conducted to support the institutional analysis, and the energy system analysis, which is conducted to simulate the Danish energy system in order to reach the 2030 goal, where the specific numbers used to simulate the energy system are obtained through a literature study.

To summarise how the different methods have been used in order to answer the research question, a research design is compiled in order to visualise the interplay between the different components in this thesis, which is further described in Section 5.5.

5.1 Data Collection

The purpose of this section is to describe the two methods used to collect data. To gain a greater knowledge of the subject, empirical data were collected through literature study, which is described in Section 5.1.1 . The purpose of conducting interviews is to elucidate the current institutional context of the Danish energy system and what barriers exist within the Danish energy system. In addition, the literature study was used to build the scenarios in EnergyPLAN, all of this will be further described in the following sections.

5.1.1 Literature Study

The literature study has been used differently throughout this project. In the initial part, it was used to gather information about the different policies and other relevant subjects. Afterwards it was used to find information about certain technologies, and to gather some technological data and knowledge about the different technologies.

The literature study has been used to collect empirical data and knowledge on a given subject, that needed to be investigated. The literature used is mainly found through a structural search through Aalborg University library portal, but in some cases other academic sites and websites were used to get specific data either on technologies or numbers needed for the simulation e.g. certain number were only available on DEA's webpage. Therefore the numbers used are based on information from their energy statistic. If the credibility of the used source has been doubted a second source has been used to validate the given information. (Royal Litrary Fund 2017)

5.1.2 Interviews

This section will describe the approach used to conduct the interviews based upon the book *"Interview"* by Steinar Kvale and Svend Brinkmann (Kvale & Brinkmann 2010). It will further describe who has been interviewed and the purpose of interviewing these particular stakeholders. The interview guides for the interviews can be found in Appendix A.1. The interviews conducted in this thesis are conducted to give a holistic overview of the Danish energy sector and the interaction that takes place across the different levels of the plan hierarchy and the different sectors.

The approach used to conduct these interviews is the phenomenological approach, which is based upon the perception of the institutional context of the interviewees, where the organisation culture of the organisation they reside in are affecting their perception of the topic. However their educational background also affect how they perceive the current institutional context of the Danish energy system.

Phenomenology is a philosophical direction founded by Edmund Husserl, who would break with his own contemporary view of science heavily influenced by positivism. That is, the idea that there is only one objective experience-based reality. Husserl, on the other hand, argued with the phenomenology that the realities we experience do not exist independently of each other, but only occur in what he described as an inter subjective realization, that is, interpersonal experiences.(Juul 2012) Therefore, it is relevant to investigate the different levels of the planning hierarchy in order to deem if the current institutional context reflects the goals and visions implemented by the Danish government, and how it is perceived through the planning hierarchy. It can be argued that, it would be difficult to evaluate the current institutional context through interviews with only one level of the planning hierarchy represented. To give a holistic overview of the Danish energy system, it is relevant to interview stakeholders who can be ranked through the different levels of planning and across the different energy sectors.

The starting point of the interviews was going through the interview guide chronologically. This served as guideline and shaped the basis of the conversation. Therefore it can be stated that this interview form is of a semi-structured character. The questions can be divided into the following subcategories: Current institutional context based on the organisation, reduction of CO_2 emissions, and the Danish energy system.

The interviewees were not interrupted in the course of answering a question and if the interviewees were answering one of the other questions related to the topic that particular question would be disregarded. Therefore it was not always necessary to revise all of the questions, since the interviewees managed to answer the first asked question on a satisfactory level.

The following people were interviewed:

Table 5.1: Overview of the interviewees

Interviewee	Organisation	Function	Interview form
Louise Carøe Foldberg	Vestforsyning	Utility company in Holstebro Municipality	Telephone interview
Lene Kirk Dalum	Holstebro Municipality	Municipality in Central Denmark Region	Telephone interview
Thomas Jensen	Hjørring Municipality	Municipality in North Denmark Region	Skype Business interview
Lars Hedegaard	North Denmark Region	Region in Denmark	Skype Business interview
Per Skrumsager Hansen	Ministry of Transport	Ministry in the Danish government	Telephone interview
Asger Øland	The Danish Energy Agency	Part of the Ministry of Energy, Utilities and Climate	Skype Business interview
Ulrich Bang	The Danish Chamber of Commerce	Lobbyist	Telephone interview
Søren Djørup	Aalborg University	Lobbyist	Skype Business interview

The rationale behind interviewing these individuals is that these individuals have knowledge of each sector or a specific sector and represent a stakeholder at each level of planning. This is illustrated through Figure 5.1

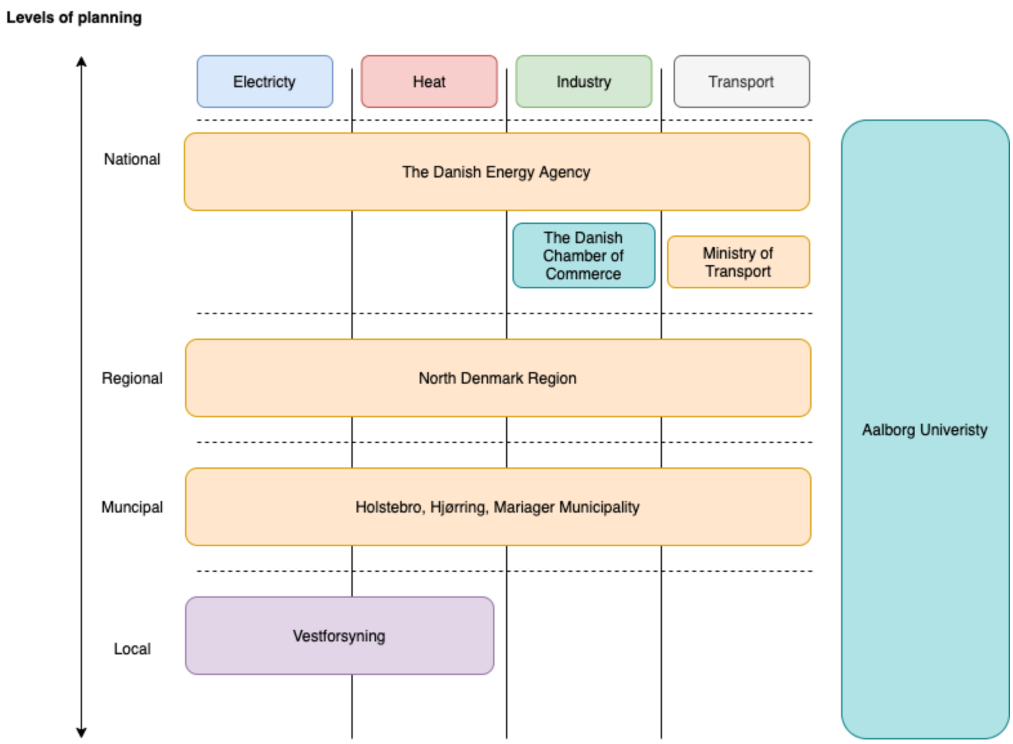

Figure 5.1: An overview of the different stakeholders interviewed based upon their influence in accordance with the level of planning

Figure 5.1 illustrates the specific sector in which the stakeholders are regarded as a valuable stakeholder. It can be argued, that it is difficult to distinguish between the municipal level and the local level since the interplay between the municipality and the utility company is highly regarded. However, since the municipality's role can be perceived as two-fold since they function as the authority, but also as a sparring partner for the utility companies, it is necessary to distinguish between the two. The purpose of interviewing the utility company, Vestforsyning, is to illustrate the tasks of a local utility company, and how the heat and electricity sector needs to be transformed in order to achieve the 2030 goal on a local level, and how the goals set by the Danish government, region and municipalities transcends through the system, and how it is perceived by a utility company. The reasoning behind interviewing Holstebro Municipality and Hjørring Municipality is to illustrate how a municipality is planning towards achieving the 2030 goal and if there are any hindrances.

Furthermore, it is also to give an overview of the interplay between the different level of planning, the purpose of interviewing two different municipalities from two different regions is to investigate, if the interplay between the level of planning differs and if it is perceived differently. The interview with North Denmark Region and Hjørring Municipality were conducted as a focus group interview. This allowed for an investigation of the interplay between the different levels and how it was perceived by each stakeholder and confront any possible barriers or hindrances during the interview.

It was also deemed a necessity to investigate the role of the regions since they are producing a strategic energy strategy for their specific region and highlights what the specific municipality can do in order to reduce CO_2 emissions. The transport sector and industry sector can be hard to represent due to the large quantity of interests and therefore, the most suitable stakeholders to interview in this thesis were The Danish Chamber of Commerce and the Ministry of Transport because of their holistic interests.

Furthermore the Danish Energy Agency and Aalborg University can be perceived as stakeholders who influence the energy system as a whole, but they have different roles, the Danish Energy Agency is a authority figure that the regions and municipalities should oblige to through their guidelines. However, their role can also be perceived as two-fold since they are creating the overall framework for energy planning in Denmark. It is up to the specific region and municipality to follow the framework, but they also function as sparring partner for other stakeholders in the energy system.

Aalborg University is investigating different aspects through the levels of planning and investigating various solutions across the different sectors, and does not have any power in trying to enforce their suggestions. The purpose of interviewing Aalborg University is to evaluate and reflect upon the aforementioned interviews. The interview was also conducted to fully understand the role of an academic institution, and the interplay between the university and the different levels of planning, how they are affecting the strategical energy planning in Denmark.

5.2 Energy Assessment Tool

Through this project, an analysis of the Danish energy system is conducted in order to investigate how the Danish energy system can be transitioned towards a 70% CO_2 reduction by 2030. When conducting an energy system analysis, there are a variety of ways of doing so. One way of conducting an energy system analysis is through the use of an energy assessment tool. There are various energy assessment tools available with different functions (Connolly et al. 2009). Consequently, it is important to note what the purpose of the energy system analysis is in order to choose a fitting energy assessment tool. As this project focuses on the transition of the Danish energy system, it is a requirement of the energy assessment tool that it can model and simulate an energy system on a national scale. Additionally, due to the scope of the project, the energy assessment tool must be able to model and simulate every sector of the energy system in order to investigate the possibilities of transitioning within the different sectors while also giving an overview of the energy system in its entirety. As the goal of Denmark revolves around annual CO_2

emissions, the energy assessment tool must be able to simulate a one-year period as well as the environmental impact of the energy system. Other factors such as investments and operational costs, time for implementation and lifespan of technologies may be relevant when considering how the Danish 2030 goal can be met, but these are not considered necessities when making the scenario for 2030.

In the paper *"A review of computer tools for analysing the integration of renewable energy into various energy systems"* (Connolly et al. 2009) a number of energy assessment tools are presented along with their characteristics including number of users, geographical scale of the analysis, scenario timeframe, operation and investment optimisation and more. While many of the energy assessment tools described in the paper may have some or all of the required characteristics described previously, EnergyPLAN has been chosen as the energy assessment tool that will be used to conduct an energy system analysis of Denmark throughout this thesis. EnergyPLAN's application is described as a user-friendly analysis of national energy systems with the possibility of simulating a scenario with both the electric, heat, industry, and transport sector over a one-year period. Additionally, the simulation includes both environmental impact in the shape of CO_2 emissions as well as economic parameters such as annual investment and operational costs. (Connolly et al. 2009) Due to this, EnergyPLAN is able to simulate the energy system of Denmark and optimise the use of the chosen technologies in the system. EnergyPLAN is also developed as well as extensively used at Aalborg University which can contribute to the acquisition of data and knowledge regarding EnergyPLAN. This results in EnergyPLAN being a suitable energy assessment tool for establishing a scenario for the Danish energy system by 2030 with a specific emission goal as well as showing the costs of such a system.

5.3 Methodology of the Energy System Analysis

The primary goal of conducting an energy system analysis through the use of EnergyPLAN is to illustrate the necessity of additional action in the energy sector in order to meet the goal of 2030 as well as showing which additional actions that can appear. However, the use of the tool itself may also affect the outcomes of the scenario.

5.3.1 Simulation Strategy for Scenarios in EnergyPLAN

The tool used through this thesis is entirely deterministic, meaning that the same input into the model will always yield the same result when simulating the energy system. This is due to the simulation being decided by predetermined distributions over an entire year. This also results in EnergyPLAN not taking changing factors from year to year into account. The tool does, however, have different options of simulating the energy system. The tool has two different simulation strategies which are a Technical Simulation and a Market Economic Simulation (Connolly 2015). The Technical Simulation revolves around simulating and minimizing the consumption of fossil fuels and functions without economic parameters. Additionally, the Technical Simulation prioritises meeting the demand through internal production in the energy system and will only import energy if the demand exceeds the production capacity. Similarly, energy will only be exported if energy production exceeds the consumption. (Connolly 2015)

On the other hand, the Market Economic Simulation seeks to match the supply and demand of the energy system while maintaining the lowest cost rather than lowest fuel consumption. This also results in the external electricity market playing a larger role when meeting the demand of the energy system, as the prices of producing energy as well as the price of energy varies. This results in energy being purchased rather than produced, when the price is favorable. As with other parameters used in the tool, the market conditions and prices must be manually put into the tool. (Connolly 2015) These conditions may change in the future with the implementation of more renewable energy, which can affect the prices of energy.

Throughout the energy system analysis of the thesis, the Market Economic Simulation has been chosen, as this is considered to simulate a national energy system to a higher degree than the Technical Simulation would and as such give a more realistic picture of the energy system. Additionally, the Market Economic Simulation is also used in the scenario for 2020, and using the same simulation strategy in the scenario for 2030 improves the comparability as well as the difference of the scenarios.

5.4 Parameters for the Scenario in EnergyPLAN

In order to evaluate the energy scenario, some parameters have been set which contributes to illustrate the purpose of the simulation in EnergyPLAN. The purpose of the simulation is thus to demonstrate that it is possible to reduce CO_2 emissions by 70% in 2030 compared to 1990. However, this also implies that it is realistic to be able to carry out these measures. Therefore, it is chosen to examine several parameters to show whether the measures are implementable.

The Danish Energy Agency's prognosis of the development of the Danish energy system and the Climate Council's report are based on setting limitations for the implementation track as described in Section 7.2.1. In addition, the scenario is assessed on the basis of the four parameters:

- CO_2 emissions
- Total Annual Cost
- Fuel Consumption
- Renewable Energy Share

These criteria have been chosen as it is relevant to be able to illustrate a reduction in CO_2 emissions in order to meet the 2030 goal. In EnergyPLAN the CO_2 emissions are multiple types of emissions between the different fossil fuels used in the simulated energy system. There is one for coal, oil and natural gas. It is stated in the EnergyPLAN guide made by David Connoly *"Finding and Inputting Data into the EnergyPLAN Tool"* (Connolly 2015) that oil does not account for one fuel, but instead for a of group fuels. The fuel, oil, represents a quantity of different types of oils, which includes diesel, coke, and kerosene. Furthermore, the emissions from coal are two fuels, peat and coal, which have been combined in order to make up for the coal emissions in EnergyPLAN. .(Connolly 2015)

The total annual cost can be described as the costs required to supply the energy system constructed. This includes the implementation cost, fuel cost. In relation to the annual cost in EnergyPLAN, it is relevant to investigate whether the specific measures taken are profitable and realistic to carry out. However, it is not possible to determine the total annual cost of the Danish energy system in 1990, therefore this parameter is disregarded when comparing other scenarios to the 1990 levels.

Fuel consumption is the total amount of fuels consumed in the energy system, which includes consumption from fossil fuel based technologies and energy supplied from renewable technologies. It is relevant to investigate, how the total consumed amount changes with the construction of each of the energy scenarios conducted in this thesis. This is due to the fact that, if the fuel distribution changes, it might alter the fuel consumption. Furthermore the renewable energy share for each scenario is deemed a parameter since the target against the 2030 target is a milestone towards meeting the overall objective of a CO_2 neutral system in 2050, it is relevant to examine how much of the Danish energy system has been converted to renewable energy sources.

5.5 Research Design

The research design illustrates the report structure of this thesis, which can be observed in Figure 5.2. The purpose of the research design is to give an idea of the interplay of the different elements utilised in this thesis.

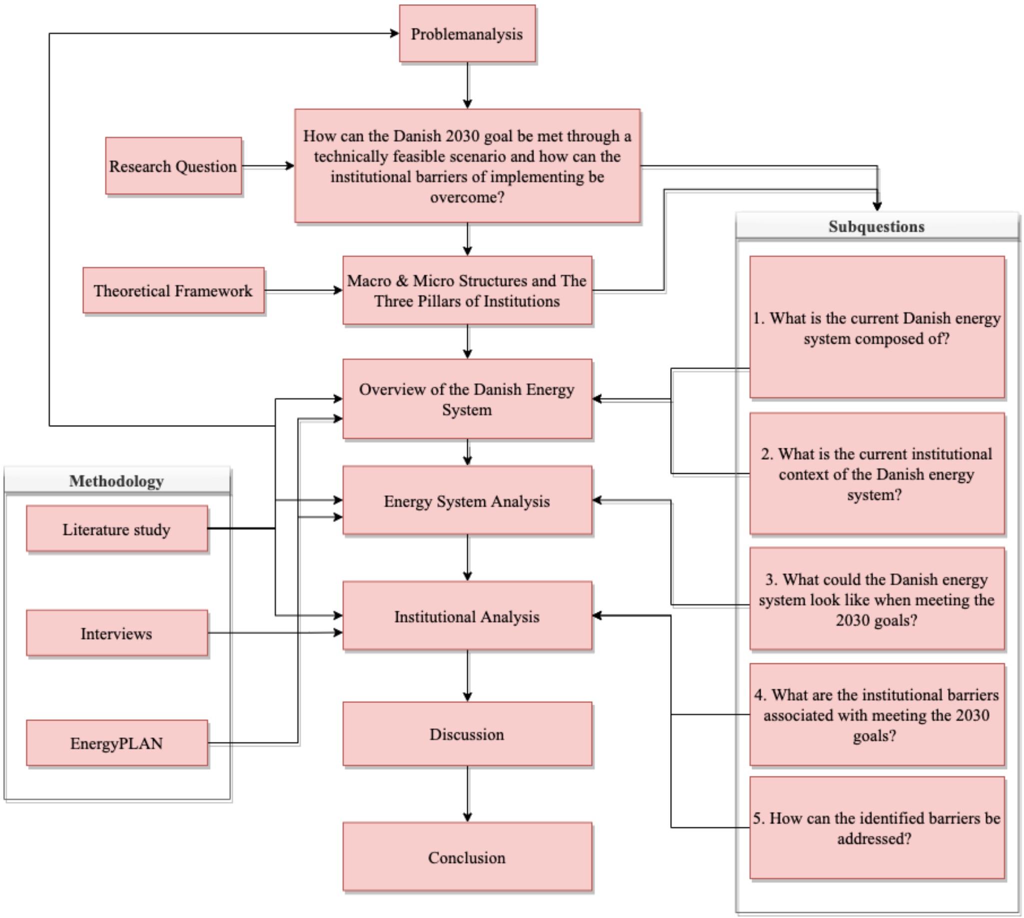

Figure 5.2: Overview of the research design

The thesis has its point of departure in the problem analysis, which describes the different goals and visions Denmark is obligated to fulfill, and the problematic of implementing the 2030 goal into the current Danish energy system. Both in terms of a technical aspect and the institutional hindrances that occurs. In order to fully grasp the magnitude of the problem, it is necessary to understand the interplay between the stakeholders involved in the Danish energy system. The stakeholders shape the Danish energy system and determines which technologies are adequate to implement, which will be portrayed later in the project.

The conclusion of the problem analysis results in the formulation of the research question, which is further supported by 5 sub questions. The purpose of establishing sub questions it is to guide and support the analyses of the thesis. The sub questions are based on different aspects of the analyses, where the theories are utilised to promote and illustrate the complexity of the problem both in terms of the technologies used, but also in terms of the institutional context.

The role of theoretical framework is to create an analytic tool, which can describe the problems related to the research question. The thesis aims to show the possibilities and barriers of implementing such and energy system within the time frame. The context of the Danish energy system is explained through the macro and micro structure and overview of the energy scenario for the thesis is presented.

Through the energy system analysis, the thesis aims to show the societal impact of the revised 2030 CO_2 reduction goal of Denmark with a reduction of 70% compared to the 1990 levels. This is done using EnergyPLAN with inspiration from The Danish Society of Engineers' Energy Plan 2030. Following this, the barriers of the energy system made in the energy system analysis are identified through the application of the Three Pillars of Institutions where the barriers of the heat, electricity, transport, and industry sectors will be identified as well as how these barriers can be overcome. This will be done through interviewing different individuals, who are located in different levels of the planning phase and going through how they are facing the tasks of reducing the CO_2 emissions with 70% compared to the 1990 levels.

The energy system analysis and the institutional analysis contribute to create the basis for the discussion and conclusion.

5.6 Reflection on Methodology

The purpose of this section is to reflect on the different methods chosen in this thesis and how these methods may have influenced the results of the analyses performed in this thesis.

Due to the COVID-19 pandemic, it has not been possible to conduct the interviews physically as Denmark have been placed in lock down from the 11$^{\text{th}}$ of March and all unnecessary contact is prohibited from the Danish authorities. In relation to the compiling of this thesis, it might have added an extra element to the interviews if they were done physically due to the ability to analyse body language and personalise the interview in relation to the interviewees. Thus, it can be argued that some communication is lost compared to conducting the interviews by telephone or online. It could also be an opportunity to conduct all interviews as a video interview so that one could observe the body language of the different interviewees. However, this method was not preferred by some of the interviewees and therefore all interviews were not conducted in that manner. It was considered a necessity that all interviews were conducted online, due to uncertainty about COVID-19, it was not known whether it would be possible to do the interviews physically at another time .

The use of EnergyPLAN as an energy assessment tool makes it possible to give a theoretical picture of the Danish energy system in 2030 while meeting the goal of a 70% CO_2 reduction. There are, however, certain aspects that have affected the scenario or could have been done differently. This includes certain assumptions that have been made in order to create a scenario 10 years ahead, to which a level of uncertainty is related. This means that the scenario will likely not show a true image of the energy system as it will look in 2030. Assumptions have also been made related to the data available. In some cases, data is not available for the current year. For the sake of comparison the data from previous years has been used instead. An example of this may be that the CO_2 emissions of 2020 are not available, where the emissions of 2017 instead have been used to compare. As EnergyPLAN only simulates a single year, it does not account for the gradual implementation of the different technologies. This could to some extent be circumvented by making a scenario for each year towards 2030 showing the development. In relation to this, the time of implementation is not considered when simulating the energy system. In reality the investment is one of the first steps in an energy project while the realisation of the project can take months or years. This means that in order to reach a sufficient energy system in relation to the goals, the implementation of technologies must start before the final year. Additionally, some external factors may also affect the energy system in 2030, which could include examples such as behavioural changes of consumers, which could be included in the demands of the scenario, but this falls outside of the scope of the project.

The simulation strategy of the scenario favors low costs over prioritising renewable energies. This means that fossil fuels will be used if it is available at a lower cost. This may be inconvenient when seeking to reach a specific goal related to reducing CO_2 emissions. The Technical Simulation could be used in this regard if the scenario was made with an isolated perspective and disregarding the external market, which in reality plays an important role as seen in Figure 6.2 on page 32, where it can be observed that the consumption of Denmark is significantly higher than the production in Denmark, which means that energy is imported.

The institutional analysis is based, among other things, on interviews of various stakeholders who are representatives of the organisations. Thus, there may be a risk that their individual opinions may influence their responses, although this was highlighted, it is hard to avoid, this is also pointed out by the phenomenological approach. By using another scientific theoretical approach to the interview, it could have contributed to another result beyond what has been presented in this thesis. In addition, it would also have opened up another way of predicting conversation. In this thesis the focus has been emphasised in the individuals opinion and the representative organisation. Therefore, as often as possible, the interviews are conducted as a individual interview besides the interview with North Denmark Region and Hjørring Municipality. One of the advantages of doing a focus group interview is confronting any possible barriers or hindrances during the interview. However one of the risk was that, based on the phenomenological approach, that their answers may have affected the other stakeholder's answers, and therefore their answers could be altered.

Overview of the Danish Energy System 6

The purpose of this chapter is to give a better understanding of the current institutional context that the Danish energy system is embedded in and answering the following sub questions of the problem formulation: *What is the current Danish energy system composed of?* and *What is the current institutional context of the Danish energy system?*. This is done through a description of the first and second order macro structures, where the different elements will be examined in order to understand the institutional context of the reference energy scenario from 2020. The reference energy scenario will function as a base for the energy system analysis in Chapter 8. Each sector will be examined in this chapter and evaluate the current status of each sector based upon the parameters in Section 5.4 in Chapter 5 .

6.1 Institutional Context of the Danish energy system

The macro structures will help define, how to reach the 2030 goals. However, the theory can also be used to help identify, which institutional context Denmark is embedded in. The first order macro structures can be defined as the regulations, legislation and visions that shapes the outcome of the Danish energy system and this contributes to defining the second order macro structures. It is nearly impossible to list all of the first order macro structures since there are many elements that define the current institutional context. It can be distinguished into short and long-term plans and visions, where the short term plans and vision could be:

- Energy politics both nationally and internationally
- Environmental politics both nationally and internationally
- Financial politics
- Technological development
- Building regulation
- Supply laws and legislation

These short term plans can be altered based on who has the political control in Denmark, and can be affected by the EU and the international community as well, in order to reach the long term plans and visions. The long term visions and plans can be:

- The Paris Agreement
- Energistrategien 2050

- Regional and Municipal energy strategies
- European energy strategy 2030 and 2050

It can however be noted, that some plans and visions may contain both short term and long term aspects. The strategies contribute to defining one of the first order macro structures that currently exists. The current first order macro structures have been affected by past way of conducting energy planning both nationally and internationally. Hvelplund defines the first order macro structures as elements, which can not be altered during the bicycle trip. These should be understood as short and long-term visions and plans which contributes to creating the framework for which Denmark should operate within in order to reduce 70% of the CO_2 emissions. These short and long term visions and plans are a general setup in this thesis, and therefore it may be perceived differently by other stakeholders and thereby create deviations in how it is perceived.

As with the bicycle trip, a second order macro structure can also be made in relation to the 2030 goal of Denmark. In this case, the person as it was with the bicycle trip can be described as the entirety of Denmark. While Denmark may be made up of numerous actors, the goal of a 70% reduction of CO_2 emissions is set for the entire country. In addition to the primary goal, several additional goals may also be relevant when seeking to meet the primary goal. This could be goals such as ensuring economic feasibility and growth, maintaining security of supply, keeping nature and environment in consideration and ensuring efficient use of resources. The starting point in the case of Denmark is the current situation with the currently existing energy system. In Denmark, the means of reaching the goal will be the implementing of technologies through energy planning as the bicycle and the road is used to reach point B. However, in the case of Denmark, there may be a large number of bicycles and roads that need to be used to reach the goal, meaning that different technologies must be implemented, which requires large amounts of planning. Additionally, when planning towards meeting the goal, there may be actors that are relevant to include. These actors may however also have their own goals that do not necessarily match the goal of Denmark. This could be actors such as citizens, industries and utility companies. Lastly, some factors may be more locally bound such as the local community, the topography or the local resources. All these factors as well as their ability to affect one another should be taken into consideration when looking to achieve the Danish 2030 goal. This results in one second order macro structure which is shown in Figure 6.1.

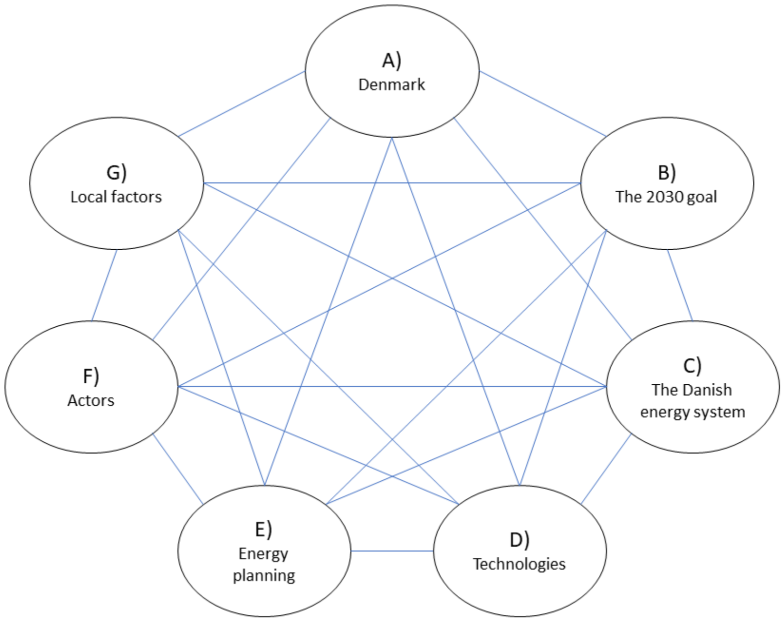

Figure 6.1: The second order macro structure of meeting the 2030 goal. Inspired by (Hvelplund 2001)

Figure 6.1 illustrates the interplay between the different elements of the second order macro structure. The different lines between the different elements indicate that complexity of each element, and how each element is evolving constantly. Therefore, it is necessary to constantly reevaluate each element of the second order macro system in order to stay aligned with the goals set, this will also be highlighted later in the thesis, when the energy system analysis will be conducted. In order to examine the Danish energy system, it is necessary to create a scenario which illustrates the different aspect of the current Danish energy system. This will be examined in the following sections.

6.2 The Danish Energy System

Throughout this section, an overview of the current Danish energy system will be presented. The overview will consist of a short presentation of the chosen model used to build upon later in the thesis, followed by a description of the four sectors of the energy system, the electricity, heat, transport, and industry sector.

6.2.1 The 2020 Model

Seeing as this thesis aims to illustrate some of the necessary changes required to meet the 2030 goal from an energy perspective, it is relevant to have a starting point. In this project, the starting point will for the changes be the current year, 2020. In this case an already existing model is used to illustrate the current energy system of Denmark as the scope of the project is to show the required changes towards 2030. The model is compiled by Peter Sorknæs from Aalborg University. (Sorknæs 2019) The model is primarily based on data from the Danish Energy Agency with additional data from sources such as Energinet. (Sorknæs 2019) Additionally, this scenario is modelled through the use of EnergyPLAN which is the chosen energy assessment tool to model and illustrate the required changes to meet the 2030 goal as described in Section 5.2 in Chapter 5. This makes it possible to make changes to the model and further adjust it to meet the 2030 goal.

6.2.2 The Electricity Sector

Denmark is connected by a single large electricity grid. Energinet is the Danish transmission system operator for electricity and natural gas and is responsible for operation and maintenance of the electricity grid. (Energinet 2019)

The electricity that is provided through the regular outlet in households can be supplied by many different sources. In the 1990s, the primary supplier of electricity was large coal-fired power plants(PP) in Denmark. This has since undergone a relatively large change with the implementation of smaller natural gas fired plants followed by implementation of wind turbines, bio fuels and photovoltaic cells. The electricity provided by these sources is constantly traded between consumers and producers nationally and across borders. Additionally, the electricity in the grid is usually a combination of electricity provided by different sources meaning that the specific source of the electricity at a given time is unknown.(Energinet 2019)However, the annual production and consumption is measurable and can be seen in Figure 6.2.

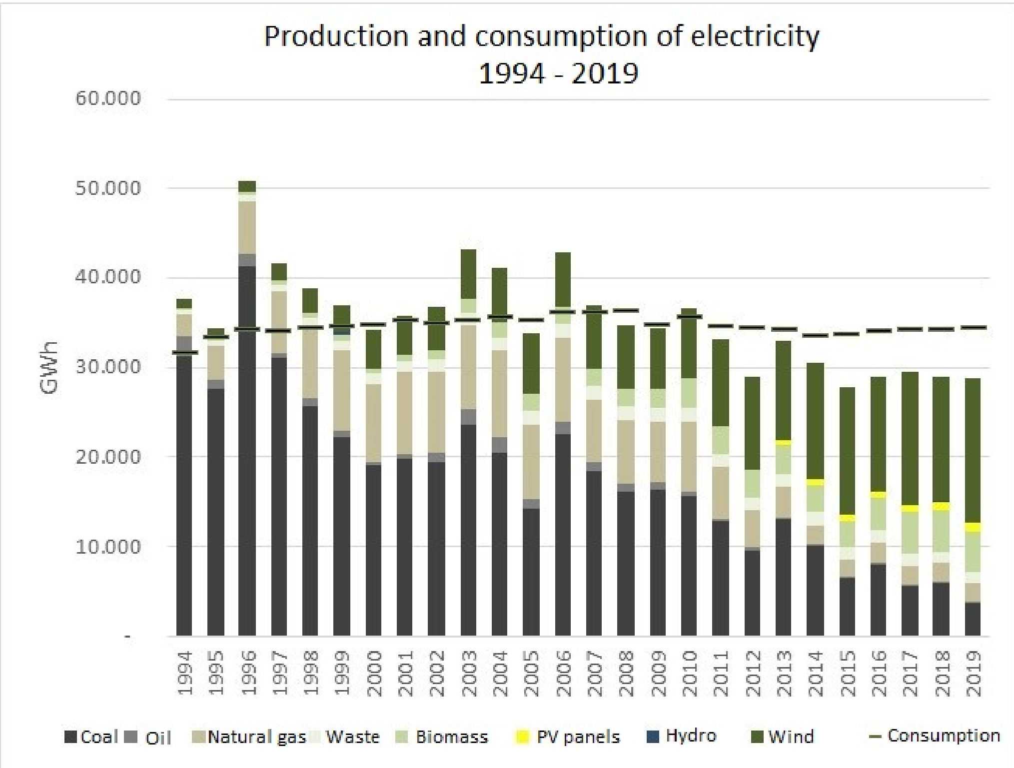

Figure 6.2: Annual production and consumption of electricity in Denmark. (Energinet 2019)

As seen in Figure 6.2, the production of electricity has changed rapidly from being primarily based on fossil fuels to renewable energy sources such as biomass and wind power. When comparing the production with the consumption it is clear that these are often not equal to each other. This is where trading of electricity across borders plays a role. This often happens when prices are favoring either import or export of electricity. If the prices of electricity in other countries are high compared to the cost of producing electricity, additional electricity can be produced for profit. On the other hand, if the price of electricity are low compared to the price of producing, electricity may be purchased from neighboring countries rather than producing it. (Energinet 2019)

Electricity is a versatile energy source and widely used in the energy system. Due to its versatility, electricity is also prevalent in each of the following three sectors.

In the scenario, the electricity demand is 33.78 TWh/year which includes regular usage, electric heating and cooling as well as electricity for transportation.

6.2.3 The Heat Sector

In Denmark, the heat sector covers the use of heating houses, domestic hot water and private businesses heat usage. This can be supplied through the use of different technologies but can generally be divided into two sectors: the individual supply and the public supply. Roughly 80% of households in Denmark are supplied by public supply while the remaining 20% are supplied by individual means. (Danish Energy Agency n.d)

Individual Heating

Individual heating in Denmark is often supplied through the use of oil-fired boilers, individual heat pumps or biomass-fired boilers. Oil-fired boilers was previously the most widely used method of heating, but as the public heat supply was expanded upon, individual heating is mostly seen in smaller towns and rural areas. Additionally, oil-fired boilers are often replaced with individual heat pumps, ground source heat pumps, or biomass-fired boilers as these can have environmental and economic advantages over oil-fired boilers. (Danish Energy Agency n.d)

Public Heat Supply

The public heat supply in Denmark consists of two types of supply. The first and most prominent type is the DH where heat is produced at a local plant and then transported to users as hot water. Two thirds of Danish households are supplied through this method. Heat produced by these plants is often produced in combination with electricity production. The other type of supply is by natural gas, which is supplied by a public distribution network. 15% of Danish households are supplied by heat produced by publicly distributed natural gas. The public heat supply is primarily utilised in urban areas or areas where a high density of households are found. Both types of public heat supply are regulated through the Danish Heat Supply Act. (Danish Energy Agency n.d)

Municipalities and utility companies are the primary actors in the public heat supply. The municipalities conduct heat planning and are responsible for the development of the heat sector as well as the choice of public heat supply if any. This planning must be conducted in line with the regulation of the Danish Heat Supply Act. The DH and natural gas companies have the operational responsibility of supplying heat to the users. The Danish Energy Agency sets the general conditions for establishment and operation of the public heat supply to ensure positive socio-economics and favorable prices for the user. (Danish Energy Agency n.d)

In the scenario, the total heat demand of Denmark is 50.38 TWh/year, when accounting for both DH and individual heating. The production of heat is slightly higher due to the losses of heat within the DH-system.

6.2.4 The Transport Sector

In Denmark, the energy consumption of the transport sector has been steadily on the rise since the 1970s. The vast majority of this increase has been through the use of oil in the transport sector while a small part of the increase has happened through the use of biofuels. The use oil in the transport sector can partially be credited to the increasing amount of registered cars in Denmark where the majority uses oil while a marginal amount uses electricity. (Drivkraft Danmark 2019) A graph showing the development of different vehicles can be seen in Figure 6.3.

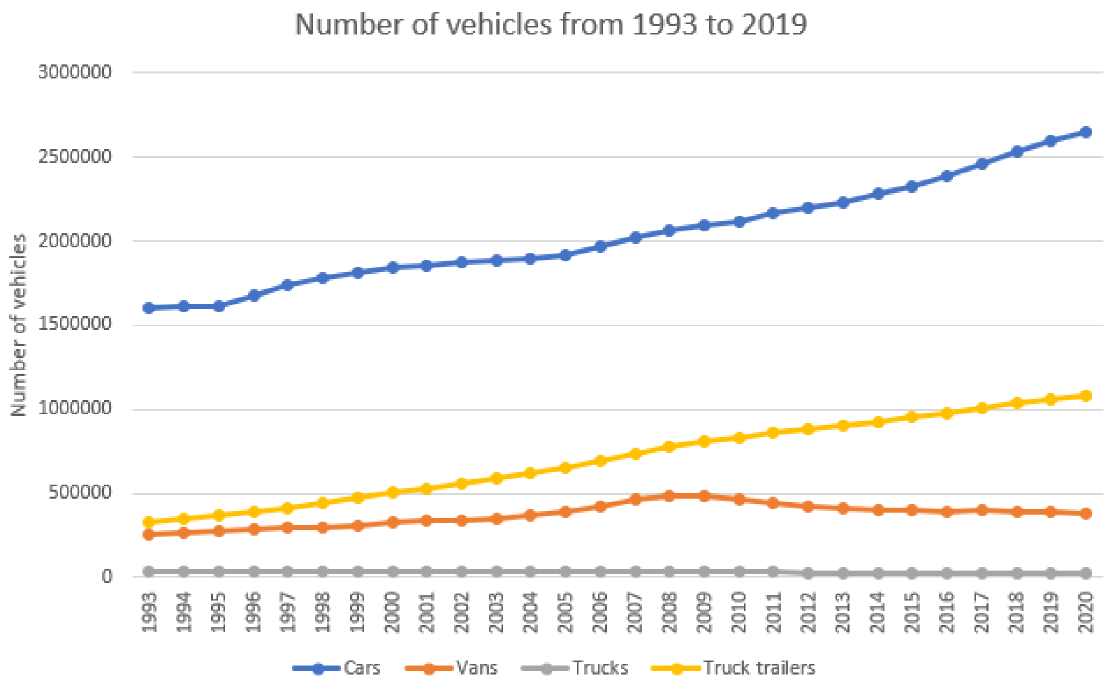

Figure 6.3: Number of vehicles from 1993 to 2019. (Statistics Denmark 2020a)

In Figure 6.3 it can be seen that the number of cars has risen greatly since 1993 while the number of vans and trucks remain almost similar. Additionally, it can be seen that the number of truck trailers has been rising steadily in the same period. While the number of cars has gone up in the last two decades. The number of ships and planes in Denmark has been somewhat consistent. This is illustrated in Figure 6.4

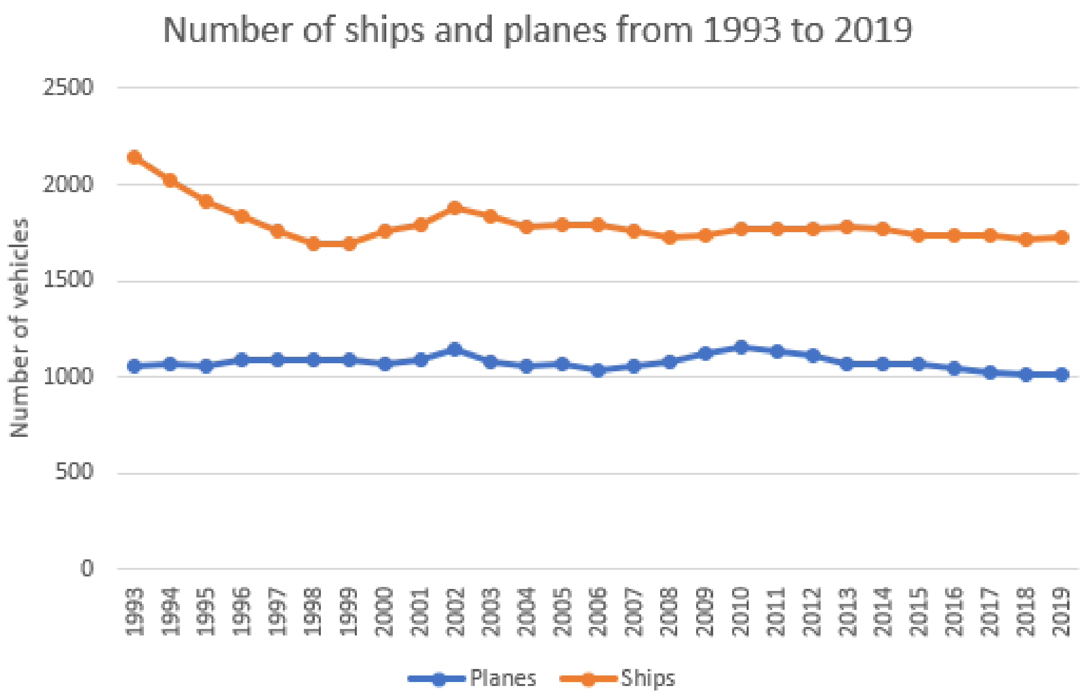

Figure 6.4: Number of ships and planes from 1993 to 2019. (Statistics Denmark 2020e,d)

In the scenario, the transport sector has an energy consumption of 59.97 TWh/year aside from the electricity used for transportation as mentioned in the electricity section. This mainly stems from the use of oil while a minor part of the consumption consists of bio fuels and natural gas.

6.2.5 The Industry Sector

Denmark is home to a large amount of industries and professions. These can range from small shops and service businesses that consume relatively small amounts of energy to large scale industries that consume immense amounts of energy. In the period from 2012 to 2014, the energy consumption of the industrial sector was declining while it has been increasing in the following period from 2014 to 2018. (Statistics Denmark 2020*c*) This development is shown in Table 6.1.

Table 6.1: Energy consumption of the industrial sector from 2012 to 2018 (Statistics Denmark 2020c)

Year	2012	2014	2016	2018
Consumption (TWh)	26.46	25.15	25.97	27.44

The increase shown in Table 6.1 may be closely tied to the production of the industries which saw an increase in production of around 7% from 2016 to 2018. In comparison the energy consumption in this period increased about 6%. The increase in energy consumption may however not necessarily result in increased emissions. The industry sector is a large consumer of electricity, which means that the source of consumed electricity in reality plays a role in the environmental impact of industries. (Danish Industry 2019)

In the scenario for 2020, the industry and various uses have an energy consumption of 38.16 TWh/year. The various uses cover own consumption in the energy sector for production and refining fuels. Additionally, it also covers use for non-energy purposes.

6.3 Summary

The macro structure forms the framework for the Danish energy system and its development. The macro structure and the underlying micro structures influence how the energy system is designed. This is also implemented in the compiling of the reference scenario, in order to understand how the energy system looks today, it is necessary to examine past trends for each sector in order to gain an insight into why the energy system looks the way it does today. As this helps to determine the current macro and micro structures and will affect the future macro and micro structures.

The reference scenario is compiled, based on an energy scenario developed by Aalborg University, this is done as this thesis focuses on the changes that need to occur to achieve the 2030 goal. Figure 6.5 has been compiled to give a better understanding of how the reference scenario is constructed and what technologies are currently being used in the Danish energy system.

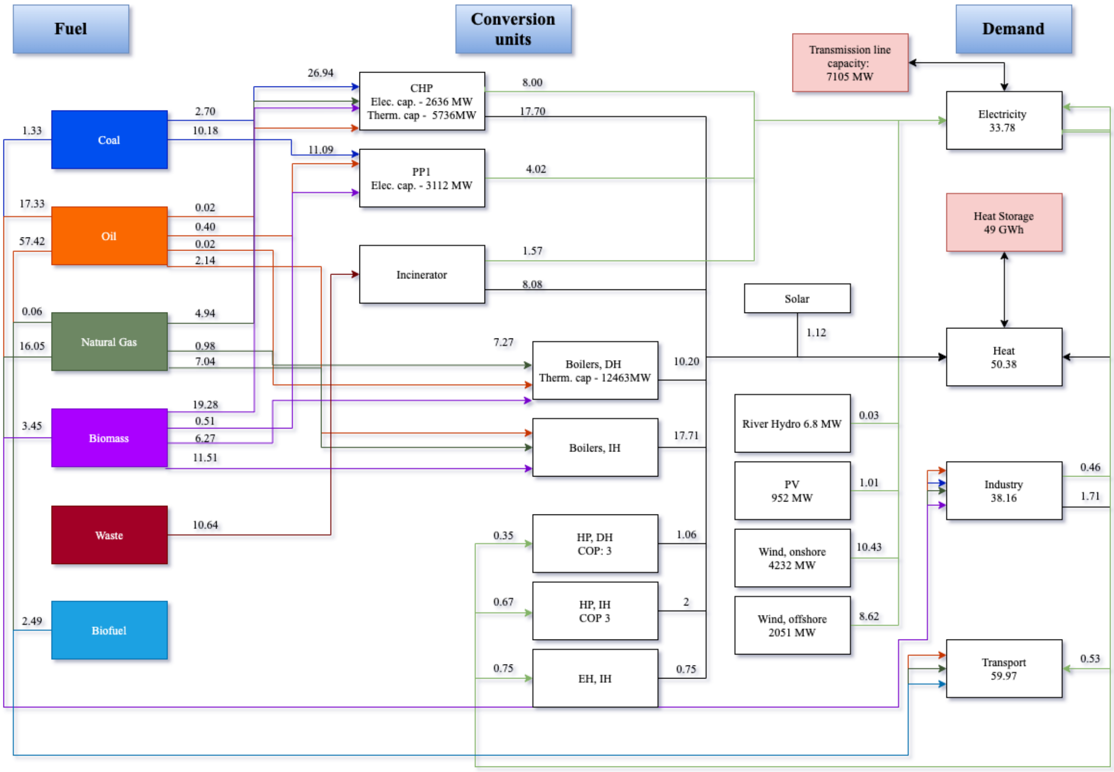

Figure 6.5: Overview of the reference scenario

Figure 6.5 illustrates the various fuels, technologies and demands. It can be observed from Figure 6.5 that the Danish energy system uses multiple types of fuel, this is a result of the oil crisis from the 1970s, since then there has been a strong desire for the Danish energy system to be flexible and not dependent on one fuel. The different technologies used are the culmination of several decades of work, both in relation to past policy, goals, visions, as well as concrete research in the various sectors, which can be described as past macro structures that have had an impact on today's technology choices. In addition, the demands of the different sectors are illustrated. There is a large interaction between the different sectors, which makes the sectors more dependent on each other. Therefore, it is also difficult in today's energy system to talk about the different sectors as four incoherent sectors, as each sector affects one another.

The methodological approach for assessing the various energy scenarios in this thesis is described in Section 5.4 in Chapter 5.

Table 6.2: Overview of the different parameters for the reference scenario and 1990.

Parameters:	**Reference scenario 2020**	**1990**	**Difference**
CO_2 emissions	31.408 Mt	44.237 Mt	29%
Total Annual Cost	18815€ M	-	-
Fuel Consumption	195.80 TWh	117.94 TWh	39%
Renewable Energy Share	41.2%	10.8%	30.4%

Table 6.2 indicates what the different values are for the 4 parameters: CO_2 emissions, RES, Fuel consumption, and Total Annual Cost, which are evaluated on in this thesis for both

the reference scenario and 1990, which is the level that is compared to in the 2030 goal. The number that determines the different parameters for the 1990 comparisons are based on the Energy statistics from the Danish Energy Agency.(Danish Energy Agency 2017)

It can be observed that the level of CO_2 emissions have decreased compared to 1990 by 29%. This is related to the increase of the RES in Danish energy system which have increased by 30.4%. This can be perceived as a step towards the right direction in order to reduce the CO_2 emissions with 70%. Both of these changes can be regarded as a positive impact compared to the 1990 levels, which is why they are assigned a green color.

However, an increase in fuel consumption has occurred within this 30-year span, but that can partly be explained due to the population increase and a higher living standard in Denmark. This can be regarded as a negative factor compared to 1990 levels, which is why it is indicated with a red color.

In addition, the reference scenario 2020 and 1990 levels will function as the base for comparisons for the following scenarios, which will be presented in the next chapter, which will further investigate how Denmark should be able to reach the 2030 goals.

7 A Energy System Analysis of Denmark

Throughout this chapter an energy system analysis of the Danish energy system will be conducted. This will contribute to portray a holistic overview of the Danish energy system as a whole. The analysis will be conducted in order to answer the sub question: *What could the Danish energy system look like when meeting the 2030 goals?* The analysis aims to demonstrate how the 2030 goal of Denmark can be met through a technical scenario of the Danish energy system. The scenarios will primarily focus on four sectors within the energy system: Heat, electricity, transport, and industry. The initial scenario will be based on the expected development of the energy system towards 2030 under the current macro and micro structures as described in Section 6.1 in Chapter 6. Following this scenario, a scenario will be made highlighting how the 2030 goal can be met without being limited by the existing macro and micro structures. The technical analysis helps to illustrate some institutional barriers in relation to the interviewees' responses, so they can complement each other and help identify barriers, and help to prevent gaps in relation to energy planning in Denmark.

7.1 Approach

The chronological order used for designing each technical scenario can be observed in Figure 7.1

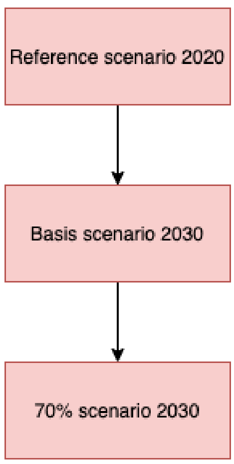

Figure 7.1: Overview of the different scenarios constructed in EnergyPLAN.

The reference scenario will function as a foundation for the basis scenario. The purpose of the basis scenario is to illustrate whether it is possible to achieve the 2030-goal with the current macro and micro structures. The 2030 scenario is based on the Danish Energy and Climate Outlook 2019 (Energistyrelsen 2019), which means that the implementation rate is a continuation for how technologies have been changed or implemented in the Danish energy system. The scenario will be used to illustrate how far the Danish energy system can reach, in order to achieve the 2030 goal by implementing changes in the energy system based on the current implementation rate.

The 70% scenario is conducted to illustrate how to reach the goal and illustrate, if something needs to change in the macro and micro structures in order to achieve the 2030 goal. The 70% scenario has been compiled based upon that the previous scenario, the basis scenario 2030, does not reach the target of a 70% reduction in CO_2 emissions. Data has been used on potential focus areas from the Climate Council's report, as well as potentials for technologies of IDA's energy vision.

It is important to note that the 70% reduction covers the energy system as a whole, meaning that some sectors may not achieve a 70% reduction, while other sectors may reduce the CO_2 emissions by more than 70%. This is also apparent in some of the other Danish goals as mentioned in Section 2.3, where one of the goals is at least 90% of DH being supplied by renewable energy sources.

7.2 Steps Towards the 70% Reduction

Throughout this section, some of the possible options in regards to reaching the 70% CO_2 reduction will be showcased as well as highlighting some of the actions that will be carried out when making a scenario where the goal is met.

When looking to reduce the CO_2 emissions of the Danish energy system, there are a near endless number of possibilities regarding how to reduce the CO_2 emissions with different technologies, political approaches and behaviour of consumers. Despite this, there will be a natural development of the energy system towards 2030. The Danish Energy Agency annually publishes a prognosis for the development of the Danish energy system without political changes. The recent prognosis made in 2019, shows that the development without any political changes is not sufficient in order to meet the 2030 goal (Energistyrelsen 2019). Based upon this, two points can be deduced: Firstly, it is clear that the natural development is insufficient when looking to meet the 2030 goal. Secondly, it shows that political action is needed in order to steer the development towards meeting the 2030 goal. Once again the possibilities are numerous with political actions and related technologies.

The Danish Council on Climate Change published a report in March 2020 with suggestions on how to further reduce the CO_2 emissions towards 2030 in order to meet the goal of a 70% reduction. (The Danish Council on Climate Change 2020) Throughout the report, The Danish Council on Climate Change presents a series of actions, which can push the Danish energy system towards a 70% reduction. These actions are divided into two general tracks, which happen simultaneously towards 2030. These tracks are the implementation track and the development track. The difference between these two tracks is that the implementation track focuses on expansion of already existing and widely used technologies where renewable energy replaces fossil fuels. Meanwhile, the development track focuses on new transitional elements such as new technologies and changes to the consumers habits and usage of energy. (The Danish Council on Climate Change 2020)

Throughout this thesis, already existing technologies will primarily be applied to show a possible CO_2 reduction of 70% as mentioned in Section 3.1. Based on this, the following description will mainly focus on the implementation track.

7.2.1 The Implementation Track

One of the primary suggestions of the report by The Danish Council on Climate Change is a wide tax on emissions covering every energy consuming sector in Denmark with the philosophy that the polluter is the payer. This is one of the prime instruments in order to push the implementation of renewable energy. (The Danish Council on Climate Change 2020) Additionally, the report points toward sector specific actions, that can further push the reduction towards 70%. A table showing the actions in the individual sectors can be seen in Table 7.1.

Table 7.1: Possible actions which can contribute to the 70% CO_2 reduction (The Danish Council on Climate Change 2020)

Heat and Electricity	**Buildings**	**Transport**	**Industry**
Outphasing of coal	Energy renovation of buildings	Electric cars	Energy savings
Sorting of plastic in waste	Heat pumps	Electric vans	Electrification including heat pumps
Outphasing of oil and gas	Transition to district heat	CO_2 neutral trucks	Biomass in processes
		CO_2 neutral buses	Green cement and transition from coal and coke to gas

As seen in Table 7.1, there are various elements within each sector which can help the transition. These will be a factor in the following scenario of how the 2030 goal can be achieved.

7.2.2 Priority of Actions

In order to illustrate the required additional actions so the 2030 goal can be meet, the scenario will first show the development towards 2030 from 2020. Following this, the remaining needed reduction will be identified. When the required reduction has been identified, the actions shown in 7.1 will be implemented. The general approach here will be that actions that will affect the demand will be implemented prior to changes in supply as this will prevent adjusting the supply for two different demands.

7.3 Basis Scenario for 2030

Throughout this section, a scenario for 2030 will be presented as well as the primary changes from 2020 to 2030. The scenario takes its point of departure in the 2020 scenario made by Aalborg University as described in Section 6.2 and Section 6.3. This scenario is then developed further upon using the expected development described in the report "Denmark's Energy and Climate Outlook 2019" published by The Danish Energy agency (Energistyrelsen 2019). The objective of this scenario is to illustrate the development of the energy system towards 2030 without changes of policies, which means that it is the expected development based on current policies. This will then be compared to the national 2030 goal of a 70% CO_2 reduction compared to 1990. This will then give an indication that additional action is necessary in order to reach the goal as well as which sectors of the energy system are lacking in relation to meeting the 2030 goal. As such, this scenario will be used as a stepping stone towards a scenario where the 2030 goal is met. Additional information regarding the scenario can be found in Appendix B. An illustration of the energy system showing fuel consumption and demands of each sector is shown in Figure 7.2.

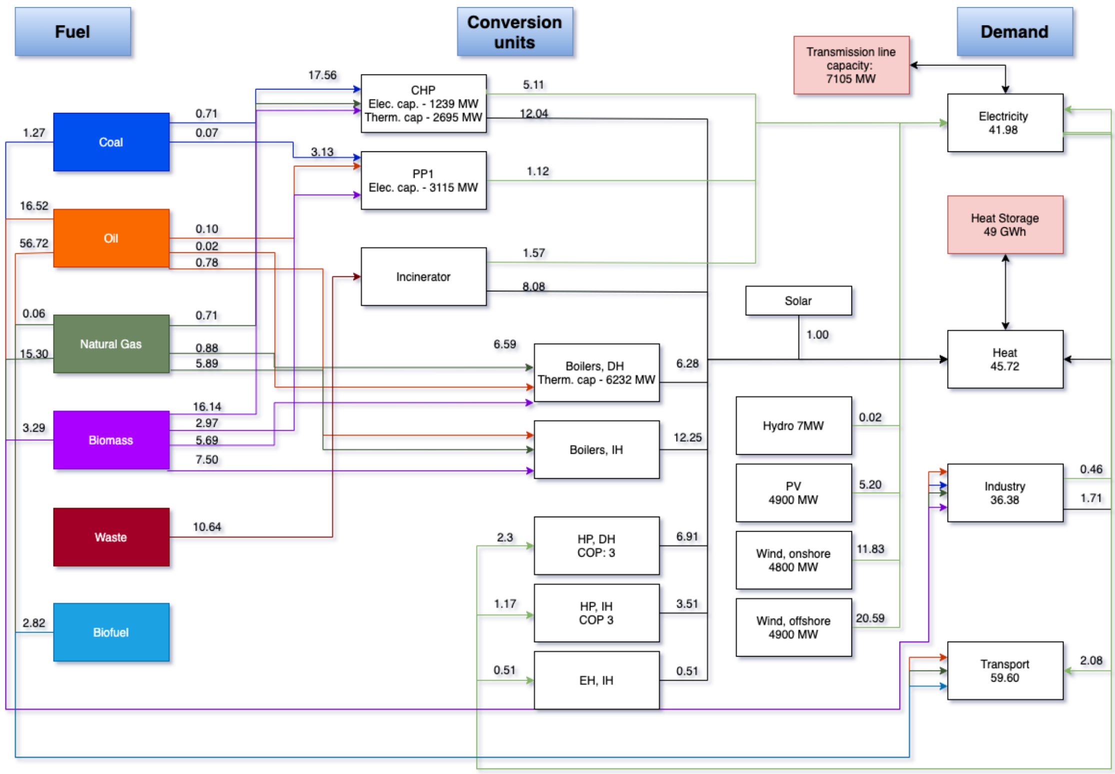

Figure 7.2: Overview of the basis scenario 2030

7.3.1 Electricity and Heat

In Denmark, the electricity and heat sector are the most advanced sectors when it comes to producing energy from renewable energy sources. A part of the production is however currently based on the use of fossil fuels. This is primarily the case with the large scale CHP plants and usage of coal. Some of the individual heat production is also reliant on fossil fuels with the use of natural gas and oil (Energistyrelsen 2019). Towards 2030 the electricity and heat sector undergoes changes where almost the entire sectors are transitioned to more renewable ones. This is due to the coal fired CHP plants either shutting down or transition their production to be based on renewable energy. A large factor in this is the recent change in legislation, where the requirement of CHP production is no longer in effect (Danish Ministry of Climate, Energy and Utilities 2018). This allows the utility companies to produce heat based on heat pumps and rely on electricity produced by renewable energy sources such as wind turbines or photovoltaic cells which also faces a large expansion towards 2030, where the capacities of offshore wind turbines and photovoltaic cells are massively increased. Onshore wind turbine capacities also undergoes a minor increase but this is primarily due to older turbines being replaced by newer, larger and more effective turbines (Energistyrelsen 2019). A result of this electrification is that the demand of electricity is constantly on the rise towards 2030. This is also in part due to the expectation of large data centers being built in Denmark. Based on the fuel consumption of the sectors, the CO_2 emission of the heat sector is 2.9 Mt while the CO_2 emission of the electricity sector is 0.36 Mt in 2030.

7.3.2 Transport and Industry

The transport and industry sectors face relatively few changes towards 2030. The energy consumption of the transport sector is close to constant in the period towards 2030(Energistyrelsen 2019). There is however a slight change in the fuel used within the transport sector. The railways and light transportation will transition a minor part to using electricity rather than fossil fuels, while heavy transport and maritime transport will transition an almost negligible part to electricity. On the other hand, the air transportation will remain fully supplied by fossil fuels in 2030 and during the period towards 2030 (Energistyrelsen 2019).

The total energy consumption of the industry sector is on the rise towards 2030. This is primarily due to the large data centers being located in Denmark. The share of renewable energy within the industry sector is also slightly on the rise, while the share of fossil fuels is slightly decreasing in the period from 2020 to 2030. This is based on an increased usage of heat pumps and renewable energy sources (Energistyrelsen 2019). The CO_2 emission of the transport sector is the highest of the four sectors in 2030 with a CO_2 emission of 14.9 Mt, followed by the industry sector with a CO_2 emission of 7.9 Mt.

7.3.3 Summary

In Table 7.2 an overview of the parameters can be seen.

These numbers show that the development of the energy system results in a significant reduction of CO_2 emissions at 44% with an increased renewable energy share of 49.9%. However, there is also an increase in fuel consumption.

It can be concluded from the scenario, that the development of the energy system based

Table 7.2: Key paramters of the 2030 basis scenario

Parameters:	**Basis scenario 2030**	**1990**	**Difference**
CO2 emissions	24.986 Mt	44.237 Mt	44%
Total Annual Cost	19407€ M	-	-
Fuel Consumption	186.68 TWh	117.94 TWh	37%
Renewable Energy Share	49.9%	10.8%	39.1%

on the current first and second order macro structure is not sufficient, as the development will not reach a reduction of CO_2 emissions of 70%. It can in this regard be argued that there is no radical change to the technology of the energy system as described in Section 4.1. Despite the energy system being different in 2030 compared to 2020, there are no significant changes to the five elements that are described to constitute a technology as this scenario can be viewed as a continuation of the current energy system and policies. Based on this, it can be assumed that a radical change to the technology may be required in order to meet the 70% reduction goal in 2030. This will be the focus area of the following scenario.

7.4 New 2030 scenario

While some development within the energy system is expected towards 2030, the energy system in 2030 will not meet the goal of a 70% reduction in CO_2 emissions. This means that additional action towards reducing CO_2 emissions must be taken. Throughout this section, a scenario illustrating how the reduction can take place will be presented. Additional information regarding the 70% scenario can be found in Appendix B. An overview of the final scenario can is shown in Figure 7.3.

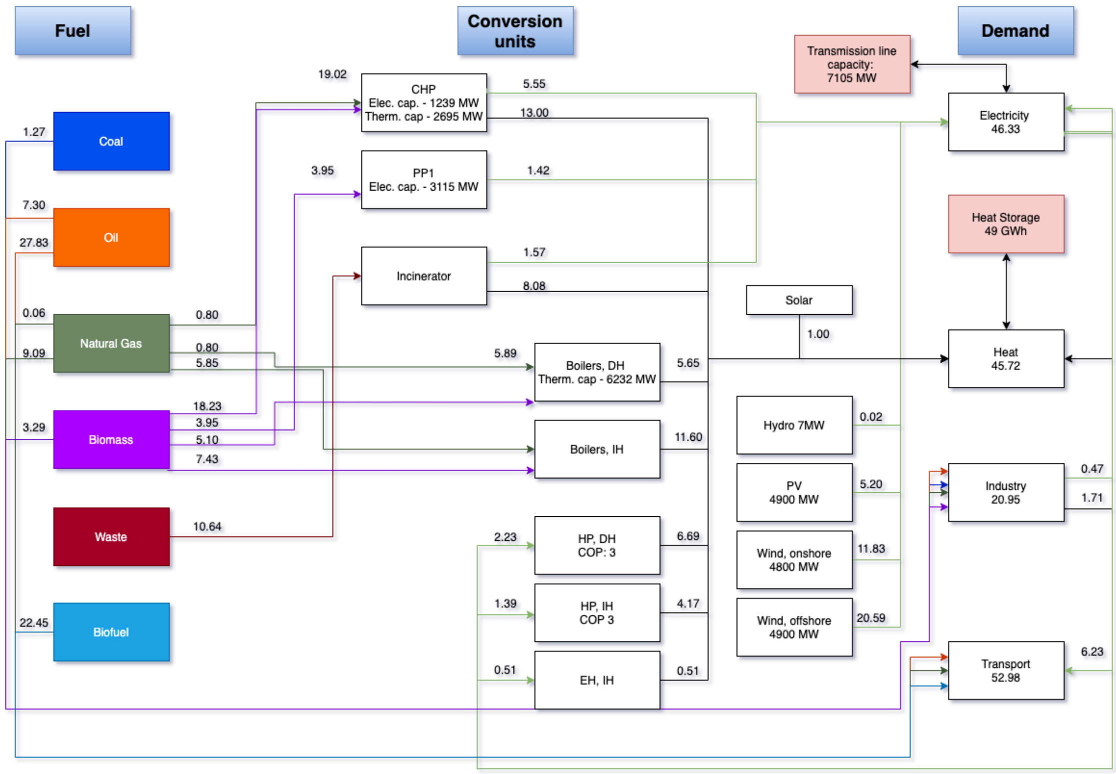

Figure 7.3: Overview of the 70% scenario 2030

The scenario takes its point of departure in the previously shown scenario, where the expected development towards 2030 under the current macro structure is shown. Based on this, additional efforts must be made in order to fully reach the 2030 goal of Denmark. As this is a fictional scenario showing a potential energy system that meets the 2030 goal, it is in this regard important to note that this is one of many possible scenarios that can meet the goal and the actual energy system may vary from the energy system shown here in 2030. Therefore, the objective of this scenario is not to predict how the energy system will meet the 2030 goal but instead show how the goal of a 70% CO_2 reduction can be met and the required changes to do so through an example shown in the scenario. The scenario is primarily inspired by the report from the Danish Council on Climate Change (The Danish Council on Climate Change 2020) as well as IDA's Energy Vision 2050 which has a scenario for 2035 as a stepping stone towards (Aalborg University 2015). It is in this regard important to note that the inspiration used from the energy vision is 5 years further than the energy system shown in this scenario. An in-depth explanation of how the scenario is designed can be found in Appendix B.

7.4.1 Electricity and Heat

As shown in the previous scenario, the electricity and heat sectors of Denmark are already relatively advanced in terms of renewable energy, meaning that the improvements on these sectors are limited. The primary difference from the previous scenario in this sectors are that the remaining coal and oil are removed from the production of electricity and heat and is instead replaced by biomass. This results in the electricity and heat sectors being almost entirely supplied by renewable energy. The remaining fossil fuels in the electricity sector is natural gas which is used for both heat and electricity production. This is assumed to be used during the few peak hours of the year where additional production is required during relatively few hours. While it is deemed technically possible to increase the capacity of renewable energy such as wind turbines and photovoltaic cells even further in 2030 (Energinet 2015, Danish Energy Agency 2011), these have not been increased in this scenario. This is due to the fact that the increase in capacity shown in the basis scenario in 2030 is already relatively large, which in practice may be difficult to increase due to the time horizon of such technologies. Additionally, an increase in capacity showed no impact on the energy used in the scenario. Based on the fuel consumption of the sectors, the CO_2 emission of the heat sector has decreased from 2.9 Mt to 2.5 Mt whereas the CO_2 emission of the electricity sector has decreased from 0.36 Mt to 0.25 Mt in 2030.

7.4.2 Transport and Industry

The transport and industry sectors are the sectors that face the most drastic changes from the 2030 basis scenario. This is due to the fact that these sectors are the main consumers of fossil fuels which must be reduced in order to reduce the CO_2 emissions.

For the transport sector, a variety of different technologies have been utilised in order to transition from fossil fuels to renewable fuels. For the air transport it was stated that this was likely to remain fully supplied by fossil fuels towards 2030. This has been changed in this scenario in order to reach the goal of a 70% CO_2 reduction in combination with the other shifts in the transport sector. Specifically for air transport, a part of the fossil fuels have been replaced with electrofuels. It should here be noted that while such a transition is relatively simple within EnergyPLAN, as it merely replaces one number with another, in practice it requires a change of technology to utilise the chosen fuel. This is not only the case for the air transport, but also for other technologies. A large part of the petrol usage has been converted to electricity, as this covers personal vehicles which relatively easy can utilise electricity. For diesel usage which covers heavy transportation, a large part is converted to electrofuels, as this part of the transport sector can not efficiently utilise electricity for transportation of goods for example. A part of the fossil fuels of the transport sector has also been transitioned to hydrogen, which has a wide variety of uses in both light transportation such as cars and heavier transport such as trucks or busses. The partial transition of different vehicles has resulted in none of them being entirely renewable but instead being partially converted. This is due to the time frame being limited towards 2030 and a complete conversion of the transport sector may take longer than the available time frame in this scenario.

In the basis scenario for 2030, a similar situation is present for the industry sector in the sense that it has a significant consumption of fossil fuels. In order to meet the 70% reduction, these must be reduced significantly. In the scenario, the use of fossil fuels within the industry sector have been reduced by almost half compared to the 2030 basis scenario as energy savings. The reduction of fossil fuels can also happen through other means such as electrification or use of other renewable fuels, but the reduction here is used to show the extent of the reductions in order to meet the goal of 2030.

When comparing to the 2030 base scenario, the CO_2 emission of the transport sector has been decreased from 14.9 Mt to 7.3 Mt while the CO_2 emission of the industry sector has decreased from 7.9 Mt to 4.2 Mt

7.4.3 Summary

Overall, the entire energy system needs additional changes in order to fully meet the goal of 2030, with varying degrees in the different sectors, where the transport and industry sector are the most important sectors that currently hinder achieving the 2030 goal. The parameters of the scenario which meets the goal are shown in Table 7.3.

Table 7.3: Key parameters of the 70% scenario

Parameters:	**70% scenario 2030**	**1990**	**Difference**
CO2 emissions	13.202 Mt	44.237 Mt	70.2%
Total Annual Cost	18000€ M	-	-
Fuel Consumption	166.81 TWh	117.94 TWh	30.3%
Renewable Energy Share	57.3%	10.8%	46.5%

In Table 7.3 it can be seen that the goal of reducing CO_2 emissions by 70% is met as well as an increase of the renewable energy share. It can also be seen that the costs of the energy system are the lowest in the 70% scenario. This may be due to the changes in technologies, fuels, energy savings and the surrounding infrastructure, where there may be some uncertainty related to the costs. Due to this since the cost of the energy savings are not included in the scenario. There is also some uncertainty related to who the costs are related to. The future energy system may see a change in which actor is responsible for the different sectors of the energy system with changes from public owned to privately owned parts of the energy system or vice versa.

Based on the definition of technology presented in Chapter 4 section, it can be argued that a technological radical change occurs during this scenario, as more than one of the elements defining technology is changing. This can be seen in Figure 7.4, where the various affected elements are highlighted in yellow.

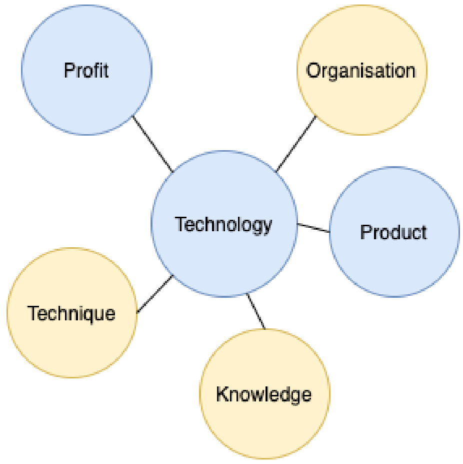

Figure 7.4: Illustration of the elements affected in order to create a technological radical change

Both the technique and knowledge within the Danish energy system are changing, there is a correlation between these two elements. This is reflected, among other things, by the changes in the transport sector, where there is a greater focus on renewable transportation compared to the basis scenario 2030. This is done by a larger share of cars being converted to bio fuels and as electric cars. Currently, the technology and knowledge to change the cars exist, but there is an obstacle to whether it can be realised on a larger scale. There are currently no country where half of their transport sector has been transformed from fossil fuels to renewable energy sources. All this is influenced by how the organisation has determined the macro structure of the energy system. In this case it can be argued that this transformation in the transport sector has not been taken into account in order to meet the 2030 goal.

The current macro structures that define the institutional context of the Danish energy system can be observed in Chapter 6. Therefore, a change in the element, organisation, is also needed in order to meet the 2030 goal. The energy scenarios constructed in this energy system analysis can function as an example that changes need to occur in order to reduce CO_2 emissions by 70% in 2030.

Furthermore, the elements that are not deemed affected directly, such as profit, can also play a significant role as the economy often deselect of certain technologies, as these may not be well developed and tested enough to be able to be a part of the energy system.

7.4.4 Comparison of Scenarios

The different energy scenarios constructed in the energy system analysis indicate, that it is necessary to change the current order of the Danish energy system in order to achieve the 2030 goal. The parameters defined in this thesis indicates what can change in order to achieve the 2030 goal. However it is necessary to take into consideration that, the scenario constructed in this thesis is one way to achieve the 2030 goal, there are multiple ways to achieve the goal. To examine how the constructed scenarios differ from one and another, it is necessary to further examine the parameters based on the energy system constructed.

Figure 7.5 illustrates the CO_2 emissions for each of the scenario constructed in the energy system analysis, and the reference year of 1990.

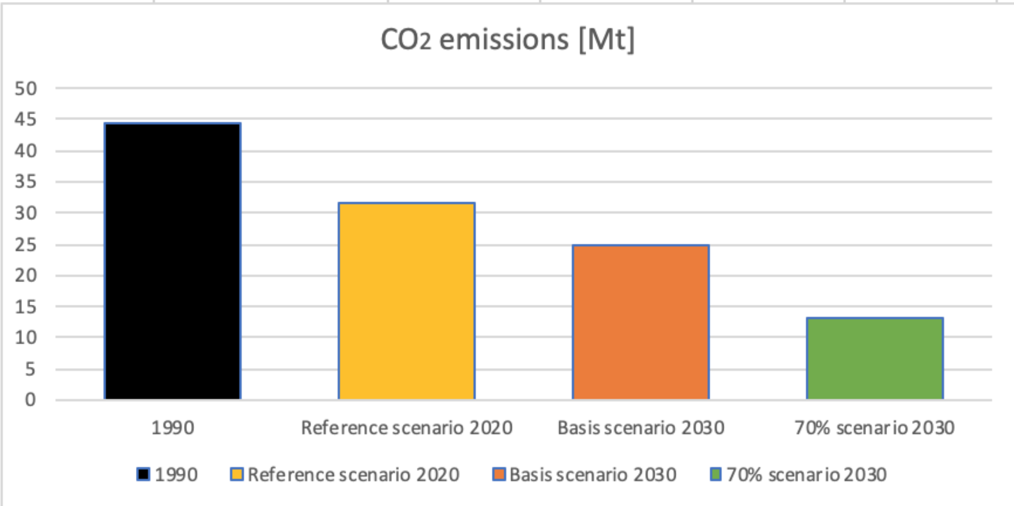

Figure 7.5: Graph over the CO_2 emissions for each scenario, The y axis illustrates the amount of CO_2 emissions in Mt

Since this parameter can be defined as the main parameter, since a 70% reduction in CO_2 compared to 1990 will determine whether the 2030 goal will be achieved. Based upon Figure 7.5 it can be observed that there is a decrease in CO_2 emissions for each scenario. The development of CO_2 emissions in each sector for each scenario is also shown in Table 7.4.

As seen in Table 7.4, all sectors of the energy system has undergone varying reductions of CO_2 emissions. It is shown that the electricity sector is almost completely CO_2 neutral with a CO_2 emission close to zero. It can also be seen that the most emitting sector continues to be the transport sector which is due to the large quantities of oil still being used for transportation.

The reduction of CO_2 emissions are based upon the changes that have occurred in the energy system compared to 1990, which mainly relates to the fuel consumption and renewable energy share in the Danish energy system. Since there is a reduction of fossil fuels used in the energy system, the emitted CO_2 emissions are reduced compared to 1990. This is also the cases for the reference scenario 2020 and the basis scenario 2030, since the share of renewable energy is higher for the 70% scenario 2030 compared to the two other scenarios, the reduction in CO_2 emissions is inevitable. This is illustrated in Figure 7.6

Table 7.4: Mt CO_2 emissions within each sector throughout the different scenarios

Sector/Scenario	**2020**	**2030 Base**	**2030 70%**
heat sector	4.5	2.9	2.5
Electricity	4.6	0.36	0.24
Transport	15.1	14.9	7.3
Industry	8.3	7.9	4.2

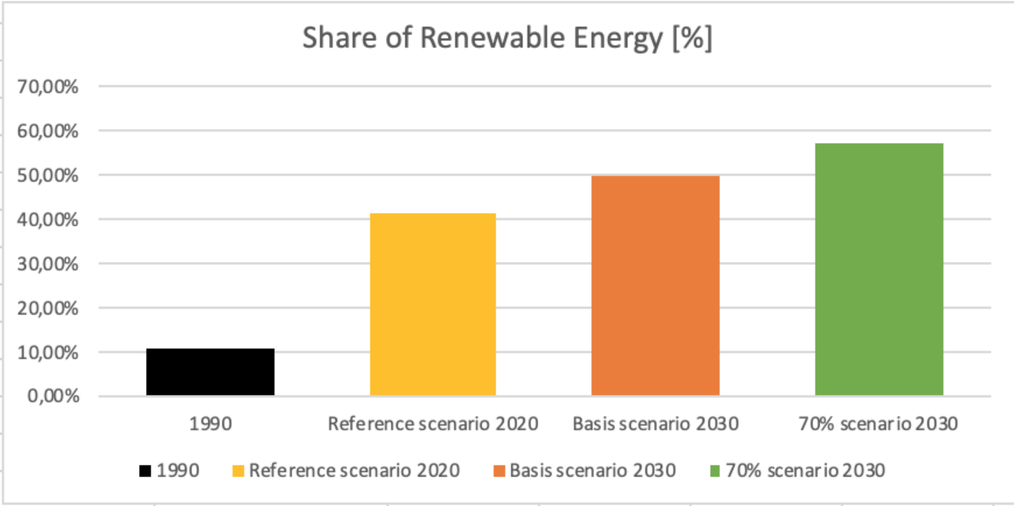

Figure 7.6: Graph over the renewable energy share for each scenario, The y axis illustrates the percentage of the renewable energy share

As illustrated in Figure 7.6 the share of renewable energy has increased for each scenario. Since 1990 where the renewable energy share was 10.80%, there has been an ambition to implement more renewable energy in the Danish energy system. This is reflected in the reference scenario 2020, where the renewable energy share is 41.20%. However, in order to achieve the 2030 goal, it is necessary to increase the amount of renewable energy in the Danish energy system. With the development towards 2030 with the current macro structures, the share of renewable energy is 49.90%. The increase between the reference scenario 2020 and the basis scenario 2030 is due to the fact an decrease of fossil fuels based technologies in the heat and electricity sector, and a conversion from conventional cars to electric cars. The difference between the basis 2030 scenario and the 70% scenario are that more fossil fuels technologies were reduced in order to fully optimise the usage of the renewable energy in the system. Furthermore, a higher share of convectional cars were converted to operate as electric cars or cars utilising bio fuels, which reduced the amount of oil used in the transport sector. This was previously considered a hindrance due to the macro structure of the current Danish energy system, it can be argued that changes in the transport sector is necessary, in order to achieve a 70% reduction in CO_2 emissions compared to 1990. Another factor in the increase of renewable energy share is the energy savings made in the industry sector. Due to the energy savings made in the industry sector, the usage of fossil fuels has decreased, which contributes to the renewable energy share of the system as a whole increasing.

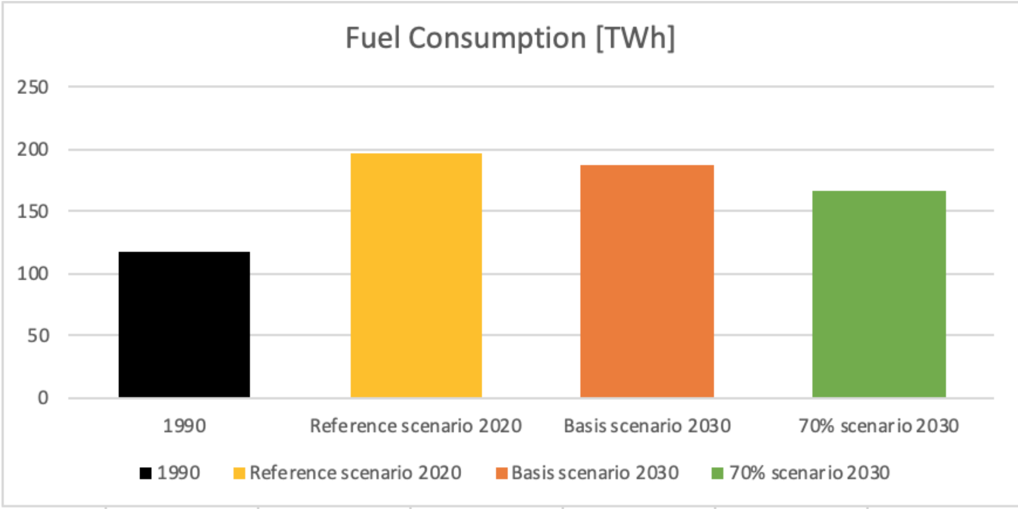

Figure 7.7: Graph over the fuel consumption for each scenario, The y axis illustrates the fuel consumption in TWh

The fuel consumption has increased from 1990 to 2020. There may be a correlation between an increased fuel consumption and the increased amount of citizens in Denmark. The population in Denmark went from 5.1M in 1990 to 5.8M in 2020 (Statistics Denmark 2018). However with newer technologies implemented in the Danish energy system compared to 1990, it can be assumed with a high degree of certainty that the technology utilised today is more efficient than the technologies used in 1990. Furthermore, there are implemented energy savings, which can be explained as optimisation of buildings and industries which contributes to a lower fuel consumption, but with the increased consumption due to the increased population it can be hard to observe based in Figure 7.7. In terms of the basis scenario 2030 and 70% scenario, the difference in fuel consumption is made by the removal of coal and oil in the electricity and heat sector regarding the CHP plants and PP. Therefore, there is a direct correlation with the lower fuel consumption and the increased share of renewable energy presented in Figure 7.6

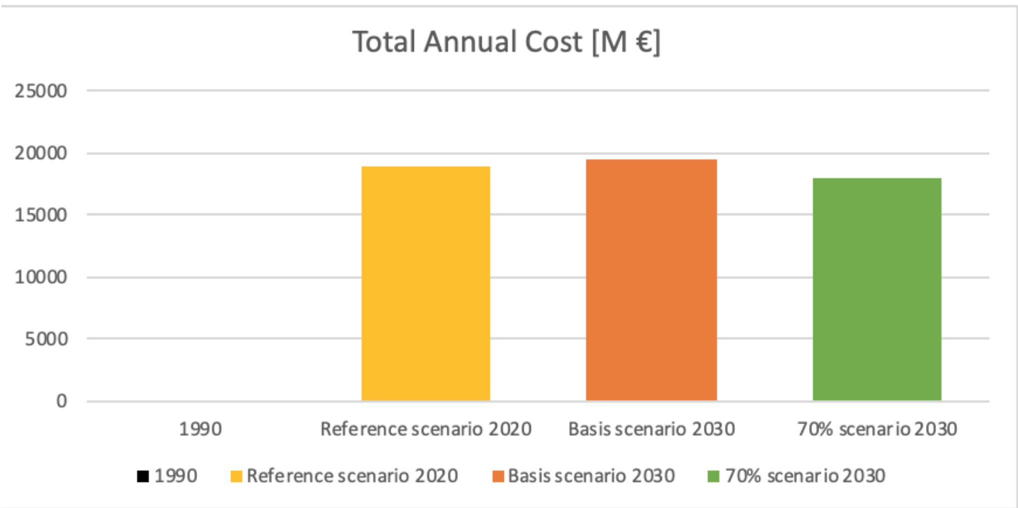

Figure 7.8: Graph over the total annual cost for each scenario, The y axis illustrates the total annual cost in millions €

As mentioned in Chapter 5 it was not possible to find the total annual cost for the 1990 reference. Therefore the 1990 reference is disregarded in this parameter. It can also be argued that the costs of the energy system in 1990 are irrelevant to consider due to the energy system and its costs being outdated. A comparison of costs may be more relevant when considering a change from the current system. The cost range between the three other scenarios is relatively similar. The small variation in cost is based upon the changes in the fuel distribution. However the cost for the basis scenario and 70% scenario can be somewhat misleading, due to the energy savings not included as a expense.

7.5 Conclusion

Based on the energy system analysis conducted in this thesis, it is illustrated that it is necessary to change the macro structure in order to achieve the 2030 goal as the development towards 2030 under the current macro structure is insufficient. This is illustrated in Figure 7.5, where the different scenarios compiled in the energy system analysis is compared to the 1990 levels. The most significant changes that are deemed needed in order to reach the 2030 goal can be argued to be a higher degree of sector coupling with utilisation of electricity in the different sectors, as well as, energy savings in places where fossil fuels can not be replaced.

Table 7.5: Overview of the different parameter, where 1990 is used as reference to the other scenarios

	1990	**Reference scenario 2020**	**Basis scenario 2030**	**70% scenario 2030**
CO2 emissions [Mt]	44,237	-29%	-44%	-70%
Share of Renewable Energy [%]	10,80%	30%	39,10%	46,50%
Fuel Consumption [TWh]	117,94	166%	158%	141%
Total Annual Cost [M €]	0	€ 18.815,00	€ 19.407,00	€ 18.000,00

Overall it can be observed in Table 7.5, that there is significant difference between the expected development under the current macro structure and the required development to meet the 2030 goal. The radical technological change that is occurring in the 70% scenario 2030 such as sector coupling further promotes that it is necessary, that in order to achieve the 2030 goal, a change in the organisation needs to occur. The organisation that is embedded in the current macro structure can be defined as multiple stakeholders, whom have an interest in affecting the Danish energy system. Therefore, it is necessary to examine the general perception of how the changes needs to occur, to create an holistic overview of how to change the macro structure in order to achieve the 2030 goal. This will be the primary objective in the following chapter.

8 Institutional Analysis of the Danish Energy System

Based upon the energy system analysis in Chapter 7, changes are required to the institutional context as well as the organisational structure in order to realise the 2030 goal. The purpose of the institutional analysis is therefore to analyse the current institutional context that the Danish energy system is embedded in and understand the organisational structure and thereby answering the sub questions described in Chapter 3: *"What are the institutional barriers associated with meeting the 2030 goals?"* and *"How can the identified barriers be addressed?"*. The methodological approach for the institutional analysis is highlighted in Chapter 4.

The magnitude of the sectors and the current issues in each sector could be part of a study on their own. However, to try create a holistic overview of the Danish energy system, it is necessary to examine issues regarding each sector, to get an understanding of the interplay between the legislation and the current approach used. Based on this, the institutional analysis will analyse the key barriers identified by the interviewees and the energy system analysis conducted in Chapter 7, related to the transition towards renewable energy in the different sectors.

The macro and micro structures functions as the framework for how to operate within the Danish energy system, where the the Three Pillars of Institutions investigates the organisational structure and which legislation affects how the Danish energy is operated. This referrers to the regulative pillar and the cultural-cognitive pillar. The purpose of the normative pillar in this thesis is to give an recommendation of changes both in terms of an organisational recommendation and a technical recommendation, that might need to occur in order to fulfill the Danish 2030 goal.

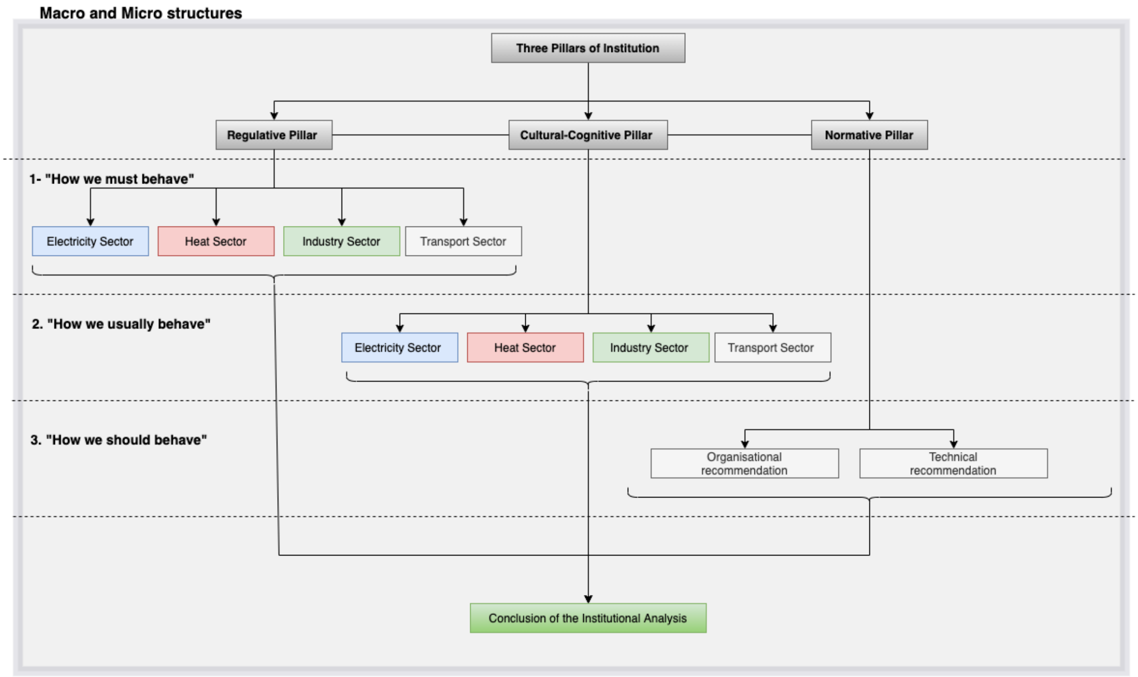

Figure 8.1: Illustration of the institutional analysis

Figure 8.1 gives an overview of the institutional analysis, and how it is going to be carried out in this thesis. The grey square illustrates the institutional context that Denmark is embedded in, due to the macro and micro structures identified in Chapter 6.1. The dotted lines illustrate the different pillars which function as the analytic tool. Each pillar will investigate each sector, with the regulative pillar as the main legislation in the specific sector, where the cultural-cognitive pillar consist of the behavior of the key stakeholders of the Danish energy system. This is scoped down to the following stakeholders:

- Aalborg University
- Danish Chamber of Commerce
- Danish Energy Agency
- Ministry of Transport
- Region of Northern Jutland
- Hjørring Municipality
- Holstebro Municipality
- Vestforsyning

This thesis tries to include stakeholders from the different level of planning, and further assemble stakeholders across the different sectors of the Danish energy system. Thus the interviews of these actors will function as the base for the institutional analysis. How the interviews are carried out can be found in Appendix A.1. The interviewees have a profound knowledge of different aspects of the Danish energy system and together create a holistic overview of the current institutional context and the organisational structure of the Danish energy system. This will contribute to identifying possible barriers in the Danish energy system, both in terms of the approaches used on the different level of planning and in terms of a specific sector. The normative pillar will function as a recommendation of what to change based on the analysis of the regulative and cultural-cognitive pillar.

8.1 Regulative Pillar

In Chapter 4, the regulative pillar is explained and describes *"how we must behave"*. The pillar consists of the visions and legislative aspect of the organisation. The organisations are defined as multiple stakeholders, and can be observed in Figure 4.3 in Chapter 4. Each sector will be examined, and it will be attempted to identify the main legislative barriers pointed out by the interviewees.

8.1.1 Heat

The main stakeholders regarding the heat sector in Denmark can be identified as the utility companies, who are providing heat solutions locally, and the municipalities who are regulating and envisions the changes in the sector locally. However, the guidelines from the Danish government is affecting how heat planning is compiled on a local and municipal level. In this case, the representative for the utility companies is Vestforsyning, which is a utility company based in Holstebro Municipality. The representatives for the municipalities are Hjørring Municipality and Holstebro Municipality.

Electrification

Currently the heat sector in Denmark is undergoing changes, due to the passing of the Energy Agreement in 2018. The Energy Agreement is a result of a desire to have a higher share of electrification in the heat sector in Denmark. This is supported by the statement made by the Danish District Heating Association:

"Electrification of Denmark is a crucial prerequisite for the green transition. It is clear that when we talk about a DH sector that covers two-thirds of the Danish heat demand, it is an important and major player in energy consumption." (Danish District Heating Association 2019*a*)

The electrification will mainly happen in the DH-sector. The DH-sector contributes to cover 2/3 of the total heat consumption in Denmark(Danish District Heating Association 2019*a*). Therefore, the impact in this DH-sector will heavily impact the overall structure of the Danish heat sector. This among other aspects created the incentive for the passing of the Energy Agreement. This have resulted in a lower electricity tax and electricity-to-heat tax with respectively 15% and 50% (Danish Ministry of Climate, Energy and Utilities 2018). Hence it would be favorable to implement technologies such as heat pumps in the Danish DH-sector. This is further enforced with the disappearance of the requirement of CHP. (Danish Ministry of Climate, Energy and Utilities 2018)

Market Structure and the Role of the Utility Company

Additionally the obligation to connect to the DH-system and stay connected to the DH-system disappeared. This has forced the utility companies to act proactively in order to gain customers in decentralised areas. It can be argued that the monopoly-oriented market in the heat sector is changing to a commercial market with open market conditions due to the disappearance of the obligation to connect to the DH-system and stay connected to the DH-system (Energy Commission 2016), this is supported by a statement made by Thomas Jensen from Hjørring Municipality:

"[...] They are in the process of removing the obligation to connect. In the old days, you could get everyone connected to DH in the new areas. We can no longer do that, you get a free choice and that means DH is going to be part of the open market with heat pumps and other technologies. Whether that is an advantage or disadvantage, I do not know, but at least it can make it harder.[...]"(A.2.3[23:00])

With the open market conditions and a transition to a commercial heat sector a barrier is created, due to the fact that the legislation regarding the utility companies are unchanged. This is affecting how the utility companies can operate, which is further explained in the following statement by Louise Carøe Foldberg from Vestforsyning:

"[...]You can also say by the individual heat pump, anyone can choose it, so if they have chosen it instead of us, you can say the commercial competitors has it a little easier. We have a CHP plant, this is a challenge in order to compete in the market since it is uncertain how we need to approach this. Furthermore we have to enter the market and get a project approval from the municipality in order to deliver heat in a given area, and with all that it might not be us who are getting the deal in the last place. It is not thought thoroughly and is certainly a barrier for us."(A.2.1[7:16])

In the statement by Louise Carøe Foldberg, it is highlighted that the utility companies are facing changes and barriers in order to implement their solutions in the heat sector in the future. The utility companies are a part of a commercial market, and there is no guarantee if they are going to deliver DH or other solutions in an area, if the area is not registered. The other competitors are subject to the market conditions. However, the utility companies are both subject to market conditions, but also the Heat Supply Act. Therefore, a utility company is at a disadvantage since they are subject to a law, that primarily does not apply to other competitors in the new commercial heat sector. Furthermore, it is not possible for utility companies to offer DH, if it is not socio-economical feasible cf. Heat Supply Act §1 (Danish District Heating Association 2019*b*), and with the uncertainty of the degree of connected units in area due to the disappearance of the obligation to connect to the DH-system and stay connected to the DH-system, it might be difficult to determine, when it is feasible to offer DH in an area.

Therefore it is necessary to conduct a sensitivity analysis of how low the degree of connected units can be, in order for the solutions not to be socio-economical feasible anymore. *"[...]They also want some sensitivity calculations in relation to what it looks like if there are certain numbers of connected units, so it is not 100%, which have been what we were used to[...]"* (A.2.1 [21:30]). Even though there is a socio-economical case to enter an area, it might be altered due to the fact that, it is now possible for consumers to leave the DH-system, which might affect the prices for the other consumers and alter the entire business case for the utility companies to enter an area. It could also affect the consumer economic case to have DH in the area, if the degree of connected units decreases the price for each connected units will increase and thereby make the solution less attractive in the area.

Non-profit Principle

The utility companies are subject to the non-profit principle cf. the Heat Supply Act §20 stk. 1 and 2 (Danish District Heating Association 2019*b*). The utility companies are only allowed to collect revenue corresponding to the costs necessary to be able to run the company. This might be another barrier since it may be interfering with the free market conditions displayed by the commercial market. Furthermore, it might act as an hindrance regarding the technological development of the heat sector in general. In the interview with Ulrich Bang from The Danish Chamber of Commerce, he explains the concept as following:

"[...]The DH area is composed of public companies or utility companies, which makes the infrastructure in Denmark, it is not exported, it does not require any of them to supply pipes, it is not a developer that makes DH. I do not see any reason why it could not be a public-private partnership in the DH-sector in Denmark as well. So I think this is especially interesting when you think about the future, where we have to have companies that have to go and make this a global business. This is a competency development that one does through the transition, and it can also be scaled to something that will be exported and create Danish jobs.[...]"(A.2.5[13:35])

Partnerships

Due to the non-profit principle, possible future partnerships between the public and private stakeholders can not be entered, due to the fact it can be unappealing and unprofitable for the private stakeholders. It is necessary to promote the technologies used in order to achieve the 2030 goal. However, it is also necessary to utilise the position Denmark has in relation to the transition to a more renewable energy system. Asger Øland from the Danish Energy Agency supports the statement made by Ulrich Bang:

"We are in many ways a leading country, where we discover different challenges, we can actually sell these solutions to other countries. We make a lot of money with solutions for green transition. 2 years ago, our export of green solutions was 90 billion."(A.2.7[31:45])

The statement made by Asger Øland from the Danish Energy Agency and Ulrich Bang from the Danish Chamber of Commerce indicates that the non-profit principle can act as a barrier in the future, and the concept of a public-private partnership should be explored in the heat sector as well.

Visions and Ambitions vs. Legislation

In the Danish Heat Supply Act §1 stk. 2 states the following: *"The heat supply shall be in accordance with the provisions of §1. The purpose of §1 is to promote the co-production of* *heat and electricity as much as possible."* Based upon the fact that the utility company is forced to co-produce heat and electricity hinders the utilisation of technologies, such as heat pumps in centralised areas. Therefore, it can be argued that there is a conflict between the current Heat Supply Act and the envision of a more electrified heat sector, which is illustrated through the Energy Agreement from 2018 with initiatives such as lowering the electricity-to-heat tax by 50% and the electricity tax by 15% although these initiatives are not implemented before 2025. The legislation is affecting how heat planning is conducted, it can be argued that the approach is based upon how the legislation is formulated even though the ambition regarding a higher electrification of the heat sector is highlighted by multiple interviewed stakeholder, the ambition is not currently matching what is possible to implement. This is highlighted by the following statement made by Louise Carøe Foldberg from Vestforsyning:

"In relation to heat, where new rules have been made where you can say it may not quite match what we can, and what it is possible based upon their new proposal." (A.2.1[0:52])

The goals and visions set by the Danish government can be difficult to be meet, since the laws do not align with the ambitions. This is deemed a barrier by Vestforsyning, since the desires and ambitions stated by the Danish government can not be fulfilled, due to legislation affecting how the utility company have to operate. (A.2.1[0:52])

Summary

Even though the Danish energy system is undergoing technological changes in order to achieve the 2030 goal, it is also currently undergoing institutional changes in order to change the current macro structure of the energy system to achieve the 2030 goal. This is illustrated through the different legislative barriers, where the ambition and visions made by the Danish government have not transcended through the legislation that determines how the utility companies operate, and with the transition to a commercial market, it might affect the technological transition as well, since the interplay between the two - technical and institutional, cannot be distinguished since they are affecting each other constantly. Therefore, the biggest barrier in the heat sector is that the visions and ambitions do not transcend through the legislation, and is currently affecting how heat planning is conducted in a Danish context.

8.1.2 Electricity

The electricity sector can be described as the main pillar of the future Danish energy system, since the other sector are going to be partially electrified. As described in Chapter 7, the changes in the electricity and heat sector is minor, due to the fact that a major part of the sectors are already consisting of renewable energy sources and have reduced the fossil fuels based technologies. This is further expressed by Ulrich Bang from The Danish Chamber of Commerce:

"[...]The electricity sector is an obvious example, there is no need to discuss what is the right and cheapest form of electricity production. It is some sun, and onshore and offshore

wind, more or less. It can be seen in the prices, we cannot discuss this since it is a global escalated industry[...]"(A.2.5[6:45])

However, the legislation differs from the two sectors and is thereby affecting how each sector is operated within. To understand this, it is necessary to examine why these changes were made. As mentioned in the previous section, the heat sector is slowly transitioning from a monopoly oriented sector to a commercial sector.

Monopoly Oriented Market to a Commercial Oriented Market

This is not the case for the electricity sector, which has been a commercial sector since the beginning of the 2000's, with the passing of the electricity reform from 1999. Prior to this, the sector was a monopoly oriented sector, where the production, distribution and trade with electricity was conducted by one company, who had monopoly due to the geographical location.

The non-profit principle was also a factor in the electricity sector. However, with EU's desire to joint electricity market across national borders, it was necessary to change the current way of supplying electricity in Denmark. One of the focal points from the electricity reform in 1999, was the separation between the monopoly oriented market and the commercial oriented market. This resulted in the production and trade of electricity to be part of the free competition, where the operation and system responsibility were subject to being part a of the monopoly. (Energy Commission 2016)

Electricity Supply Act

Currently, the electricity sector is subject to the Electricity Supply Act. The purpose of the act is expressed in §1:

"The purpose of the Act is to ensure that the country's electricity supply is organised and implemented in accordance with the security of electricity supply, socio economy, environment and consumer protection. Within these objectives, the law must ensure that consumers have access to cheap electricity and continue to influence consumers in the management of the electricity sector's values."(Danish Ministry of Climate, Energy and Utilities 2020)

Based upon §1 cf. the Electricity Supply Act, it is stated as a necessity to have access to cheap electricity, and influences how consumers value the electricity managed in the sector. However, it is affected by the planning methods utilised in order to produce electricity. This should be understood as the planning for the electricity sector is also affecting the outcome of which technologies that are being utilised in the energy system. An example could be that an onshore wind turbines is an adequate technology to use, since it is utilising wind, which is deemed as renewable energy source. However, since the land used to implement onshore wind turbines is affecting the surrounding area, it might have some socio-economic cost for other residents in the implementation areas.

Stakeholders' influence in the Electricity Sector

"[...]The two most important stakeholders are the politicians, as it is about making some important decisions. But then there are also the citizens, who can be both a hindrance but also a partner. You do not get around the citizens in terms of energy efficiency, but they are also the ones who can be the hindrance in relation to wind turbines and biogas plants. We need to have citizens on board."(A.2.3[37:25])

The citizens can influence the establishment of renewable energy based technologies, since projects have to be approved through an environmental assessment and undergo a public hearing phase cf. §35 of the Act on Environmental Assessment of Plans and Programs and of Specific Projects (Ministry of Environment and Food of Denmark 2016). In relation to this, citizens can significantly prolong or hinder the implementation of renewable energy based technologies.

Thomas Jensen from Hjørring Municipality describes the citizens as an important stakeholder in order to implement renewable technologies on land. He further describes the changes in the citizens' mentality, that has affected energy planning in general.

"[...]We all want to be green and contribute to it. But it shouldn't be in my backyard. There has been some attitude, but we are still experiencing great resistance in relation to wind turbines. It is the citizens who are the key to this."(A.2.3[38:20])

The NIMBY(Not In My Back Yard) principle can be applied, to be a hindrance, when implementing renewable energy sources on land. This has affected the electricity sector. With the passing of the Energy Agreement in 2018, it was determined that a reduction of land wind turbines was needed (Danish Ministry of Climate, Energy and Utilities 2018). It can be partially argued that the perception of the land wind turbines in the public had an effect of, how the planning for wind turbines were compiled. This can function as a barrier for the implementation of other technologies as well.

Summary

Therefore, it can be argued that the biggest barrier regarding the electricity sector is not the possibility to implement the most adequate technology, but how the public and citizens affect energy planning in Denmark. It can be argued, that technology wise that that the Danish electricity sector is a front runner and first mover, but the most adequate technologies can be hindered to be implemented due to the fact, it is not perceived well in the public eye.

8.1.3 Industry

The industry sector in the Danish energy system can be defined as being part of the consumers. They are consuming electricity or heat to produce their respective product, where the electricity and heat recovered from this sector can be defined as bi-product and utilised in the energy system again.Therefore, the industry sector is not fully subject to any direct law in order to produce heat or electricity. However, they are affected by elements in the Heat Supply Act and the Electricity Supply Act through excess production. (Danish District Heating Association 2019*b*, Danish Ministry of Climate, Energy and Utilities 2020) It can be somewhat misleading, that the industry sector is defined as one sector since it includes a wide range of businesses. Some can contribute to the Danish energy system through their excess production and some cannot.

Environment as a Business Opportunity

Economy is big part of the industry sector, since the main purpose of the stakeholders included in this sector are selling their products and earning a profit, it can be argued that with the current trends, that being sustainable and being environmentally aware are selling points, which might increase sales.

"[...] It is clear that there is a greater consciousness about the environment in Denmark. This was reflected in the election in 2019.[...]" (A.2.3 [38:20])

It can be argued, that the industry sector is converting to renewable energy sources and trying reducing their CO_2 emissions in order to align with national and international goals. However, their main focus is to sell a product, and with the increased awareness regarded the environment, it is necessary for them in order to survive, to commit to this transition, that is currently happening in the Danish energy system.

Utilisation of Excess Products

The sector is not directly regulated in the Danish energy system, since the main priority is not to produce heat or electricity, but to provide a product that sells. However, the sector is indirectly regulated in terms of excess electricity and heat through taxation, or through CO_2 quotas in order to help contribute to reduce the CO_2 emissions in the Danish energy system.

Currently most companies that utilise excess heat internally are currently paying less in taxation. However, this is not the case for companies, who are selling their excess heat to the DH-system. (Danish Energy Agency 2019) Due to structure of the taxation, it could possibly be more feasible for companies to not sell the heat to utility companies, since it can be seen as a burden. This may be a barrier to get companies to sell excess heat to the DH-system. This is supported by the following statement made by Lene Kirk Dalum from Holstebro Municipality:

"[...]We still have a challenge in relation to excess heat. We could utilise it in the DH-system even if there are some changes in the taxation. So that does not solve the problem for one of the largest company, we have here in the municipality, which has some excess heat that we really want to use." (A.2.2[8:20])

It can be argued that the clear cut guidelines, which are missing from the Danish government, contributes to innovative ideas in the industry sector, since they are not subject to direct laws like the heat and electricity sector. This is represented in Kalundborg, where local companies are placed strategically close to one another in order to utilise the waste products with each other, which contributes to lowering the expenses for the companies and reduces the waste produced by each company, since they can contribute to a cradle to cradle for their products. (A.2.7 A.2.5) This incentive was created by the companies themselves, and has benefited the local community, the involved companies, and the Danish energy system.

In order to get a shared vision with the stakeholders from the industry sector, it is necessary to collaborate with the industry. As mentioned in Section 8.1.1, it is possible to create products, which can contribute to reducing CO_2 emissions, which can sell on a global scale. This will be beneficial for the industry sector as a whole, but will also be beneficial for the Danish energy system since it can contribute to reduce the CO_2 emissions and create innovative solutions in the sector.

Summary

The current view of the industrial sector is affecting the contribution of excess energy from the sector. Currently, it is debatable whether the current taxation is the correct one to use. Lene Kirk Dalum from Holstebro Municipality states that even with changes it will still be difficult to change the sector regarding utilisation of excess energy from the sector (A.2.2 [8:20]). In addition, it can be debated whether the guidelines issued by the Danish government are not clear enough and thus can have a negative effect on how the industrial sector acts in the future. There is a risk that, with the current trends, the industrial sector and the Danish government will not become a joint partner, which could potentially have an impact on the design of the future energy system.

8.1.4 Transport

The transport sector is not subject to any direct legislation in relation to the Danish energy system. The transport sector is utilising fuels in order to create mobility, thereby the transport sector can be described as a consumer of the Danish energy system. (A.2.4 [27:07])

Inconsistency in Ambitions and Visions

Since there are multiple types of fuels in the transport sector today, it is difficult to describe the current regulative effect. In the past years, it has been a mission to promote vehicles who are emitting less CO_2 than fossil fuel based vehicles. However, it can be difficult to fulfill the ambitions and visions stated by the Danish government and the EU. This is supported by Per Skrumsager Hansen from the Ministry of Transport:

"The framework often comes from many different areas and when the framework conditions come from maybe three different ministries and the EU at the same time, there is a risk that it is not fully thought through[...]"(A.2.4[19:41]

This indicates that there is a barrier when guidelines are issued from different agencies. This indicates that there is not an adequate level of communication between the different ministries, which may affect the development of the transport sector. Another aspect, in relation to reducing the CO_2 emission in the transport sector is the tax structure which may contribute to a more renewable transport sector.

Taxation Structure

This has been reflected in the reduction of registration fee for electric cars, where in 2016, 2017, and 2018 there was a deduction of 10,000 DKK of the final tax. In 2019 and 2020, the rate was increased to 40,000 DKK, after which the deduction disappears. (Danish Tax Agency n.d)

It can be argued that this is a necessary approach in order to change the transport sector to at more renewable sector as it is dependant on the customers and the manufactures. The manufactures will produce fossil fueled cars, as long there is a market for it which is decided by the customers. However, this cycle can be affected by the Danish government and the taxation on cars. As mentioned before there are some incentives to buy electric cars and hybrid cars, but this is not deemed adequate enough as the sector consist of many types of vehicles, and thereby creates issues if it is feasible to invest in. This may also create an issue on a national scale due to the income from taxation being altered, and thereby it can create a barrier, since it might be considered lost revenue for the Danish government.

Summary

In general, it is the citizens and the government that must help contribute to the development in terms of personal vehicles. Additionally, there are some problems in relation to the heavy transport, which indicates that there is currently no definite solution for the conversion of heavy transport. Thus, it can be discussed whether the solution must be found in collaboration between different actors to find the right solution in relation to fuel in heavy transport, since the current knowledge is not adequate enough.

8.1.5 Summary of the Regulative Pillar

The Danish energy system has been influenced by the current first order macro structure. A general trend that can be deduced from the analysis of the regulative pillar is that the lack of communication between the different parts of the plan hierarchy has an influence on the design of the Danish energy system. This is reflected in the heating sector, where the utility company, Vestforsyning, says that it is not always easy to follow the ambitions of the Danish government, as there are too many changes in the ambitions and visions for the utilities to follow the development. This is also reflected in the transport sector, where Per Skrumsager Hansen from the Ministry of Transport states, the influence of other ministries and the EU has an impact on how the development of the transport sector will take place. If there is no consensus on how the development have to take place, it can help prevent future work in the sectors.

In general, it is debatable whether the organisational part of technology described in Chapter 4 is ready for the transition that is taking place towards 2030. It may well be that the ambitions and visions illustrates a willingness to meet the 2030 goal, but is it realistic to meet the goal if legislation does not fully support the development that is expected to take place? In addition, the broad guidelines from the Danish government contribute to more confusion than benefit, as finding out the adequate technologies towards 2030 can be problematic at a local level.

8.2 Cultural-cognitive Pillar

The cultural-cognitive pillar covers the underlying values and approaches that the energy sectors of Denmark are currently embedded in and describes *"how we usually behave"*. This section will highlight some of the roles of the different actors in the energy sectors as well as the underlying values that have resulted in these roles and how these may pose a barrier and affect the future transition.

In relation to the roles of the different actors, these can vary greatly depending on the specific actor and sector. Certain actors are prevalent in more than one sector, while some actors may have several roles in certain sectors. These roles are may also be subject to change over time as the underlying values regarding the energy sector may change in accordance with changes such as environmental awareness which favors renewable energy. Despite such changes, the values may still favor technologies already in use due to a reluctance to change as described in Section 4.2.

This reluctance to change can be caused by a number of factors, which can include unfamiliarity with new technologies, economic factors and path dependency as mentioned in Section 4.2. These factors can vary greatly depending on the specific actor as well as the specific context. The purpose of this section is to explore some of these factors in the different sectors.

8.2.1 Heat

In Denmark, the heat sector is divided in two general categories: individual heating and DH. DH is a relatively old technology in Denmark which has been used since the 1920's with a wider use in the 1970's with the utilisation of waste heat from electricity production. Since then, DH has been the most commonly used source for heat and currently supplies roughly two thirds of the households in Denmark. (SparEnergi 2019) As described in Section 8.1.1, the main stakeholders regarding the heat sector in Denmark are the utility companies, who are providing heat solutions locally, and the municipalities who are regulating and envisions the changes in the sector locally. Currently, the heat sector is undergoing both technical and organisational changes, since it is transitioning in terms of technologies used in the sector in order to convert to a more renewable sector. However, the stakeholders involved in the sector are also affected in terms of how to cope with the changes.

It can be argued that currently, there is only a public partnership with the utility companies and the municipalities even though the role of the municipality can be perceived two-fold, as an authoritative body and a sparring partner(A.2.2[1:50]). There is a chance that the public partnership can be affected by path dependency. This should be understood that if a partnership is formed by two influential stakeholders, as the case is in the heat sector, these stakeholders can heavily influence the technologies implemented in the sector. Thereby, they are creating a common course in terms of the development in the sector.

Changes in the Organisational Structure

However, the transition to a commercial heat sector due to the Energy Agreement is changing the organisational body of the heat sector, where the influence by the public partnership between the utility company and the municipality can be considered less crucial than before. Additionally, this can contribute to the clarification of different roles within the heat sector where the municipality to a higher degree is considered a valuable sparring partner for other actors than the utility companies.

The transition that the heat sector is currently undergoing may contribute to a public-private partnership, where the free market conditions are creating the framework for which technology to implement in the Danish energy system (A.2.5 [13:35]).

With a public-private partnership it would be unlikely that technologies will be subject to path dependency and could hinder conflicts regarding the reluctance to change from technologies which are supported by the positive feedback mechanism, since the market conditions to a higher degree will affect the decision on which technologies to implemented. Such a development may include a barrier where the most advantageous technology from a renewable energy perspective is not chosen due to market conditions not favoring these technologies.

A barrier for private stakeholders to enter the heat sector is the non-profit principle, which hinders private actors from generating revenue. The barrier regarding a public-private partnership is further emphasised by Ulrich Bang

"[...] One challenge is that with non-profit principle and all public ownership, public-private ownership must be about what the public stakeholders can do something and where the private stakeholders should be able to step in[...]"(A.2.5 [13:35])

Thereby, it can be argued that the incentives for the private stakeholders are not currently present. Based on the current values and legislation regarding the heat sector, a public-private partnership could be hindered by the non-profit principle.

Changes in the Technological Development

Based on the development of DH, it can be assumed that there may be a level of path dependency in relation to the current heating sector in Denmark, according to the amount of time the sector has been structured in these two categories as well as the positive feedback mechanisms related to this. Some of the positive feedback mechanism are ease of use, pricing, or lack of required maintenance. Due to the practicality of DH, this is typically used in areas with a higher density of households. This has caused the general train of thought that if you live in cities, you have access to DH and if you live in rural areas, you must have your own supply. This train of thought may cause a reluctance to change within these two categories as the path dependency of so many years as well as the positive feedback mechanisms may be too prevalent to consider change despite the change within the regulative pillar where the choice is no longer clear and forced.

Despite the reluctance to change, there still is a level of uncertainty due to the change within the regulative pillar. This uncertainty relates to the development of the future heat sector and how much must be developed as DH, as well as how much must be left to the free market as emphasised by Thomas Jensen from Hjørring Municipality:

"[...] In the old days, you could get everyone connected to DH in the new areas. We can no longer do that. You get a free choice and that means DH is going to be part of the open market with heat pumps and other technologies. Whether that is an advantage or disadvantage, I do not know, but at least it can make it harder.[...]"(A.2.3[23:00])

Summary

This means that the typical approach of having DH in urban areas may be subject to change towards a commercial sector, but on the other hand the reluctance to change based on various factors may result in DH continuing to be the dominant heating method. This may contribute to the future transition and implementation of certain technologies, as the amount of consumers are more or less known.

8.2.2 Electricity

In Denmark, the electricity sector is a single grid integrated with producers all over the country. As such, the electricity grid can be generalised to a greater extent than the heating sector with many actors and roles in the same system.

Stakeholders' Roles Within the Electricity Sector

The electricity sector in Denmark can be distinguished into consumers and producers. Additionally, there are some authoritative bodies which regulate the electricity sector such as the government through legislation and municipalities through project approvals and planning. The electricity sector has largely revolved around production of electricity on CHP plants based on fossil fuels which typically resulted in the production being based on the current demand. The operation of these is typically conducted by a utility company which is owned by the municipality or the municipality in collaboration with a private company (Danish Ministry of Climate, Energy and Utilities 2015). This has to some extent faced a change with the introduction of renewable energy in the shape of wind turbines and photovoltaic cells where the production is less controllable and low in costs.

This has changed the role of the utility companies slightly, to complementing the renewable technologies by producing energy when the production from renewable technologies is insufficient to meet the demand of consumers.

The production of the utility companies has also been subject to change over the last 50 years with the independence of oil in the 1970's followed by a more recent switch from fossil fuels to renewable energy sources which is still underway. It can be argued that with a break of the path dependency of fossil fuels have created uncertainties in terms of how to cope with the change in order to transition to a more renewable electricity sector. This is not a new phenomenon and can be argued to be a continuous problem, since the electricity sector will change continuously as well.

This transition from fossil fuels towards renewable energy sources can create a barrier in terms of the transition of the other sectors which may be relying heavily on electricity. The barrier here exists due to the production of renewable energy to a great extent being fluctuating due to weather conditions and thus may not always be available when it is needed across all sectors and thereby decrease the security of supply across the Danish energy system.

The role of the consumers of households has more or less remained the same in the sense that electricity is available whenever it is needed through various outlets. This has created some sense of path dependency where power is available whenever it is needed, and the consumption at given times is not considered. However, the consumers do also have a newer role which comes from their required involvement in implementing renewable technologies such as wind turbines. This involvement can be both a hindrance and an opportunity as emphasised by Thomas Jensen from Hjørring Municipality:

"[...]But then there are also the citizens, who can be both a stop block but also a partner. You do not get around the citizens in terms of energy efficiency, but they are also the ones who can be the stop in relation to wind turbines and biogas plants. We need to have citizens included.[...]"(A.2.3[37:25])

This illustrates the potential barrier surrounding the planning of renewable energy sources in Denmark.

Incoherence Between Visions and Practicality

A related issue to the planning of renewable energy is related to the lack of coherence between the different levels of planning. This is both across the different levels of planning, but also between certain sectors on the same level. An example of this is mentioned by Louise Carøe Foldberg from Vestforsyning:

"So you can say with electricity and electric cars, that sometimes the thoughts are a little faster than what we can practically do. It is both with electric cars and perhaps also in relation to, this with heat, where new rules have been made where you can say it may not

quite be in line with what we can do and what it looked like before they started with their new proposal."(A.2.1[0:52])

Another example is shown through the national visions presented by the Danish government where the Energy Agreement of 2018 set a limit on the capacities for wind turbines on land which is now up for reconsideration. (Danish Ministry of Climate, Energy and Utilities 2018, Øyen 2020) This shows that the visions and surrounding decision making is subject to change rapidly, which can affect the planning on shorter term.

Summary

Overall the electricity sector Denmark is not hindered by technological limitations as the renewable energy is already well integrated in the sector. There is a profound knowledge regarding the technologies, but it is instead facing barriers in terms of the organisational aspect of the sector as well as the technologies utilised in the other sectors of the energy system. This results in the the electricity sector to an extent influencing the development of the three other sectors of the energy system. On the other hand, the three remaining sectors may also influence the development of the electricity sector.

8.2.3 Industry

In Denmark, the industry sector has primarily been considered as a consumer within the energy system where energy was a commodity that was used in order to produce certain products within the given industry. The industry sector largely consists of private actors and businesses where decision making is primarily based on business economic parameters. This may cause some reluctance to change from an energy perspective as the economic parameters can create a barrier for certain technologies. However, a large part of this may be due to the tax structure surrounding certain energy technologies such as utilisation of excess heat. This is also pointed out during the interview with Lene Kirk Dalum from Holstebro Municipality as mentioned in Section 8.1.3, which results in these initiatives being infeasible.

The industry sector in Denmark has more recently taken steps towards becoming a producer in the energy system in addition to being a consumer of the energy system with certain industries supplying the DH system with excess heat rather than wasting it. This collaboration opened the door for similar collaborations between utility companies and private businesses where usage of other waste products can be utilised in production of energy. Examples of this includes utilisation of agricultural waste as pointed out by Asger Øland from the Danish Energy Agency:

"[...] We can talk about agriculture. I know you are not talking about it, but it's actually a really important sector. Not because they have emissions. It is handled in another resort, but we are actually interested in the cow feces and we are also very interested in all those straws and other things that just sits right on a field and gasifies[...]"(A.2.7[7:17])

This underlines the fact that the industry sector is undergoing a change of role where it is not only a consumer in the energy system but also a supplier. The role of consumer is still a major aspect of the industry that is looking to connect to the energy system. This is especially present with the recent announcement of several data centers of massive industries being placed in Denmark, which will result in an increased consumption from the industry as a whole (Energistyrelsen 2019).

Summary

The industry sector is primarily focused around economic factors where delivering a specific product must be profitable in order for the production to take place. As this sector is environmentally regulated through the use of CO_2 quotas, this does not create an incentive to reduce emissions as long as the costs of producing outweighs the costs of CO_2 quotas. This may pose as a barrier from an energy perspective and in relation to meeting the goals. With the low incentives to actually perform changes in the section, it can be argued that the natural development in the sector is adequate enough in order to achieve the 2030 goal.

8.2.4 Transport

The transport sector in Denmark which is similar to the industry sector, is primarily seen as a consumer from an energy perspective, as its primary purpose is to move goods or people from one point to another. The transport sector consists of different vehicles such as ships, planes, cars, and trucks with cars representing the vast majority as shown in Figure 6.3 on page 34. The transport sector primarily consists of private actors that freely select their vehicles of choice, which is indirectly affected by the legislative body, The Danish Ministry of Transport. Another characteristic of the transport sector is that this sector is dominated by the use of fossil fuels with recent changes towards renewable fuels such as gas or electricity.

As energy is not the primary objective of the transport sector, other factors also play a large role when planning for the sector as mentioned by Per Skrumsager Hansen from The Danish Ministry of Transport:

"We are users of the energy system and we have the objectives mentioned here which are called low price, high availability and security of supply.[...]"(A.2.4[27:07])

The primary concern when planning for the transport sector is as Per Skrumsager Hansen mentioned: Price, availability and security of supply. Based on this, these three parameters must also be considered when planning for the energy usage within the transport sector and that alternatives in the transport sector must be sufficient within all three parameters.

In order to secure availability and security of supply, surrounding infrastructure must also be present. This is further emphasised by Per Skrumsager Hansen from The Danish Ministry of Transport using an example with electric cars:

"It is enabling us to get electric cars, because if there is no charging infrastructure, then consumers will not demand electric cars."(A.2.4[19:41])

This illustrates that the demand of certain transport types is directly tied to the surrounding factors. This may also include prices, which is exemplified through limited supply of biofuels by Per Skrumsager Hansen from The Danish Ministry of Transport:

"Then you can say that if there are supply constraints, then you can imagine that prices are going to go up so it can be expensive, and then again if it gets expensive then it affects the mobility and you can say that it is crucial for us that we have a high mobility, so if it becomes too expensive to run these biofuels, then it is a problem [...]"(A.2.4[6:03])

When planning for the transport sector, it is important to consider the surrounding factors such as infrastructure and price related to the specific type of transport as the choice of transport is free. Due to this, it is vital that there are sufficient incentives related to the desired development within the transport sector. This was also seen when the registration fee of electric vehicles was increased in 2016 where the sale of electric cars plummeted (Valeur 2017).

Technological Limitations

As illustrated through the different examples, the transport sector is facing a choice regarding which technology the transport sector will make use of through the transition towards renewable energy. This is an issue that is already clear now, as these technologies are yet to be utilised on a scale similar to that of oil. There is in this case reluctance to change as the path dependency of oil is too prevalent, resulting in alternative technologies being insufficient as a replacement for oil. This is also mentioned throughout the interview with Ulrich Bang from The Danish Chamber of Commerce:

"If you look at the transport sector and what fuel to use in relation to heavy transport, ships and trucks, we have thousands of scientists who come with a test tube and say here we have the fuel of the future, but no one can produce 50 tons a day. So you only have the research idea, but you have not scaled and commercially made the solution.[...]"(A.2.5[6:45])

This points towards the notion that the transport sector is facing a crossroads in regards to the choice of technology that will be primary driver behind the ongoing transition. This is further emphasised by Lene Kirk Dalum from Holstebro Municipality:

"[...]But for heavy transport, air transport and ferry transport we also lack some knowledge as to how to change the smartest and which fuel to be used." (A.2.2[8:20])

"[...]The main problem with electric trucks is that batteries with today's technology will become so large that it cannot carry nearly as much load, so that they will run around with a lot of heavy batteries and not as much goods as they do now, so it is not really realistic"(A.2.4[6:03])

The transition in the transport sector is complex, due to the different technologies in the transportation sector. This can be described through the definition of technology presented in Chapter 4, where the knowledge in which fuel to utilise in the future in large scale is not currently present.

Summary

It is clear that certain barriers are present in the transition of the transport sector. In general, the transition of the transport sector faces a barrier due to additional factors that must be sustained through the transition. This covers factors such as prices, security of supply and sufficient infrastructure. Additionally, there is a level of uncertainty regarding specific technologies that will be used throughout the transition as this is yet to be decided due to a lack of knowledge. Furthermore, there are a numbers of stakeholders that needs to participate in order for the transition in the transport sector to be aligning with the Danish goals.

8.2.5 Summary of the Cultural-Cognitive Pillar

Through the analysis of the cultural-cognitive pillar, it is evident that the different sectors of the Danish energy system are vastly different in both how far the specific sector is in relation to the transition, as well as the different actors involved in the different sectors. The sectors of the energy system do have one characteristic in common which is that they all have undergone some form of development over time. This has in some cases created path dependency when the development has favored a certain technology or approach while the development in other cases has shaped and changed the different roles within certain sectors over time. An example of this is seen with the industry sector where certain parts of the sector has taken on the role of supplier within the energy system as opposed to merely being a consumer.

A general notion through the Danish energy system is that there are a wide selection of possibilities and choices when developing the energy system. The choices do however depend on a number of factors such as prices or certain goals and priorities of the given municipality. This can also result in none being prioritised over the others which can hinder the development as seen in the transport sector.

8.3 Normative Pillar

The normative pillar describes *"how we must behave"*, and this thesis will function as a recommendation in how to cope with changes towards 2030 and afterwards. The recommendation is divided into two: The organisational and the technological.The recommendation of the institutional context is based on the analysis of the regulative and cultural-cognitive pillar conducted in this Chapter .The recommendation of technological development is based on the energy system analysis conducted in Chapter 7.

8.3.1 Organisational recommendation

There is a general consensus among the interviewees, that there is going to be changes in the Danish energy system, in order to be able to handle the barriers that exist and will arise with the transition of the Danish energy system. Therefore, it is necessary to maintain a holistic overview of the system. As it can be discussed currently, that initial measures have been taken to increase sector coupling in the Danish energy system. With the increased amount of sector coupling in Danish energy system, it can be argued that Denmark has to collaborate with the neighboring countries in order to evolve the Danish energy system further. This will eventually affect, how energy planning is conducted in Denmark, since the technological and organisational factors are affecting the holistic view of the Danish energy system.

However, it is necessary to investigate which technological changes that need to occur in the Danish energy system, since the technological changes are affecting the organisational set up in Denmark. As it is necessary to obtain a greater knowledge in the various sectors, it is therefore essential to have more actors involved in order to create a holistic view and highlight the different interests in the sectors. This may contribute to the absence of a reluctance to change in relation to the technologies, which are most often reflected in the organisational.

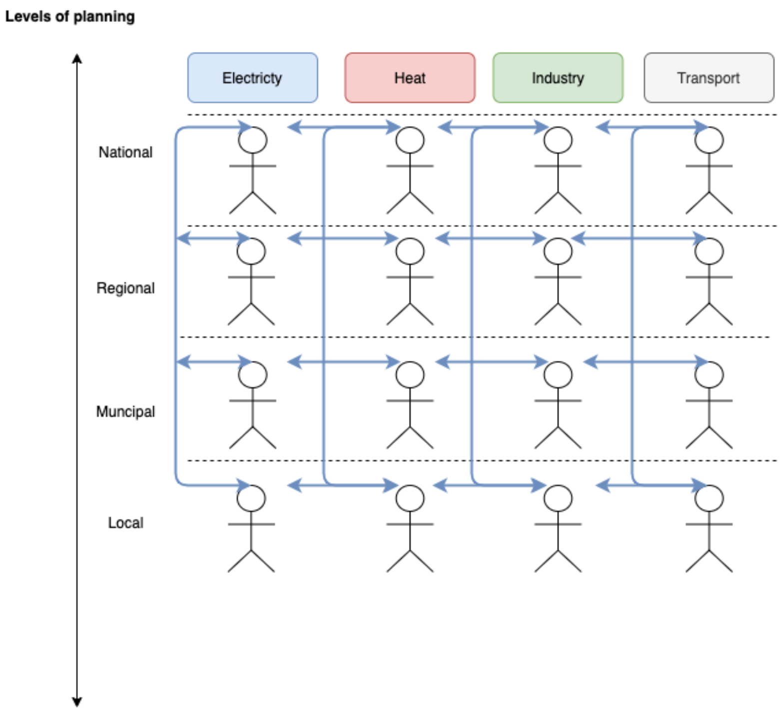

Figure 8.2: Illustration of an organisational structure of the Danish energy system based upon the disappearance of the sector division.

Figure 8.2 illustrates how the interaction between the different stakeholders in the Danish energy system should be perceived. It is necessary to have an increased interaction between the levels of planning and the different sectors, this is illustrated with the arrows, this contribute to transform the Danish energy system to a more networking oriented system, and less sector divided. It is necessary to establish a connection between the different stakeholders in the respective sector. A new aspect that needs to occur or happen in the Danish energy system is the collaboration across sectors, since it can be argued that the best technology in one sector is not necessarily the best technology to utilise in general in the Danish energy system, since the outcome of the technology should be evaluated based upon the effects of the technology across the sectors and not the effect of a technology in a single sector. Thereby when implementing technologies, a holistic approach is needed due to the fact a technology should be able to encourage an increased form of sector coupling, and a result of that should be to disregard the current sector division, in the transitioning to a more renewable energy system. This can be expressed by increased networking between the involved stakeholders, since it is necessary to change the organisational structure to align with the technological changes, so the ambitions and visions from the different stakeholders are aligning with one another and thereby creating a common course.

This contributes to a more complex structure of the Danish energy system, where excess products are able to be utilised in another context, and thereby promoting other activities such as circular economy, which has been highlighted by Asger Øland from The Danish Energy Agency:

"[...]Many of the solutions to the challenges we see are precisely taking something from one sector and putting it into another. That is, a form of circular economy where you utilise some excess products for one sector and put them into another sector.[...]"(A.2.7[16:40])

Furthermore, Asger Øland also states the following: *"In order for this to be possible, legislation must also make it possible and very often what has been seen is that the legislation is made through sector division.[...]"*(A.2.7[15:40])

With the disappearance of the sector division both in terms of the general perception of the Danish energy system, but also in the Danish legislation, it is possible to break down barriers in the regulative pillar, since it is possible to align the visions from the Danish government with the practise of different stakeholders in the Danish energy system.

Another aspect that can be discussed is that the Danish energy system is not only about being able to fulfill a demand anymore, but it is a complex system and an essential factor towards reducing CO_2 emissions in Denmark, but has also become a bigger part of the free market in Denmark. There is an opportunity to sell our knowledge and technology in order to promote the transition in Denmark or elsewhere in the world. However, it may be assumed that technological development must be directly beneficial to the Danish energy system, but there may be a chance that this is not possible, due to the size of Denmark and the current funds of the Danish government.

This is reflected in the transport sector, where Ulrich Bang is expressing the limitation regarding gaining knowledge in the transport sector.

"[...]A big gain for the German car industry, which produces many of the cars. There is not a particularly big effect in Denmark, it is an area where we say here, we invest in a foreign technology that becomes cheaper in the long term and it is not us who directly contribute to the learning curve, as the Danish car market is so small compared to the other markets "[...]"(A.2.5,[21:40])

Due to the size of funds, it might be difficult to structure the taxation of cars to align with the ambition of the Danish society in order to promote a more renewable transportation sector. Ulrich Bang emphasises this by comparing the transition to other countries, such as Norway and Germany. Norway has currently invested a lot in this transition of the transport sector regarding personal vehicles. This has been obtained through a change in the taxation. However they are able to do this through their oil funds, if Denmark should participate in this transition on the same level as Norway, it could affect the current welfare society in Denmark. The motivation for the Germans might be, that they are currently controlling the learning curve, which is expressed by Ulrich Bang. This creates incentives for the German government to further promote the transition in the transport sector in order to become a part of the German business model regarding car sales, since the market can be exploited in the rest of the world.(A.2.5,[21:40])

It can be argued, that this will result in the cumulative effects of the implementation of a technology in the Danish energy system, since it should be reviewed in socio-economical context. Due to the fact, that it is not possible to obtain control of the learning curve in every sector, it might be necessary to exploit the sector where it is possible, and this can be done through a public-private partnership. However, in the current system it can be argued that the public sets the playing field for the private players, in the future it is necessary that the public acts as a definite sparring partner. Elements of this can already be seen today where the Danish Energy Agency must be technology neutral. However, due to the structure of the sectors, there has been a tendency to favor a technology and thus create a form of path dependency.

The broad guidelines set out by the Danish government and the various ministries can contribute to function as a barrier to whether the transition and the specific practice are consistent. Both Vestforsyning and the municipalities surveyed, Hjørring and Holstebro Municipality call for specific guidelines, but this can be problematic, as emphasised by Asger Øland:

"Municipal participation is central to the sectorial laws, we write about and this is how it is. A good example is the revenue framework regulation where you have to be aware of not to tighten the regulations, because if something can be done that is beneficial to society, then we will not stop it, so you have to take care of it, but how to do it there are great discussions about in the community. It is also there if something can be done, then it must be done but there is also a consideration.[...]"(A.2.7[17:50])

The bottom line is that, it is not possible to directly go in and dictate what to do, because it will always depend on the geographical location, but also on the political conditions, which should be understood as the politicians are elected by people and what will be prioritised in the various municipalities.

In general, it is necessary to innovate the Danish energy system, and thereby change the perception of the energy system. With the new initiatives being proposed in the normative pillar, it is necessary to have a new approach to energy planning. It can be debated that the energy system has become so complex that it is not possible for the sector to be divided.

It is not possible to have a modern energy system with modern or new technologies based on old, outdated organisational structures. This is reflected in the gradual transitions that have occurred in each sector, where each and every measure has contributed to an increased form of sector coupling. This means that the following actions are required in order to able to create a sufficient organisational structure in order to achieve the 2030 goal:

- Networking across different energy sectors and different levels of planning, but also on a international level, so it is possible to be part of the learning curve regarding new technologies.
- Willingness to be part of a networking community from authoritative body.
- Encourage public-private partnerships through incentives for both parties.
- Redefining the balance between mandatory actions and actions that are up to interpretation.
- Redefining the general approach to energy planning in order to achieve the 2030 goal.

Therefore, it can be concluded that the organisational aspect of energy planning in a Danish context needs to change, but based upon this analysis, the initial measures have already been applied. This will lead to changes in the macro structures, which will contribute to define the new Danish energy system.

8.3.2 Technological recommendation

Based on the energy system analysis in Chapter 7, it is clear that new technologies must be integrated into the Danish energy system towards 2030 in order to fulfil the goal. However, as shown through the energy system analysis, these new technologies will not be implemented under the current institutional context. This means that changes to the institutional context including the organisational structure are required in order to ensure that these technologies can be implemented in the Danish energy system and that the goal will be met by 2030. Additionally, certain technologies are limited through other means such as the maturity of the technology as shown throughout the regulative and cultural-cognitive pillar. This section will describe these aspects of the development towards the 2030 goal.

As shown through the energy system analysis, the heat and electricity sector are already advanced in terms of the renewable transition, which is emphasised by Ulrich Bang from The Danish Chamber of Commerce:

"Where we are the farthest today are probably the electricity and heat sectors, I do not think that the change will be big because we are already really far. There are the last drops and last tear of coal that need to be phased out, more or less."(A.2.5[29:15])

On the other hand, the industry and transport sectors are where the development towards 2030 is lacking behind as shown in the energy system analysis. This is where there are many potential technical solutions that can contribute to the transition of the sectors which can contribute to achieving the goal. Examples of these technical solutions cover sector coupling with increased electrification and waste utilisation with production of bio fuels.

That does however not entail that the electric and heat sectors are without barriers within the development towards 2030. As all the sectors may face some sort of electrification, this may create a barrier as this results in heavy dependency of electricity which faces changes to the production where a large part of the electricity has a fluctuating production. This may result in dependency of certain fuels and technologies and perhaps production from neighboring countries to ensure security of supply. A solution to this technological barrier can be overcome through the use of energy storage such as batteries or Power-2-X as pointed out by Asger Øland from the Danish Energy Agency:

"[...]But for that we need a better storage option when it comes to electricity, we need some better batteries. There we see some technology challenges, we see many technologies that can emerge. One of them is Power-2-X, but another thing is also lithium batteries, which stands for improvement hopefully."(A.2.7[23:10])

Additionally, these types of storage where a synthetic fuel is produced can also open up for potential contributions within the transport and industry sector where these can be used similarly to how fossil fuels have been used previously. As mentioned in Section 8.2.4, there is a large uncertainty regarding which technology will be the preferred one going forward as these are yet to be tested on a large enough scale to supply an entire energy system. This means that there is also a barrier in relation to the technology itself where further research is required in order to be able to fully apply these technologies to the energy system. In order to break down this barrier, it is necessary to get a profound knowledge in terms of evolving the Danish energy system. This can be done through subsidies to projects that contributes to evolving the current technological change.

Despite the technologies being partially present, there does not currently exist any regulative means of ensuring this development as pointed out by Søren Djørup from Aalborg University:

"The technical barrier is not the greatest. Of course, there are some pretty obscure things compared to the 100% renewable target. Eg. with electrofuels, etc. There are some technologies that haven't quite been tested yet. At least a large part of the cake is probably more resistance in regulation and resistance maybe among certain actors who want a different development, etc."(A.2.6[12:45])

This points to the fact that there is a political lack when it comes to the transition towards 2030. It is therefore crucial that there is a change within the political aspects of the energy system that can ensure the required development towards 2030. An example of such a change is illustrated by Thomas Jensen from Hjørring Municipality:

"We would like it to become compulsory for municipalities to make a strategic energy plan, and there are also some common guidelines for how to do it. Right now the municipalities choose themselves[...]"(A.2.3[17:30])

A change to the regulation around strategic energy planning may result in each municipality exploring the energy system of the given municipality further than is currently being done and find potentials within each sector where new technologies can be implemented, which can contribute to the transition towards 2030.

However, other factors also play an important role within the transport and industry sector. One of the main concerns is the cost, where some actors may value costs significantly over environmental impact. Examples of this could be consumers whose primary concern is to receive cheap electricity as mentioned by Asger Øland from the Danish Energy Agency:

"[...]But there are also some citizens who just want cheap electricity. So these are simply the considerations one has to take and try and find a solution to."(A.2.7[20:58])

It is therefore important to consider how to ensure favorable conditions in Denmark throughout the transition to prevent industries moving their production out of the country. In relation to this, it is therefore important to evaluate the regulation around taxes and subsidies to ensure the desired choices are chosen.

Much alike the organisational recommendation show, it is not possible to transition towards a more renewable energy system and reach the goal by 2030 under the current institutional context. This is apparent as the institutional context currently does not favor the implementation of certain technologies. Additionally, some of the technologies are yet to be utilised on a national scale. This indicates that the institutional context must undergo changes which favors the development, research and implementation of technologies which can contribute to achieving the goal in 2030. The technical recommendations can be summarised as the following:

- Increased amount of sector coupling.
- Redefine the tax structure to encourage the use of renewable technologies and sector coupling.
- Encourage the ability to be a first-mover since it can business opportunities for Denmark.
- Encourage the opportunity to establish or contribute to the learning curve in terms of new and established technologies in the future Danish energy system.
- Be aware of potential dependencies such as high dependency on electricity or production from neighboring countries

Based on this, it can be concluded that institutional changes are necessary in order to create a favorable framework in regards to the implementation of technologies that can contribute to meeting the 2030 goal.

8.4 Conclusion

Based on the energy system analysis and the institutional analysis, it can be concluded that a change of scenery is necessary in order to fulfill the 2030 goal.

Both the energy system analysis and the institutional analysis emphasises the pivotal role of the organisational structure in terms of legislation and visions and how it must transcend through the different levels of planning and thereby secure that development is aligning with visions and goals. It is indicated through both analyses, that the electricity sector is going to be pivotal part of the future Danish energy system and the development in the electricity sector is such a huge contributor in order to implement an increased amount of sector coupling between the different sectors. This will determine if it is possible to achieve the 2030 goal.

Despite these general indications within the energy system and its transition towards 2030, there are still aspects of the transition which may play varying roles within the transition, which gives incentive to discuss key aspects of the required transition. This will be assessed in the following discussion chapter.

9 Discussion

As the scope of the project is relatively large, many aspects are relevant to involve and consider. Not all of these are considered through the analyses of the thesis. Additionally, there are aspects related to the analyses that include some level of uncertainty. The purpose of this chapter is to discuss some of these aspects and how these uncertainties may affect the energy planning towards 2030.

9.1 Denmark as part of an International Energy System

This thesis primarily revolves around the Danish energy system and the institutional context surrounding it. In this regard, the Danish energy system is typically considered as an isolated case and the choices made throughout the analyses are not influenced by external factors. It can, however, be argued that this is not the case as the Danish energy system is connected with and largely affected by other sectors in the country such as agriculture, as well as, the energy systems of neighboring countries. Consequently, there may be an uncertainty regarding the influence of the energy sector in Denmark meeting a 70% CO_2 reduction, as the other sectors may not meet a similar goal, resulting in the nation as a whole not meeting the goal. On the other hand, the other sectors may contribute to a much larger CO_2 reduction, which can minimise the necessity of reducing emissions from the energy sector on short term.

With regard to the surrounding system nationally, the energy systems of neighboring countries may also play a significant role in the development of the Danish energy system. Examples of this can already be seen as energy in the shape of electricity being traded across borders and as seen on Figure 6.2 on page 32, the electricity production was lower than the consumption in 2019, which means that Denmark to some extent is dependent on the production of neighboring countries. This implies that the consumed electricity in Denmark may be based on usage of fossil fuels in these neighboring countries and the emissions from this consumption may not be a part of Danish CO_2 calculations.

This raises a question of whether or not it is appropriate to measure a single country's CO_2 emission as this may not truly reflect the emissions caused by the consumption of a given country. Additionally, a solution to reducing a single country's emission may be to move the production that emits CO_2 out of the country meaning that the CO_2 emissions of the specific country will be reduced while it stays the same in a global perspective. On the other hand, it may give an idea of which countries contribute towards the global issue and which countries do not, which can contribute to an overall global emission reduction as it illustrates where the highest emissions are present and allows for a focused effort in reducing this.

9.2 The Economical Aspect of the Transition

Based upon the energy system analysis conducted in Chapter 7, the industry is facing major changes in order to achieve the 2030 goal. A major factor in order to change the industry is to give incentives for the industry to change their current approach and utilise renewable energy sources in their production. This is further emphasised in the Institutional Analysis conducted in Chapter 8, as mentioned in the Institutional Analysis a full commitment from the industry sector might result in higher profitability and increased sales.

The current approach in the Danish energy system consists of regulating the sector through taxation and thereby creating incentives for the industry sector to change their production to a more renewable production. It can be argued that the industry sector will eventually adapt to the renewable transition. However, it can be discussed that the sector will meet the timeline set by the Danish government. It is necessary to convert a sector, such as the industry sector, so that a direct link between the environment and the economic aspect can be drawn, since the changes should be profitable or at least not affect the industry negatively. If not, this can contribute to part of the industry sector being outsourced to other nations, which will result in lost jobs in Denmark, and this is not beneficial for the Danish economy in general. If big companies are choosing to relocate in order to stay competitive in their respective markets, it will be harder to attract new industries to Denmark and thereby it will affect the Danish economy as a whole.

As mentioned, one of the solutions to convert the industry sector, is to create incentives to establish a public-private partnership. This is also aligning with the changes in the Danish energy system, where an increased amount of sector coupling is happening, and it is necessary to think as a whole in terms of determining the right solutions in the Danish energy system. However, an issue with the public-private partnership is: Who is going to pay for the transition? It can be argued that both parties are benefiting from the transition. The public is benefiting through a more renewable energy system, which is aligning with the goals and visions. However, the private stakeholders are benefiting by gaining knowledge and possibly a technology, which can be implemented across the world and thereby generate profit for them.

In the ideal situation, the expenses will be shared equally, but this will probably not be the case, as it can be discussed that the stakeholder, who possesses the most knowledge or whom it is less beneficial for will allow the other stakeholder to pay more since they have some form of leverage. This is a part of the consequences of having changed the Danish energy system to a commercial oriented market as the free market forces enter into planning for the Danish energy system. However, it will always be a possibility for the private stakeholders to withdraw from the partnership, if they determine that it is not beneficial for them to commit to the public-private partnership, where the public stakeholders have to commit to the transition.

Furthermore, it can be discussed that the citizens are contributing to form parts of the future Danish energy system, since they are a huge part of the consuming sectors, transport and industry. In the industry sector, it can be argued that if the demand is present for a given product, the supply will be met. However, if the demand is not met due to the increased awareness of the environmental aspects of products, it might result in lower demand and thereby decrease the supply. Therefore, it is possible for the consumers to actually control which products will be sold on the market and can possibly influence the outcome of the fuels used in the industry sector as a result of increased environmental awareness from the public.

In the transport sector, the citizens can be argued to have a bigger impact in the changes, since they are the ones who are determining which vehicle they are using. It is possible for the Danish government to indirectly affect the transition, e.g. with changes in the taxation structure to create incentives to invest in electricity vehicles or other vehicles that are preferable to the transition, and try to improve the infrastructure of charging stations.

Based upon these arguments, there is a high uncertainty in how the economical aspects will affect the transition. It is necessary to assess the impact of the economical aspect, since it is such a huge factor which will definitely affect the outcome of the Danish energy system both in terms of how it is designed, but also the interaction between the stakeholders.

9.3 Scenarios for the Future Energy System

The energy system analysis as well as the institutional analysis are based on possible developments of the energy system, which can be considered as specific scenarios for the future. As these scenarios describe a possible development within the energy system, there is bound to be a level of uncertainty related to these. The uncertainty related to the scenarios stems from a large number of varying factors that may affect the development of the energy system, such as technological development, political agenda etc. Additionally, the scenarios are built upon either an expected development or a desired development. Both the expected development and the desired development may be subject to change over time due to changes in the various factors. In relation to this, it can in relation to this be argued that this uncertainty can affect energy planning as this must take future development into account.

Based on this, a discussion of how energy planning is carried out is relevant. On one hand, energy planning may be conducted based on the current expected development and base a future energy system of this with continual improvements and adaptations according to the current data, scenarios and expected development. This dynamic approach does however require a level of constant planning and revision, which can be resource-intensive. On the other hand, energy planning may be conducted with the intention of creating the most favorable energy system from an energy and environmental perspective. This does, however, also require intense effort and a political willpower to steer the development towards the desired energy system, as well as, overcoming the influence of the varying factors.

9.4 The Public's Perception of Energy Planning

It can be argued that the perception of energy planning and how it is conducted is necessary to be expressed in the public eye, since it can quickly turn into an expert dominated debate regarding which technologies to implement. Therefore, the news outlets that are covering the public debate have to be able to inform the citizens correctly. However, if this is not done properly, this will eventually alter the public's perception of the technologies. This could result in a barrier in terms of implementing new solutions in the Danish energy system, which is assessed in Section 8.1.2 in Chapter 8.

This leads to the discussion of whether citizens should be more involved in the debate regarding energy planning of the future, as it can be argued that they are a large part of the transformation that is taking place and will take place in the future. As mentioned earlier, the debate on the Danish energy system is usually expert dominated, given that the debate often takes place between actors who have sufficient knowledge in the field of energy planning in the Danish context. The Danish media therefore has an extremely important role in relation to the fact that citizens can become an active party in the debate when it comes to energy planning in Denmark. The media has to contribute to legitimise the whole process and clarify the debate for citizens, who do not already have the knowledge needed to participate in the public debate on energy planning in Denmark.

Currently, it can be argued that the perception of the citizens are that, they can be a barrier in order to implement solutions, which is described in Section 8.1.2 in Chapter 8. It is necessary for the citizens to be an active part of the debate, since they are such a huge factor in the transition. This have to be done through increased awareness of the issues regarding energy planning in general, and not only involve them in aspects that they have direct impact on. Furthermore, it can contribute to new ownership models, where the citizens can gain partial ownership of energy projects and thereby be part-owner of the Danish energy system. This may create more incentives for the citizens to get involved in the transition.

Conclusion 10

This chapter will focus on giving an overall conclusion of the research question according to the energy system analysis and the institutional analysis conducted in this thesis.

The national and international goals in relation to reducing CO_2, this have led to the preparation of achieving the goal of reducing CO_2 emissions by 70% towards 2030. The goal towards 2030 has been part of the reason why new technologies have been used in the Danish energy system. It has also led to some organisational changes that will contribute to Denmark meeting the 2030 goal, but there are some problems associated with this, which has led to the following research question:

"How can the Danish 2030 goal be met through a technically feasible scenario and how can the institutional barriers of implementing be overcome?"

Based on the two analyses conducted in this thesis, it can be concluded that it is technically possible to meet the 2030 goal through a feasible scenario with a higher share of sector coupling between the different energy sectors.

The energy system analysis does, however, also show that the current pace of implementing technologies is not sufficient in order to reach the goal by 2030. This is caused by the institutional context, as it limits the technological development within the Danish energy system, which is also apparent throughout the institutional analysis. In order to meet the 2030 goal, it is necessary to eliminate current organisational barriers in order to promote the technological development of sector coupling. Additionally, it is crucial that the organisational structure promotes a development, which aligns with the ambitions and visions that surround the Danish energy system.

This means that changes must be made in relation to the structure of the institutional context in order to meet the 2030 goal, but also future goals for the Danish energy system. This includes changes such as:

- Networking across different energy sectors and different levels of planning, but also on a international level, so it is possible to be part of the learning curve regarding new technologies.
- Willingness to be part of a networking community from authoritative body.
- Encourage public-private partnerships through incentives for both parties.
- Redefining the balance between mandatory actions and actions that are up to interpretation.
- Redefining the general approach to energy planning in order to achieve the 2030 goal.

This result in the institutional context further supporting network based collaboration across sectors and the different levels of planning which will support public-private partnerships.

It can thereby be concluded, that in order to achieve the 2030 goal, the institutional context that the Danish energy system is embedded in needs to change to a higher degree favor the transition towards a more renewable energy system than it currently does.

Bibliography

Aalborg University (2015), *IDA's Energy Vision 2050*, https://vbn.aau.dk/ws/portalfiles/portal/222230514/Main_Report_IDAs_Energy_Vision_2050.pdf. Accessed: 13-05-2020.

Connolly, D. (2015), *Finding and Inputting Data into EnergyPLAN*, https://energyplan.eu/wp-content/uploads/2013/06/Finding-and-Inputting-Data-into-the-EnergyPLAN-Tool-v5.pdf. Accessed: 27-04-2020.

Connolly, D., Lund, H., Mathiesen, B. & Leahy, M. (2009), *A review of computer tools for analysing the integration of renewable energy into various energy systems*, https://www.sciencedirect.com/science/article/pii/S0306261909004188. Accessed: 25-04-2020.

Danish District Heating Association (2019*a*), *Fjernvarmesektoren ruster sig til vækst*, https://www.danskfjernvarme.dk/nyheder/nyt-fra-dansk-fjernvarme/arkiv/2019/190326-branchestatistik-fjernvarmesektoren-ruster-sig-til-v\T1\aekst. Accessed: 19-05-2020.

Danish District Heating Association (2019*b*), *Varmeforsyningsloven og projektbekendtgørelsen i forbindelse med varmeprojekter og varmeplanlægning lokalt*, https://www.danskfjernvarme.dk/-/media/danskfjernvarme/videnom/til_kommuner/nemmere_kommunal_sagsbehandling_maj2019/varmeforsyningsloven-og-projektbekendtg\T1\orelsen_2udgave_maj2019.pdf. Accessed: 19-05-2020.

Danish Energy Agency (2011), *Notat om potentiale for solceller og muligheder for dannelse af solcellelaug*, https://ens.dk/sites/ens.dk/files/EnergiKlimapolitik/notat_om_potentiale_for_solceller_og_solcellelaug.pdf. Accessed: 13-05-2020.

Danish Energy Agency (2013), *Strategisk Energiplanlægning i Kommunerne*, https://ens.dk/sites/ens.dk/files/Varme/system_og_scenarieanalyse_vejledning_081013.pdf.

Danish Energy Agency (2017), *Energistatistik*, https://ens.dk/sites/ens.dk/files/Statistik/pub2017dk.pdf. Accessed: 04-05-2020.

Danish Energy Agency (2019), *Afgifter på overskudsvarme*, https://sparenergi.dk/offentlig/produktion/overskudsvarme/afgifter. Accessed: 23-05-2020.

Danish Energy Agency (n.d), *Information om varmeområdet*. Accessed: 12-04-2020.
URL: *https://ens.dk/ansvarsomraader/varme/information-om-varme*

Danish Industry (2019), *Industrien har brugt mere energi*. Accessed: 12-04-2020.
URL: *https://www.danskindustri.dk/di-business/arkiv/nyheder/2019/8/mere-energieffektivisering/*

Danish Ministry of Climate, Energy and Utilities (2015), *Forslag til Lov om ændring af lov om varmeforsyning og byggeloven*, https://www.retsinformation.dk/eli/ft/201412L00177?fbclid=IwAR3TkkixhFE3dt2mULuUrfp57bgQwqFGqpTMLM_hIxRvLYOSw9_ed3OtGRE. Accessed: 21-05-2020.

Danish Ministry of Climate, Energy and Utilities (2018), *Energiaftale*, https://efkm.dk/media/12222/energiaftale2018.pdf.

Danish Ministry of Climate, Energy and Utilities (2020), *https://www.retsinformation.dk/eli/lta/2020/119*, https://www.retsinformation.dk/eli/lta/2020/119. Accessed: 20-05-2020.

Danish Ministry of Climate, Energy and Utilities (n.d*a*), *Dansk Energipolitik*, https://ens.dk/ansvarsomraader/energi-klimapolitik/fakta-om-dansk-energi-klimapolitik/dansk-energipolitik.

Danish Ministry of Climate, Energy and Utilities (n.d*b*), *Klimaindsatsen i Danmark*, https://kefm.dk/klima-og-vejr/klimaindsatsen-i-danmark/.

Danish Tax Agency (n.d), *Betaling af og satser for registreringsafgift*, https://skat.dk/skat.aspx?oid=2234529. Accessed: 26-05-2020.

Drivkraft Danmark (2019), *Energistatistik 2019*. Accessed: 12-04-2020.
URL: *https://www.drivkraftdanmark.dk/wp-content/uploads/2019/05/DD_Energistatistik_2019_WEB-spreads.pdf*

Energinet (2015), *HVOR MEGET LANDVIND ER DER PLADS TIL I DANMARK?*, https://energinet.dk/Analyse-og-Forskning/Analyser/RS-Analyse-Januar-2015-Potentialet-for-landvind-i-2030. Accessed: 13-05-2020.

Energinet (2016), *Energiscenarier for 2030*, https://energinet.dk/Analyse-og-Forskning/Analyser/RS-Analyse-Energiscenarier-for-2030.

Energinet (2019), *HVOR KOMMER STRØMMEN FRA*. Accessed: 12-04-2020.
URL: *https://energinet.dk/El/Gron-el/Miljoedeklarationer/Hvor-kommer-stroemmen-fra*

Energistyrelsen (2019), *Basisfremskrivning 2019*. Downloaded: 17-03-2020.
URL: *https://ens.dk/service/fremskrivninger-analyser-modeller/basisfremskrivninger*

Energy Commission (2016), *Baggrundsnotat med fakta om den danske energisektor i dag*, https://efkm.dk/media/8283/baggrundsnotat-med-fakta-om-energisektoren-i-dag.pdf. Accessed: 23-05-2020.

European Comission (2018), *2030 climate & energy framework*, https://ec.europa.eu/clima/policies/strategies/2030_en. Accessed: 28-05-2020.

European Comission (2020), *Committing to climate-neutrality by 2050: Commission proposes European Climate Law and consults on the European Climate Pact*, https://ec.europa.eu/commission/presscorner/detail/en/IP_20_335. Accessed: 28-05-2020.

European Commission (2014), *Natioan Action Plan*. Downloaded: 27-02-2020.
URL: *https://ec.europa.eu/energy/en/topics/renewable-energy/national-action-plans*

European Commission (2018), *Fossil CO2 emissions of all world countries - 2018 Report*. Downloaded: 05-10-2018.
URL: *https://ec.europa.eu/jrc/en/publication/fossil-co2-emissions-all-world-countries-2018-report*

European Union (November 2014), *The EU explained: Energy*. Downloaded: 27-02-2020.

George, P. S. (2008), 'Encyclopedia of global warming & climate change'.
URL: *http://dx.doi.org/10.4135/9781452218564.n412*

Hvelplund, F. (2001), *Electricity Reforms, Democracy and Technological Change*. Downloaded: 10-03-2020.
URL: *http://people.plan.aau.dk/~lund/Study/EM7/FS/HvelplundElectricityReformsBook.pdf*

Jens Müller, Arne Remmen, P. C. (1984), *Samfundets teknologi: Teknologiens samfund*, Systime.

Juul, S. (2012), *Samfundsvidenskabernes videnskabsteori: en indføring*, Hans Reitzels Forlag, chapter Fænomenologi, pp. 65–106.

Kvale, S. & Brinkmann, S. (2010), *InterView - Introduktion til et håndværk*, 3, 2 edn, Hans Reitzels Forlag, ISBN 978-87-412-5198-1.

Lund, H. (2014), *Renewable Energy Systems - A Smart Energy Systems Approach to the Choice and Modeling of 100% Renewable Solutions*, number ISBN: 9780124104235 *in* 'Handbook', Academic Press.

Ministry of Environment and Food of Denmark (2016), *Act on Environmental Assessment of Plans and Programs and of Specific Projects*, https://www.retsinformation.dk/eli/ft/201512L00147. Accessed: 03-06-2020.

PlanEnergi (2013), *Sammenfatning og analyse af SEP- og superpuljens energiscenariestudier*, https://ens.dk/sites/ens.dk/files/Varme/sep_puljer_-_sammenfatning_280416.pdf.

Royal Litrary Fund (2017), *What is a literature review?*, https://www.rlf.org.uk/resources/what-is-a-literature-review/. Accessed: 09-05-2020.

Scott, W. R. (2001), *Institutions and Organizations - Second Edition*. Accessed: 21-12-2019.

Shutterstock (2016), *Making sustainable medical devices: five top tips*, https://www.medicaldevice-network.com/features/sustainable-medical-devices/?fbclid=IwAR3xFaQqcTFCv0EkqvBkR9DouiJrxe4NRPhE2k5a0JWXARkCgtzanN5UJis. Accessed: 03-06-2020.

Sorknæs, P. (2019), *WP1 - Documentation for the 2020 EnergyPLAN model for Denmark based on Danish Energy Agency's "Denmark's Energy and Climate Outlook 2018"*. Downloaded: 12-04-2020.
URL: *https://www.energyplan.eu/useful_resources/existingcountrymodels/*

SparEnergi (2019), *Fjernvarme*, https://sparenergi.dk/offentlig/varme-og-koeling/opvarmning-af-bygninger/fjernvarme. Accessed: 20-05-2020.

Statistics Denmark (2018), *Befolkningsfremskrivning*, https://www.dst.dk/da/Statistik/emner/befolkning-og-valg/befolkning-og-befolkningsfremskrivning. Accessed: 28-05-2020.

Statistics Denmark (2020*a*), *BIL8: Stock of vehicles per 1 January by type of vehicle and age*. Accessed: 12-04-2020.
URL: *https://www.statbank.dk/BIL8*

Statistics Denmark (2020*b*), *DRIVHUS: Drivhusgasregnskab (i CO2-ækvivalenter) efter branche og emissionstype*, https://www.statistikbanken.dk/DRIVHUS.

Statistics Denmark (2020*c*), *ENEGEO: Energy consumption of industry by municipality*. Accessed: 12-04-2020.
URL: *https://www.statbank.dk/ENEGEO*

Statistics Denmark (2020*d*), *FLYV11: Danish registered aircraft 1st January by type and unit*. Accessed: 12-04-2020.
URL: *https://www.statbank.dk/FLYV11*

Statistics Denmark (2020*e*), *SKIB11: Danish ships 1st January by type of vessel, ship's register and unit*. Accessed: 12-04-2020.
URL: *https://www.statbank.dk/SKIB11*

The Danish Council on Climate Change (2020), *Kendte veje og nye spor til 70 procents reduktion*, https://www.klimaraadet.dk/da/rapporter/kendte-veje-og-nye-spor-til-70-procents-reduktion. Accessed: 27-04-2020.

The Danish Society of Engineers (2006), *Ingeniørforeningens Energiplan 2030*, https://ida.dk/media/2727/energiplan_sammenfatning_1.pdf.

The Ministry of Climate, Energy and Utilities (n.d), *Vedvarende Energi*. Downloaded: 17-03-2020.
URL: *https://kefm.dk/energi-og-raastoffer/energiforsyning/vedvarende-energi/*

United Nations, (2015), *Ensure access to affordable, reliable, sustainable and modern energy*. Downloaded: 27-02-2020.
URL: *https://www.un.org/sustainabledevelopment/energy/*

United Nations, (n.d.), *Goal 13: Take urgent action to combat climate change and its impacts*. Downloaded: 27-02-2020.
URL: *https://www.un.org/sustainabledevelopment/climate-change-2/*

United Nations Framework Convention on Climate Change; COP (2015), *Paris Climate Change Conference-November 2015, COP 21*. Downloaded: 27-02-2020.
URL: *https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf*

Valeur, S. (2017), *Motoren er gået i stå for dansk salg af elbiler*, www.berlingske.dk/virksomheder/motoren-er-gaaet-i-staa-for-dansk-salg-af-elbiler. Accessed: 26-05-2020.

Øyen, M. (2020), *Klimaminister vil fjerne loft over antallet af vindmøller på land*, https://www.altinget.dk/artikel/194300-klimaminister-vil-fjerne-loft-over-antallet-af-vindmoeller-paa-land. Accessed: 24-05-2020.

Appendix A

A.1 Interview guides

The following consist of the interview guides sent to the different interviewees. The introduction for each interview guide is the same and therefore will not be included in each interview guide. The questions asked vary based on the interviewed stakeholder.

We are 2 students from Aalborg University, Stephen Arguelles Johansen and Thuvaraahen Nagendiram, who are studying Sustainable Energy Planning and Management. We are in the process of writing our thesis in strategic energy planning in relation to the 2030 goals, which is a 70% reduction in CO2 emissions compared to 1990. Where, among other things, we will investigate what obstacles that exist or may exist in implementation of new alternative technical solutions in the Danish energy system and how the different institutional levels handle them. In addition, we will examine whether this practice is the ideal future for meeting national and international objectives. The interview will be conducted as a semi-structured interview with a duration of 20-30 minutes, it is made known that the interview will be recorded. This is because the material will be used in our thesis and will therefore serve as a supplement to support our memory. The recording will not be used for any other purpose and will not be published. In addition, you voluntarily participate in an interview and have the right to withdraw your consent at any time. The interview will cover the general approach to energy planning, as well as specific questions regarding how to meet the objectives

Vestforsyning

Interview guide for Louise Carøe Foldberg

- Introduction
  - Name, position and organisation
- How do you perceive energy planning in Denmark?
- What is Vestforsyning's role in relation to energy planning in Denmark?
- How do Vestforsyning relate to Danish goals and visions?
  - Both 100% renewable energy 2050 and 70% less emissions than 1990 by 2030?
- What are the biggest challenges in meeting the objectives?
- Is it going to affect you - how?
- Are there any regulatory challenges?
- How should energy planning take place to get the ideal result from you?

- How can Vestforsyning, as an institution, help to meet a reduction in CO_2 emissions?
- Which barriers do you consider to be the biggest in order to accommodate a reduction in CO_2 emissions?
- What sectors would Vestforsyning be able to help reduce?
- What action would you take?
- What do you see as the biggest barriers in each sector?
- Which sector do you think will change most and why?
- Do you think there will be a change in relation to the technologies used in the Danish energy system?
- How do you think that change will take place?
- What will be the optimal development to meet both 100% renewable energy 2050 and 70% less emissions than 1990 by 2030?

Holstebro Municipality

Interview guide for Lene Kirk Dalum

- Introduction
  - Name, position and organisation
- How do you perceive energy planning in Denmark?
- What is Holstebro Municipality role in relation to energy planning in Denmark?
- How do you relate to Danish goals and visions?
  - Both 100% renewable energy 2050 and 70% less emissions than 1990 by 2030?
- What are the biggest challenges in meeting the objectives?
- Is it going to affect you - how?
- Are there any regulatory challenges?
- How should energy planning take place to get the ideal result from you?
- How can you, as an institution, help to meet a reduction in CO_2 emissions?
- Which barriers do you consider to be the biggest in order to accommodate a reduction in CO_2 emissions?
- What sectors would you be able to help reduce?
- What action would you take?
- What do you see as the biggest barriers in each sector?
- Which sector do you think will change most and why?
- Do you think there will be a change in relation to the technologies used in the Danish energy system?
- How do you think that change will take place?
- What will be the optimal development to meet both 100% renewable energy 2050 and 70% less emissions than 1990 by 2030?

North Denmark Region and Hjørring Municipality

Interview guide for Lars Hedegaard and Thomas Jensen

- Introduction

  - Name, position and organisation
- How do you perceive energy planning in Denmark?
- What is the role of North Denmark Region in relation to energy planning in Denmark?
- How do you relate to Danish goals and visions?
  - Both 100% renewable energy 2050 and 70% less emissions than 1990 by 2030?
- What are the biggest challenges in meeting the objectives?
- Is it going to affect you - how?
- Are there any regulatory challenges?
- How should energy planning take place to get the ideal result from you?
- How can you, as an institution, help to meet a reduction in CO2 emissions?
- Which barriers do you consider to be the biggest in order to accommodate a reduction in CO2 emissions?
- What sectors would you be able to help reduce?
- What action would you take?
- What do you see as the biggest barriers in each sector?
- Which sector do you think will change most and why?
- Do you think there will be a change in relation to the technologies used in the Danish energy system?
- How do you think that change will take place?
- What will be the optimal development to meet both 100% renewable energy 2050 and 70% less emissions than 1990 by 2030?

Ministry of Transport

Interview guide for Per Skrumsager Hansen

- Introduction
  - Name, position and organisation
- How do you perceive energy planning in Denmark?
- What is the role of Ministry of Transport in relation to energy planning in Denmark?
- How do you relate to Danish goals and visions?
  - Both 100% renewable energy 2050 and 70% less emissions than 1990 by 2030?
- What are the biggest challenges in meeting the objectives?
- Is it going to affect you - how?
- Are there any regulatory challenges?
- How should energy planning take place to get the ideal result from you?
- How can you, as a ministry, help to meet a reduction in CO2 emissions?
- What barriers do you see in reducing emissions in the transport sector?
- What do you see as the biggest barriers in the transport sector?
- Do you think there will be a change in relation to the technologies used in the transport sector?
- If so, which ones?
- How do you think that change will take place?
- What will be the optimal development to meet the target of 70% less emissions than 1990 by 2030?

The Danish Chamber of Commerce

Interview guide for Ulrich Bang

- Introduction
  - Name, position and organisation
- How do you perceive energy planning in Denmark?
- What is the role of The Danish Chamber and Commerce in relation to energy planning in Denmark?
- How do you relate to Danish goals and visions?
  - Both 100% renewable energy 2050 and 70% less emissions than 1990 by 2030?
- What are the biggest challenges in meeting the objectives?
- Is it going to affect you - how?
- Are there any regulatory challenges?
- How should energy planning take place to get the ideal result from you?
- How can you, as an institution, help to meet a reduction in CO2 emissions?
- Which barriers do you consider to be the biggest in order to accommodate a reduction in CO2 emissions?
- What sectors would you be able to help reduce?
- What action would you take?
- What do you see as the biggest barriers in each sector?
- Which sector do you think will change most and why?
- Do you think there will be a change in relation to the technologies used in the Danish energy system?
- How do you think that change will take place?
- What will be the optimal development to meet both 100% renewable energy 2050 and 70% less emissions than 1990 by 2030?

Aalborg University

Interview guide for Søren Djørup

- Introduction
  - Name, position and organisation
- How do you perceive energy planning in Denmark?
- What is the role of Aalborg University in relation to energy planning in Denmark?
- How do you relate to Danish goals and visions?
  - Both 100% renewable energy 2050 and 70% less emissions than 1990 by 2030?
- What are the biggest challenges in meeting the objectives?
- Is it going to affect you - how?
- Are there any regulatory challenges?
- How should energy planning take place to get the ideal result from you?
- How can you, as an institution, help to meet a reduction in CO2 emissions?
- Which barriers do you consider to be the biggest in order to accommodate a reduction in CO2 emissions?
- What sectors would you be able to help reduce?

- What action would you take?
- What do you see as the biggest barriers in each sector?
- Which sector do you think will change most and why?
- Do you think there will be a change in relation to the technologies used in the Danish energy system?
- How do you think that change will take place?
- What will be the optimal development to meet both 100% renewable energy 2050 and 70% less emissions than 1990 by 2030?

The Danish Energy Agency

Interview guide for Asger Øland

- Introduction
  - Name, position and organisation
- How do you perceive energy planning in Denmark?
- What is the role of the Danish Energy Agency in relation to energy planning in Denmark?
- How do you relate to Danish goals and visions?
  - Both 100% renewable energy 2050 and 70% less emissions than 1990 by 2030?
- What are the biggest challenges in meeting the objectives?
- Is it going to affect you - how?
- Are there any regulatory challenges?
- How should energy planning take place to get the ideal result from you?
- How can you, as an institution, help to meet a reduction in CO2 emissions?
- Which barriers do you consider to be the biggest in order to accommodate a reduction in CO2 emissions?
- What sectors would you be able to help reduce?
- What action would you take?
- What do you see as the biggest barriers in each sector?
- Which sector do you think will change most and why?
- Do you think there will be a change in relation to the technologies used in the Danish energy system?
- How do you think that change will take place?
- What will be the optimal development to meet both 100% renewable energy 2050 and 70% less emissions than 1990 by 2030?

A.2 Outlines over the Interviews

Outline of all interviews conducted, the interview files are part of the external appendix. If it is found necessary a fully transcribed version, in Danish, can be send upon request. In the thesis all of the references are related to the outline of the interviews, the timestamp is referring to the starting point of the quote.

A.2.1 Vestforsyning

- Development consultant at Vestforsyning
  - Internal change
  - Repowering
  - Distribution and create awareness regarding new technologies in relation to customers.
- The interview guide have been discussed with the whole department for inputs.
- Thoughts are sometimes a little faster than can be practiced
  - The government's goals are not quite in line
  - Do not take other requirements into consideration
- Their role is to fulfill the requirements
- Holstebro Municipality already has its own objectives
  - Re-powering (Replacing old wind turbines with new ones)
  - Doubt regarding the long-term goals
- A small influence through the union for utility companies
- The development and opportunities play an important role in planning
- They cannot by themselves
  - The municipality must approve something
  - Authorities must approve other things
- Spatial planning can be problematic with current conditions
  - Responsible for providing for the consumers, who wants to be part of the solution.
  - Private industry have better conditions
- The ideal situation will be that the utility companies has to ensure customers are connected and stay connected
  - Possibly through an obligation for X years
- The municipality is ultimately the owner, so they have to listen to them
  - Could still use a closer relationship, currently they are doing quarterly meetings
- Utility companies can contribute to the objectives
  - Composition with several supplies for replacing old wind turbines
- Holstebro municipality is favorably set if it should not be changed with the designation of places
  - A requirement in the municipality is included in the idea otherwise it will not happen
- A clearer framework for how utility companies should act

  - It does not always make sense (It depends on the individual municipality)
- The utility companies can primarily affect the electricity and heating sector
  - Certification
- Biggest barrier is the direct transfer of transport in relation to the electricity grid
  - Gas is also an option
  - Can it be 100% electricity at all?
- CO_2 in relation to waste incineration
  - Not something utility companies can take into consideration
  - Can CO_2 be used for nothing?
- Uncertainty after 2030
- The utility companies expects the heating sector to change most for them
  - The municipality wants sensitivity calculation with different scenarios
- New technologies are expected, and is playing role towards optimising the Danish energy system
- Electrification is the way
  - Important that the various sectors are contributing to the transition
  - Practical guidelines rather than overall goals

A.2.2 Holstebro Municipality

- Different how much energy and resources are used in each municipality
- Heat planning and climate planning in Holstebro Municipality
- Climate law is ambitious
- Must not meet the requirements directly, but make an effort to meet it
- Pivotal what measures will come from the state
- Municipalities have an important role for physical facilities
  - Be a facilitator and coordinator for utilities companies, companies and citizens regarding projects
- Compiled an energy plan before the announcement of the new targets
  - Did not plan to put figures on the action plans in terms of CO_2
  - Question about the measures
  - Energy accounting can help here
- Have not started in the transport and agriculture sectors
- Strategic energy planning with region a few years back
  - Insights into common challenges
  - Function as a room for dialogue
- Problem of utilising excess heat legally
  - This is also due to the high waste heat generated by the waste incineration.
  - Changes in the taxation can make it succeed
- Lack of well-defined framework
- Physical planning for energy plants
- Financial means for various actions are a barrier
- The role of the municipality can also be a barrier
- Limited impact on transport

  - Can have an impact with charging stands
- Success with wind turbines and large energy plants
- Agriculture as a challenge
  - Requires technology and research
  - Climate-friendly crops
  - Considered the biggest challenge that requires the greatest change
- The transport area can be a challenge in relation to the objectives (2030 goal)
  - The municipality can contribute with standards regarding passenger transport
  - Doubt about heavy transport
- Energy storage
  - A lot of energy is passed on
  - Storage would increase efficiency
- The development of technologies is necessary to achieve the goals
- Combinations of different solutions
  - Not the same solution everywhere
- Taxation can contribute to a change
  - Direction can be determined by these
- Profitability can be a barrier
  - The solution must be the most favorable in the heating sector
- The ideal situation includes new technologies, integration of the energy system

A.2.3 North Denmark Region and Hjørring Municipality

- SEP Nord is an example of a region's efforts in the energy area
  - 11 municipalities in North Jutland may make this easier compared to other regions with more municipalities
  - Find a model that allows collaboration and effective realisation of the goal
- Municipalities cannot influence energy planning at national level
  - The role of the municipality is to bring together actors such as producers and plants
  - Local knowledge
- The region is the project coordinator
  - Ensures interaction between municipalities
- The municipality is also an authority that approves the location of large plants
  - Ensure consistency in the municipality
- Lack of tools in municipalities that are not voluntary or facilitating
- Strategic energy planning is voluntary
  - Some municipalities go into it a lot, others go up in other things
  - Also different which type of energy they prioritise (wind turbines, biogas plants etc.)
- All municipalities are not as far along with energy planning, which can be a challenge
- Other energy collaborations can complement each other (DK2020 supplements eg. SEP NORD)

- Hjørring Municipality does not believe that the objectives affect them so much as there is nothing concrete about the municipalities
- General CO_2 emissions are difficult as they do not specify how much to reduce in the energy sector
- Hjørring Municipality requires statutory strategic energy planning and clear guidelines on how
  - However, making it statutory would also mean money from the state that may not be in the budget
- Legislative framework conditions, subsidies and taxes are the major barriers
- Many will invest, but are not allowed
- Profitability is important
  - Positive returns are needed to have investors
- Customers ending up with the bill from the utility companies' investment can be a problem
- Uncertain whether changing the obligation to supply is an advantage or disadvantage
- Taxation and subsidies must contribute to support the desired development
- National action plan should make it more efficient, so everyone has the same direction
- Lack of how the government specifically thinks about achieving the goal
- The municipality can best contribute to the energy sector rather than transport and agriculture, which is more the government's area
- It must be attractive for citizens to choose the green transition (for example with electric vehicles)
- Different issues in transition in different municipalities
  - For example, Aalborg must find space for all the charging stations in the city center if electric cars are wanted, Hardly as big a problem in a rural municipality as Hjørring.
- Enough power to supply everyone, if they have electric vehicles
  - Time also plays a role, consumption must either be regulated or the network must be strengthened
  - Energy storage
- Subsidies is needed in order to build new and build "right"
- Different actors need to do something
  - Multiple drivers
- The two most important stakeholders are politicians and citizens
-
- Politicians make decisions
- Citizens can be a block for wind turbines and biogas plants
- Citizens will sometimes like the green changes, as long as it is not in their backyard

A.2.4 Ministry of Transport

- Introduction
  - Economist from AU
  - Experience from other ministries, Aarhus Municipality and Velux

- Ensure mobility that adds value
  - Energy is enabler - Something we need to get mobility
  - Security of supply
  - Cheap - Economy plays a role
  - Right price for externalities
  - Availability
- Energy policy objectives creates the framework
  - Living up to goals cost-effectively
- Lack of overview
  - Challenges are divided into different modes of transport and vehicles
  - Different terms for these
  - Passenger vehicles are the largest energy consumer in the transport sector
    - Perhaps not the most optimal to look at in terms of costs
- More green transport sector gives less to the state
- Electrification of transport in the long term
- Don't see any real opportunity to electrify heavy traffic
  - Ambitious opportunities with pilot projects
  - Not realistic until 2030
- Too expensive to drive = less mobility
- Possibility of biogas in Denmark?
- EU rules for vans
  - Difference between electricity and fossil fuels
- Framework conditions for charging stands
  - More conditions from several actors (More Ministries and the EU)
  - Setting up charging stations in the city (Must be installed on public land, must be allowed by the municipality, who may use the charging station, subscription from the operator)
  - Inappropriate interaction between legislation in different areas
- Availability during conversion from fossil to renewable
- Expectation and a thorough electrification of the entire transport sector
- Profitability is not necessary here and now
  - If the future proves to be more profitable, you can start implementing it earlier

A.2.5 The Danish Chamber of Commerce

- Introduction
  - Working as a climate and energy policy manager in Danish is a job
  - Represents 17000 companies in Denmark
- Traditional energy planning has focused on production
- The future energy system focuses on consumption
- Framework management and incentive structure
- Three roles
  - Energy companies/distribution companies have an interest in the transmission system
  - Members with energy consumption focus

  - Members focusing on input to the energy system
- Increased sector coupling
- 100% support for the 70% reduction towards 2030
- Important not just moving reduction to another country
- Focus on how it creates growth
- Political framework conditions and demand were important for wind turbines in their day
  - Research
  - Willingness of actors and investors
- We do not have all the solutions
  - Electricity is an obvious sector for conversion
  - Transportation is harder
    * No one can produce the necessary quantities
    * Many different elements
  - The food area is also difficult
    * Change in diets?
- CO_2 quotas
  - Provides higher prices for CO_2 quotas
- Jobs disappears in order to reach the goals
  - Competition between “fossil” jobs and “clean” jobs
  - Depends on the tax structure
- Tax reform
- Learning from the wind sector
  - Regulatory pressure
- Building regulations CO_2 friendly materials
- Fuel Quality Directives
- Ideally, market-based
  - Targeted work on what a public-private partnership should be engaged
- Scaling to a global export market
  - Danish workplaces
- Members
  - Webinar and meetings
  - How can a business be restructured
  - PPA
  - The transport sector in terms of long value chains
  - Excess heat
    * Regulatory barriers
- Not a wonder solution that solves all the problems
  - Focus broadly on several solutions
- Biggest contribution is within
  - The transport sector
  - Food sector
  - Retail sector
- Non-profit principle is a major barrier
- Interpretation of barriers to investment

- Tax on biomass
  - Subsidies
- Projects in the heat sector
- Electricity taxation and taxes do not reflect the climate impact
- Business in infrastructure (charging stands) is not feasible
- Development in the electric vehicle and infrastructure are still evolving
  - Technologies can quickly become outdated
- Regulation is not suitable for the development in the electricity sector and sector coupling
- Electricity and heat are the longest and change here will not be great
  - Passenger transport will change significantly
  - Food
- Expectation of changes and interconnection between consumption and production
- Electrification
- Low hanging fruit first with mature technologies
- Convert oil and gas to electricity or DH in the heat sector
- Waste incineration
  - Not by Danish decisions but by European
- Uncertainties about the energy system of the future
  - How many electric cars etc.
  - Maybe other things are more important
    * Replacement of coal, etc.
    * How to get rid of fossil boilers

A.2.6 Aalborg University

- The role of Aalborg University in relation to energy planning in Denmark
- Influence on a national and international level
- The year is redundant, by 2050 we see a smart energy system mindset.
- The goals are realistic, it is not easy but it is possible.
- The biggest challenge is the institutional one
  - It is very different from what it is for a technical thing to look at. It's all organisational and institutional
- AAU can help influence perceptions and try to provide solutions to achieve goals through ESA
- A holistic approach through analyses and in general the smart energy system approach
  - Under-informed in Europe
- IDA Energy Vision
- Debates and discussions are needed to promote the best solutions so that all things are reversed.
- University role has changed historically from outsider to be part of the discussion

A.2.7 The Danish Energy Agency

- Introduction
- General perception of energy planning in Denmark
- We play a central role, we control the energy in Denmark.
- An opportunity to come up with measures that reduce CO_2 emissions.
  - Measures to achieve the Danish targets can be carbon capture, but what do you do with the waste you burn off?
- Basic projection, overview of whether we will reach goals on page. 45
  - New initiatives will be needed for PTX, Electrolysis, E-fuels, biogas etc.
  - We must do something in the industry, process emissions based on the use of fossil fuels.
  - Sector coupling
  - Aalborg Portland
- Try to find the transverse laws in SENFO
  - In the process of trying to rewrite those sector laws so that is precisely the cross-cutting considerations
  - Challenges in relation to cross-cutting legislation
- Broad guidelines
  - Possibility of interpretation of the individual municipality
  - DEA's Trilemma - Supply Security, Cost Efficiency and Green Conversion
- The challenge is difficult and it is something that needs to be considered. It is not easy to change a large economy or a whole economy.
- Different solutions in the transport sector and optimisation of these.
- Changing the current structure and how the sectors have evolved
  - Excess products are an important resource
  - Kalundborg Symbiosis
- Use the right fuels in the different sectors
  - Biomass/Biogas may not belong in the DH sector.
- Make money on the green transition - One of the leading nations in terms of wind.
  - We can make money from this change
- Legislation is not sufficient in any area
- Public-private parnterships
  - Greenlab Skive
  - Research
- The industry sector can change most, the opportunity for attracting new businesses because of our energy system
- Nuclear power
- Democracy and the current structure and how it is difficult to change.

EnergyPLAN scenarios B

B.1 Technical description of the 2030 basis scenario and the 2030 70% scenario

B.1.1 The 2030 Basis scenario

For the development of the base scenario for 2030, prognoses from Denmark's Energy and Climate Outlook 2019 has been used, which describes the development of the Danish energy system towards 2030 without any new political changes. The data from Denmark's Energy and Climate Outlook has been implemented into an already existing scenario for 2020 developed by Peter Sorknæs at Aalborg Univerisity.

Changes in demand

As it is not stated that there will be any significant changes to how the energy use is distributed throughout the year in Denmark's Energy and Climate Outlook 2019, there have been no changes made to the distribution files of the 2030 base scenario. There are however expectations of change within the amount of energy used in 2030. For the electricity demand, it is stated that the consumption will increase by roughly 3% per year, mostly due to the establishment of large data centers in Denmark. This has resulted in a change in electricity demand input from 33.25 TWh to 39.897 TWh in the electricity tab.

For the heating sector, both the individual heating sector and the district heating sector has undergone changes within their demand. For the individual heating sources, the following changes have been made from the 2020 scenario:

For the district heating demand, a minor decrease is seen within the households, while the industry sees a slight increase in district heating consumption. This results in an overall decrease of 1.5% from 2020 to 2030. Addtionally, the industry sector is expected to decrease consumption of fossil fuels by 4.6% between 2020 and 2030. The reduction of specific fuels is not specified so it is assumed that the reductions are proportionally the same for each fuel.

Table B.1: Change in individual heat supply from 2020 to 2030

Production	**Oil**	**Gas**	**Biomass**	**Electric heating**	**Heat pumps**
Change from 2020	36%	84%	65%	68%	176%

For the transport sector, it is stated that air transport will remain fully supplied by fossil fuels in 2030. Additionally it is also shown that the air transport will increase by 6% in the period towards 2030. The share of fossil fuels in the overall transport sector decreases from 95% to 93% while the total energy use increases by 1%. This results in a decrease of fossil fuels and an increase of renewable fuels such as biofuels and electricity.

Changes to production units

One of the major changes towards 2030 is that the coproduction of heat and power is lowered as the production from other means is increasing. For power production, the capacities of offshore wind turbines and PV panels are massively increased, while onshore wind turbines are slightly increased. Onshore wind was increased from 4232 MW to 4800 MW, offshore from 2051 MW to 4900 MW and PV panels from 952 to 4900 MW. Additionally, it is stated that heat pumps will increase from 1% of the production to 11%. Based on this it is assumed the capacity of heat pumps is increased from 64 MW to 704 MW.

B.1.2 The 2030 70% scenario

For the development of the 70% scenario for 2030, suggestions from the Climate Council's report on how to meet the 2030 goal has been used. Additionally, inspiration has also been used from the IDA energy vision 2050 and the scenario for 2035 as an inspiration of what is possible within the time frame.

The first step in this scenario is to identify the required CO_2 reduction. Based on a CO_2 emission in 1990 of 44.237 Mt means that the required CO_2 emission in 2030 must be 13.271 or below.

Changes in demand

As the industry and transport sectors are the sectors with the highest CO_2 emission levels, these are focused on. In the IDA 2035 scenario, half of Diesel/DME usage is based on electrofuels which has been applied to the scenario. A large part of petrol usage has also been converted to electricity reducing the use of fossil fuels for petrol from 14.83 TWh to 6 TWh. Roughly a third of the jet fuel usage has been converted to electrofuels.

A reduction of fossil fuels in the industry sector was also required. The usage of fossil fuels has here been significantly reduced with coal being reduced from 1.33 TWh to 1.28 TWh, oil being reduced from 17.33 TWh to 7.3 TWh and natural gas being reduced from 16.05 TWh to 9.09 TWh.

While these may change the demand of other sectors such as the electricity sector, the demands of the heat and electricity sector have not been changed.

Changes in production units

As the demands of the 70% scenarios are changing, this also results in some of the production units changing. For the heat and electricity sector, all usage of coal and oil is removed while natural gas remains.

As the transport sector in this scenario is reliant on electrofuels, production of electrofuels has been added to the scenario.

B.2 EnergyPLAN prints from the three scenarios

The Energy Plan files can be found in the external appendix. The first and second pages is a data sheet for the reference scenario. The third and fourth pages are a data sheet for the basis scenario 2030, the last two pages are for the 70% scenario 2030.

Input DK2020_2018edition.txt — The EnergyPLAN model 15.0

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	30,16	Fixed imp/exp.	0,00
Electric heating + HP	1,42	Transportation	0,53
Electric cooling	1,67	Total	33,78

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,00	16,22	21,18	37,40
Solar Thermal	0,00	1,00	0,00	1,00
Industrial CHP (CSHP)	0,00	0,78	0,93	1,71
Demand after solar and CSHP	0,00	14,44	20,25	34,69

Wind	4232	MW	10,43	TWh/year	0,00	Grid
Offshore Wind	2051	MW	8,62	TWh/year	0,00	stabili-
Photo Voltaic	952	MW	1,01	TWh/year	0,00	sation
River Hydro	7	MW	0,02	TWh/year	0,00	share
Hydro Power	0	MW	0	TWh/year		
Geothermal/Nuclear	0	MW	0	TWh/year		

	Capacities		Efficiencies		
Group 2:	MW-e	MJ/s	elec.	Ther	COP
CHP	876	1216	0,34	0,47	
Heat Pump	64	192			3,00
Boiler		6354		0,98	
Group 3:					
CHP	1760	4520	0,28	0,73	
Heat Pump	1	3			3,00
Boiler		6109		0,92	
Condensing	3112		0,36		

Heatstorage: gr.2: 33 GWh gr.3: 16 GWh
Fixed Boiler: gr.2: 20,0 Per cent gr.3: 0,0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,36	0,52
Gr.3:	0,10	1,05

Regulation Strategy:	Market regulation NEW	
CEEP regulation	234500000	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	10	MW
Minimum PP	10	MW
Heat Pump maximum share	0,50	
Maximum import/export	7105	MW

Di:NordPoolSystemPrice2015_EUR.txt		
Addition factor	0,00	EUR/MWh
Multiplication factor	1,60	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	34	EUR/MWh
Gas Storage	6000	GWh
Syngas capacity	0	MW
Biogas max to grid	617	MW

Fuel Price level:

Capacities Storage Efficiencies	MW-e	GWh	elec.	Ther.
Hydro Pump:	0	0	0,00	
Hydro Turbine:	0		0,00	
Electrol. Gr.2:	0	0	0,40	0,50
Electrol. Gr.3:	0	0	0,40	0,50
Electrol. trans.:	0	0	0,00	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	57,42	0,06	0,00
Household	0,00	2,14	7,04	11,51
Industry	1,33	10,68	10,74	2,98
Various	0,00	6,65	5,31	0,47

Output

	District Heating										Electricity																		Exchange	
	Demand	Production									Consumption						Production							Balance					Payment	
	Distr. heating MW	Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba- lance MW	Elec. demand MW	Flex.& Transp. MW	HP MW	Elec- trolyser MW	EH MW	Hydro Pump MW	Tur- bine MW	RES MW	Hy- dro MW	Geo- thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Stab- Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Imp Million EUR	Exp
January	6491	9	1114	0	3575	183	0	1566	42	3	3976	59	185	0	183	0	0	2832	0	0	232	1607	633	100	73	974	0	974	4	24
February	6897	49	1114	0	3882	188	0	1621	43	0	3905	61	199	0	194	0	0	2496	0	0	232	1751	612	100	24	757	0	757	1	18
March	6089	69	1114	0	3402	195	0	1279	24	6	3706	62	181	0	155	0	0	2178	0	0	232	1556	581	100	18	462	0	462	1	11
April	5203	172	1114	0	2928	195	0	794	28	-29	3386	59	160	0	137	0	0	2073	0	0	232	1374	486	100	28	451	0	451	1	11
May	4174	192	1114	0	1994	189	0	556	101	28	3343	62	137	0	184	0	0	2578	0	0	232	915	301	100	151	450	0	450	4	10
June	1699	251	1114	0	188	4	0	369	61	-288	3446	61	20	0	82	0	0	2001	0	0	232	75	381	100	1051	130	0	130	23	1
July	1699	207	1114	0	107	3	0	369	133	-234	3267	59	21	0	154	0	0	2154	0	0	232	42	10	100	1253	189	0	189	22	1
August	1705	196	1114	0	180	3	0	369	69	-226	3506	61	19	0	90	0	0	1744	0	0	232	70	225	100	1451	45	0	45	29	1
September	2937	124	1114	0	898	3	0	369	74	354	3544	60	48	0	127	0	0	2014	0	0	232	354	538	100	746	106	0	106	18	1
October	4109	65	1114	0	2033	102	0	369	41	384	3654	60	106	0	123	0	0	1752	0	0	232	940	793	100	375	149	0	149	10	4
November	4949	20	1114	0	2707	192	0	868	48	0	3887	61	155	0	151	0	0	2330	0	0	232	1265	689	100	83	346	0	346	3	8
December	5238	11	1114	0	2363	193	0	1251	305	0	3873	59	164	0	415	0	0	3261	0	0	232	1013	265	100	204	465	0	465	5	8
Average	4258	114	1114	0	2015	121	0	813	81	0	3624	60	116	0	167	0	0	2285	0	0	232	910	458	100	457	376	0	376	Average price	
Maximum	10333	1437	1114	0	5736	195	0	4836	760	4719	5425	183	316	0	976	0	0	5957	0	0	232	2636	3102	100	3524	2344	0	2344	(EUR/MWh)	
Minimum	1488	0	1114	0	26	0	0	369	0	-3095	2187	0	0	0	16	0	0	5	0	0	232	10	10	100	0	0	0	0	30	29
TWh/year	37,40	1,00	9,79	0,00	17,70	1,06	0,00	7,14	0,71	0,00	31,83	0,53	1,02	0,00	1,46	0,00	0,00	20,07	0,00	0,00	2,04	8,00	4,02		4,01	3,30	0,00	3,30	122	96

FUEL BALANCE (TWh/year):	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon- version	Electro- Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	2,70	-	-	10,18	-	-	-	-	-	-	-	-	-	-	-	-	-	1,33	14,21	1,79	16,00	5,04	5,67
Oil	-	0,02	-	-	0,02	0,40	-	-	-	-	-	-	-	-	-	-	-	57,42	2,13	17,33	77,32	0,07	77,39	20,29	20,31
N.Gas	-	4,08	0,86	0,98	0,00	-	-	-	-	-	-5,42	-	-	-	-	-	-	0,06	7,00	16,05	23,60	0,00	23,60	4,83	4,83
Biomass	-	3,08	16,20	6,26	0,01	0,51	-	-	10,64	-	7,91	-	-	-	-	-	-	-	11,43	3,45	59,49	0,09	59,58	1,24	1,24
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	10,43	1,01	8,62	0,02	1,12	-	-	-	21,19	0,00	21,19	0,00	0,00
H2 etc.	-	0,00	0,00	0,00	0,00	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	0,00	-	-	-	-	-	-	-	-2,49	-	-	-	-	-	-	2,49	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	-	7,18	19,76	7,24	0,03	11,08	-	-	10,64	-	-	-	10,43	1,01	8,62	0,02	1,12	59,97	20,55	38,16	195,80	1,95	197,76	31,41	32,06

16-april-2020 [11:35]

Output specifications   DK2020_2018edition.txt   The EnergyPLAN model 15.0

District Heating Production

	Gr.1				Gr.2									
	District heating MW	Solar MW	CSHP MW	DHP MW	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age GW	Ba-lance MW
January	0	0	0	0	2815	9	395	649	180	0	1566	16	0	0
February	0	0	0	0	2991	49	395	724	185	0	1621	16	0	0
March	0	0	0	0	2641	69	395	700	192	0	1279	6	0	0
April	0	0	0	0	2257	172	395	707	192	0	794	13	2	-16
May	0	0	0	0	1810	192	395	418	186	0	556	54	4	9
June	0	0	0	0	737	251	395	5	1	0	369	0	123	-285
July	0	0	0	0	737	207	395	0	0	0	369	0	297	-234
August	0	0	0	0	739	196	395	1	0	0	369	0	466	-222
September	0	0	0	0	1274	124	395	13	0	0	369	22	447	350
October	0	0	0	0	1782	65	395	447	99	0	369	19	92	388
November	0	0	0	0	2146	20	395	638	189	0	868	24	8	13
December	0	0	0	0	2272	11	395	279	190	0	1213	182	0	0
Average	0	0	0	0	1847	114	395	380	118	0	810	30	120	0
Maximum	0	0	0	0	4481	1437	395	1216	192	0	3341	489	550	1546
Minimum	0	0	0	0	645	0	395	0	0	0	369	0	0	-1611
Total for the whole year														
TWh/year	0,00	0,00	0,00	0,00	16,22	1,00	3,47	3,34	1,03	0,00	7,11	0,26		0,00

	Gr.3									
	District heating MW	Solar MW	CSHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Stor-age MW	Ba-lance MW
January	3676	0	719	2926	3	0	0	25	13174	3
February	3906	0	719	3157	3	0	0	27	8904	0
March	3448	0	719	2702	3	0	0	18	8236	6
April	2947	0	719	2222	3	0	0	15	4832	-12
May	2364	0	719	1576	3	0	0	47	10339	19
June	962	0	719	183	3	0	0	61	2336	-4
July	962	0	719	107	3	0	0	133	3876	0
August	966	0	719	178	3	0	0	69	5247	-4
September	1663	0	719	885	3	0	0	52	4501	4
October	2327	0	719	1586	3	0	0	22	6192	-4
November	2803	0	719	2069	3	0	0	24	8477	-12
December	2966	0	719	2084	3	0	38	123	9870	0
Average	2411	0	719	1635	3	0	3	52	7179	0
Maximum	5852	0	719	4520	3	0	2906	271	15700	4719
Minimum	843	0	719	26	0	0	0	0	0	-3009
Total for the whole year										
TWh/year	21,18	0,00	6,32	14,36	0,03	0,00	0,03	0,45		0,00

	RES specification				
	RES1 Wind MW	RES2 Offshoı MW	RES3 Photo \ MW	RES 4-7 ic MW	Total MW
January	1514	1295	21	2	2832
February	1347	1107	40	2	2496
March	1191	873	112	2	2178
April	996	885	190	2	2073
May	1284	1104	187	2	2578
June	935	862	203	1	2001
July	1039	920	194	1	2154
August	761	802	180	1	1744
September	910	969	134	1	2014
October	850	831	68	2	1752
November	1480	817	30	2	2330
December	1938	1303	17	3	3261
Average	1187	981	115	2	2285
Maximum	4232	2051	952	3	5957
Minimum	1	0	0	1	5
Total for the whole year					
TWh/year	10,43	8,62	1,01	0,02	20,07

Own use of heat from industrial CHP: 0,00 TWh/year

ANNUAL COSTS (Million EUR)		
Total Fuel ex Ngas exchange =		5281
Uranium =	0	
Coal =	147	
FuelOil =	479	
Gasoil/Diesel=	1885	
Petrol/JP =	1374	
Gas handling =	185	
Biomass =	1211	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		404
Marginal operation costs =		34
Total Electricity exchange =		25
Import =	122	
Export =	-96	
Bottleneck =	0	
Fixed imp/ex=	0	
Total CO2 emission costs =		203
Total variable costs =		5947
Fixed operation costs =		4224
Annual Investment costs =		8644
TOTAL ANNUAL COSTS =		18815

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	215	967	0	1326	7	1827	4342	617	0	0	0	0	1038	2687	2687	0
February	222	1073	0	1420	7	1827	4549	617	0	0	0	0	1245	2687	2687	0
March	176	1016	0	1229	7	1827	4255	617	0	0	0	0	951	2687	2687	0
April	109	996	0	1016	7	1827	3955	617	0	0	0	0	651	2687	2687	0
May	76	604	0	773	7	1827	3288	617	0	0	0	0	-16	2687	2687	0
June	51	17	0	190	7	1827	2092	617	0	0	0	0	-1212	2687	2687	0
July	51	6	0	191	7	1827	2082	617	0	0	0	0	-1221	2687	2687	0
August	51	12	0	193	7	1827	2090	617	0	0	0	0	-1214	2687	2687	0
September	51	69	0	485	7	1827	2439	617	0	0	0	0	-865	2687	2687	0
October	51	641	0	763	7	1827	3289	617	0	0	0	0	-15	2687	2687	0
November	119	902	0	963	7	1827	3818	617	0	0	0	0	515	2687	2687	0
December	168	466	0	1031	7	1827	3499	617	0	0	0	0	196	2687	2687	0
Average	111	562	0	796	7	1827	3304	617	0	0	0	0	0	2687	2687	0
Maximum	459	1755	0	2648	7	1827	6631	617	0	0	0	0	3327	2687	2687	0
Minimum	51	2	0	151	7	1827	2037	617	0	0	0	0	-1266	2687	2687	0
Total for the whole year																
TWh/year	0,98	4,94	0,00	7,00	0,06	16,05	29,02	5,42	0,00	0,00	0,00	0,00	0,00	23,60	23,60	0,00

RES Share: 41,2 Percent of Primary Energy 88,4 Percent of Electricity 27,4 TWh electricity from RES 16-april-2020 [11:35]

Input DK2030Ny.txt

The EnergyPLAN model 15.0

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	36,55	Fixed imp/exp.	0,00
Electric heating + HP	1,68	Transportation	2,08
Electric cooling	1,67	Total	41,98

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,00	15,97	20,84	36,81
Solar Thermal	0,00	1,00	0,00	1,00
Industrial CHP (CSHP)	0,00	0,78	0,93	1,71
Demand after solar and CSHP	0,00	14,18	19,91	34,10

Wind	4800	MW	11,83	TWh/year	0,00	Grid
Offshore Wind	4900	MW	20,59	TWh/year	0,00	stabili-
Photo Voltaic	4900	MW	5,2	TWh/year	0,00	sation
River Hydro	7	MW	0,02	TWh/year	0,00	share
Hydro Power	0	MW	0	TWh/year		
Geothermal/Nuclear	0	MW	0	TWh/year		

	Capacities		Efficiencies		
Group 2:	MW-e	MJ/s	elec.	Ther	COP
CHP	412	571	0,34	0,47	
Heat Pump	704	2112			3,00
Boiler		3177		0,98	
Group 3:					
CHP	827	2124	0,28	0,73	
Heat Pump	1	3			3,00
Boiler		3055		0,92	
Condensing	3112		0,36		

Heatstorage: gr.2: 33 GWh gr.3: 16 GWh
Fixed Boiler: gr.2: 20,0 Per cent gr.3: 0,0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,36	0,52
Gr.3:	0,10	1,05

Regulation Strategy:	Market regulation NEW	
CEEP regulation	234500000	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	10	MW
Minimum PP	10	MW
Heat Pump maximum share	0,50	
Maximum import/export	7105	MW

Di:NordPoolSystemPrice2015_EUR.txt		
Addition factor	0,00	EUR/MWh
Multiplication factor	1,60	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	34	EUR/MWh
Gas Storage	6000	GWh
Syngas capacity	0	MW
Biogas max to grid	617	MW

Fuel Price level:

	Capacities	Storage	Efficiencies	
	MW-e	GWh	elec.	Ther.
Hydro Pump:	0	0	0,00	
Hydro Turbine:	0		0,00	
Electrol. Gr.2:	0	0	0,40	0,50
Electrol. Gr.3:	0	0	0,40	0,50
Electrol. trans.:	0	0	0,00	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	56,72	0,06	0,00
Household	0,00	0,78	5,89	7,50
Industry	1,27	10,18	10,24	2,84
Various	0,00	6,34	5,06	0,45

Output

	District Heating										Electricity																			Exchange	
	Demand	Production									Consumption						Production							Balance						Payment	
	Distr. heating MW	Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba- lance MW	Elec. demand MW	Flex.& Transp. MW	HP MW	Elec- trolyser MW	EH MW	Hydro Pump MW	Tur- bine MW	RES MW	Hy- dro MW	Geo- thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Stab- Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Imp Million EUR	Exp Million EUR
January	6388	9	1114	0	2160	1663	0	1358	84	0	4776	232	772	0	181	0	0	4923	0	0	232	921	423	100	600	1138	0	1138	33	19
February	6788	49	1114	0	2269	1793	0	1497	65	1	4690	239	836	0	168	0	0	4381	0	0	232	979	367	100	711	736	0	736	32	12
March	5993	69	1114	0	2293	1499	0	965	49	5	4451	241	703	0	138	0	0	4016	0	0	232	982	123	100	777	597	0	597	34	10
April	5121	172	1114	0	2095	1002	0	649	64	26	4067	231	502	0	138	0	0	4222	0	0	232	898	40	100	422	877	0	877	16	13
May	4108	192	1114	0	1420	711	0	544	126	0	4014	241	368	0	183	0	0	5059	0	0	232	594	23	100	276	1378	0	1378	10	16
June	1672	251	1114	0	147	3	0	364	85	-291	4136	240	34	0	99	0	0	4164	0	0	232	58	10	100	880	835	0	835	23	5
July	1672	207	1114	0	73	3	0	364	146	-234	3921	232	37	0	161	0	0	4377	0	0	232	28	10	100	779	1076	0	1076	13	4
August	1678	196	1114	0	153	3	0	364	93	-244	4208	241	33	0	107	0	0	3708	0	0	232	60	10	100	1158	578	0	578	25	5
September	2890	124	1114	0	789	3	0	377	113	370	4254	235	82	0	148	0	0	4037	0	0	232	309	10	100	875	744	0	744	29	7
October	4044	65	1114	0	1707	365	0	392	39	362	4387	237	250	0	94	0	0	3303	0	0	232	734	151	100	985	437	0	437	39	7
November	4871	20	1114	0	2013	1055	0	598	45	26	4667	240	510	0	114	0	0	3790	0	0	232	870	248	100	917	525	0	525	41	9
December	5155	11	1114	0	1382	1376	0	1129	157	-15	4650	232	633	0	232	0	0	5403	0	0	232	572	124	100	461	1046	0	1046	18	12
Average	4190	114	1114	0	1371	787	0	715	89	0	4351	237	396	0	147	0	0	4284	0	0	232	582	128	100	736	832	0	832	Average price	
Maximum	10170	1437	1114	0	2696	2115	0	6276	760	3599	6514	720	1145	0	910	0	0	11479	0	0	232	1239	2563	100	4451	6477	0	6477	(EUR/MWh)	
Minimum	1465	0	1114	0	26	0	0	364	0	-2606	2626	0	0	0	11	0	0	10	0	0	232	10	10	100	0	0	0	0	49	16
TWh/year	36,81	1,00	9,79	0,00	12,04	6,91	0,00	6,28	0,78	0,00	38,22	2,08	3,47	0,00	1,29	0,00	0,00	37,63	0,00	0,00	2,04	5,11	1,12		6,47	7,31	0,00	7,31	315	120

FUEL BALANCE (TWh/year):	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon- version	Electro- Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	0,71	-	0,00	0,07	-	-	-	-	-	-	-	-	-	-	-	-	-	1,27	2,05	0,00	2,05	0,73	0,73
Oil	-	-	-	-	0,02	0,10	-	-	-	-	-	-	-	-	-	-	-	56,72	0,76	16,52	74,13	-0,21	73,92	19,46	19,40
N.Gas	-	-	0,71	0,45	0,43	-	-	-	-	-	-5,42	-	-	-	-	-	-	0,06	5,85	15,30	17,38	0,00	17,38	3,56	3,56
Biomass	-	2,74	13,40	2,92	2,77	2,97	-	-	10,64	-	8,24	-	-	-	-	-	-	-	7,43	3,29	54,39	-2,10	52,28	1,24	1,24
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	11,83	5,20	20,59	0,02	1,11	-	-	-	38,74	0,00	38,74	0,00	0,00
H2 etc.	-	0,00	0,00	0,00	0,00	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	0,00	-	0,00	-	-	-	-	-	-2,82	-	-	-	-	-	-	2,82	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	-	2,74	14,82	3,37	3,22	3,13	-	-	10,64	-	-	-	11,83	5,20	20,59	0,02	1,11	59,60	14,04	36,38	186,68	-2,31	184,37	24,99	24,93

04-maj-2020 [12:22]

Output specifications DK2030Ny.txt The EnergyPLAN model 15.0

District Heating Production

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW	Gr.2 District heating MW	Gr.2 Solar MW	Gr.2 CSHP MW	Gr.2 CHP MW	Gr.2 HP MW	Gr.2 ELT MW	Gr.2 Boiler MW	Gr.2 EH MW	Gr.2 Stor-age GW	Gr.2 Ba-lance MW
January	0	0	0	0	2771	9	395	240	1660	0	460	6	23	0
February	0	0	0	0	2945	49	395	289	1790	0	411	9	16	1
March	0	0	0	0	2600	69	395	270	1496	0	364	3	23	5
April	0	0	0	0	2222	172	395	249	999	0	372	2	20	33
May	0	0	0	0	1782	192	395	125	708	0	365	0	12	-3
June	0	0	0	0	725	251	395	1	0	0	364	0	123	-285
July	0	0	0	0	725	207	395	0	0	0	364	0	301	-240
August	0	0	0	0	728	196	395	0	0	0	364	0	473	-227
September	0	0	0	0	1254	124	395	5	0	0	364	0	450	366
October	0	0	0	0	1754	65	395	209	362	0	367	0	89	356
November	0	0	0	0	2113	20	395	260	1052	0	370	0	18	16
December	0	0	0	0	2236	11	395	103	1373	0	364	5	22	-15
Average	0	0	0	0	1818	114	395	145	784	0	377	2	131	0
Maximum	0	0	0	0	4412	1437	395	571	2112	0	3409	489	559	3082
Minimum	0	0	0	0	635	0	395	0	0	0	364	0	0	-2234
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	15,97	1,00	3,47	1,28	6,89	0,00	3,31	0,02		0,00

	Gr.3 District heating MW	Gr.3 Solar MW	Gr.3 CSHP MW	Gr.3 CHP MW	Gr.3 HP MW	Gr.3 ELT MW	Gr.3 Boiler MW	Gr.3 EH MW	Gr.3 Stor-age MW	Gr.3 Ba-lance MW
January	3617	0	719	1919	3	0	898	78	24	0
February	3843	0	719	1979	3	0	1086	56	2	0
March	3393	0	719	2023	3	0	601	46	51	0
April	2899	0	719	1845	3	0	277	62	4130	-7
May	2326	0	719	1295	3	0	180	126	5672	3
June	947	0	719	146	3	0	0	85	6083	-6
July	947	0	719	73	3	0	0	146	5563	6
August	950	0	719	153	3	0	0	93	6822	-17
September	1636	0	719	784	3	0	13	113	9048	5
October	2290	0	719	1498	3	0	24	39	6744	7
November	2758	0	719	1753	3	0	228	44	6757	10
December	2919	0	719	1279	3	0	766	152	1721	0
Average	2372	0	719	1226	3	0	338	87	4385	0
Maximum	5758	0	719	2124	3	0	3554	271	15700	2712
Minimum	829	0	719	26	0	0	0	0	0	-1928
Total for the whole year TWh/year	20,84	0,00	6,32	10,77	0,03	0,00	2,97	0,76		0,00

	RES specification RES1 Wind MW	RES2 Offshoı MW	RES3 Photo \ MW	RES 4-7 ic MW	Total MW
January	1717	3094	110	2	4923
February	1528	2644	207	2	4381
March	1350	2085	579	2	4016
April	1130	2113	976	2	4222
May	1457	2637	963	2	5059
June	1061	2059	1044	1	4164
July	1178	2199	1000	1	4377
August	864	1915	929	1	3708
September	1033	2315	689	1	4037
October	965	1986	350	2	3303
November	1679	1952	156	2	3790
December	2198	3113	89	3	5403
Average	1347	2344	592	2	4284
Maximum	4800	4900	4900	3	11479
Minimum	1	0	0	1	10
Total for the whole year TWh/year	11,83	20,59	5,20	0,02	37,63

Own use of heat from industrial CHP: 0,00 TWh/year

ANNUAL COSTS (Million EUR)		
Total Fuel ex Ngas exchange =		4782
Uranium =	0	
Coal =	21	
FuelOil =	449	
Gasoil/Diesel=	1752	
Petrol/JP =	1378	
Gas handling =	144	
Biomass =	1038	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		297
Marginal operation costs =		19
Total Electricity exchange =		195
Import =	315	
Export =	-120	
Bottleneck =	0	
Fixed imp/ex=	0	
Total CO2 emission costs =		161
Total variable costs =		5455
Fixed operation costs =		4527
Annual Investment costs =		9424
TOTAL ANNUAL COSTS =		19407

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	194	126	0	1109	7	1742	3178	617	0	0	0	0	582	1979	1979	0
February	214	130	0	1187	7	1742	3281	617	0	0	0	0	685	1979	1979	0
March	137	133	0	1028	7	1742	3047	617	0	0	0	0	451	1979	1979	0
April	91	121	0	849	7	1742	2810	617	0	0	0	0	214	1979	1979	0
May	76	85	0	645	7	1742	2555	617	0	0	0	0	-41	1979	1979	0
June	50	10	0	158	7	1742	1966	617	0	0	0	0	-630	1979	1979	0
July	50	5	0	159	7	1742	1963	617	0	0	0	0	-633	1979	1979	0
August	50	10	0	161	7	1742	1969	617	0	0	0	0	-627	1979	1979	0
September	52	52	0	405	7	1742	2257	617	0	0	0	0	-339	1979	1979	0
October	54	99	0	638	7	1742	2540	617	0	0	0	0	-56	1979	1979	0
November	84	115	0	805	7	1742	2754	617	0	0	0	0	158	1979	1979	0
December	161	84	0	863	7	1742	2857	617	0	0	0	0	261	1979	1979	0
Average	101	81	0	666	7	1742	2596	617	0	0	0	0	0	1979	1979	0
Maximum	885	140	0	2216	7	1742	4969	617	0	0	0	0	2373	1979	1979	0
Minimum	50	2	0	127	7	1742	1927	617	0	0	0	0	-669	1979	1979	0
Total for the whole year TWh/year	0,89	0,71	0,00	5,85	0,06	15,30	22,80	5,42	0,00	0,00	0,00	0,00	0,00	17,38	17,38	0,00

RES Share: 49,9 Percent of Primary Energy 106,3 Percent of Electricity 44,9 TWh electricity from RES

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Input DK203070pct.txt

The EnergyPLAN model 15.0

Electricity demand (TWh/year):		Flexible demand	0,00
Fixed demand	36,55	Fixed imp/exp.	0,00
Electric heating + HP	1,90	Transportation	6,21
Electric cooling	1,67	Total	46,33

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,00	15,97	20,84	36,81
Solar Thermal	0,00	1,00	0,00	1,00
Industrial CHP (CSHP)	0,00	0,78	0,93	1,71
Demand after solar and CSHP	0,00	14,18	19,91	34,10

Wind	4800 MW	11,83	TWh/year	0,00	Grid
Offshore Wind	4900 MW	20,59	TWh/year	0,00	stabili-
Photo Voltaic	4900 MW	5,2	TWh/year	0,00	sation
River Hydro	7 MW	0,02	TWh/year	0,00	share
Hydro Power	0 MW	0	TWh/year		
Geothermal/Nuclear	0 MW	0	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	412	571	0,34	0,47	
Heat Pump	704	2112			3,00
Boiler		3177		0,98	
Group 3:					
CHP	827	2124	0,28	0,73	
Heat Pump	1	3			3,00
Boiler		3055		0,92	
Condensing	3112		0,36		

Heatstorage: gr.2: 33 GWh gr.3: 16 GWh
Fixed Boiler: gr.2: 20,0 Per cent gr.3: 0,0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	0,36	0,52
Gr.3:	0,10	1,05

Regulation Strategy:	Market regulation NEW	
CEEP regulation	234500000	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	10	MW
Minimum PP	10	MW
Heat Pump maximum share	0,50	
Maximum import/export	7105	MW

Di:NordPoolSystemPrice2015_EUR.txt		
Addition factor	0,00	EUR/MWh
Multiplication factor	1,60	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	34	EUR/MWh
Gas Storage	6000	GWh
Syngas capacity	0	MW
Biogas max to grid	617	MW

Fuel Price level:

	Capacities MW-e	Storage GWh	Efficiencies elec.	Ther.
Hydro Pump:	0	0	0,00	
Hydro Turbine:	0		0,00	
Electrol. Gr.2:	0	0	0,40	0,50
Electrol. Gr.3:	0	0	0,40	0,50
Electrol. trans.:	2454	232	0,73	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	27,83	0,06	0,00
Household	0,00	0,00	5,89	7,50
Industry	1,27	4,80	4,64	2,84
Various	0,00	2,50	4,45	0,45

Output

	District Heating										Electricity																		Exchange	
	Demand	Production									Consumption						Production							Balance					Payment	
	Distr. heating MW	Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba- lance MW	Elec. demand MW	Flex.& Transp. MW	HP MW	Elec- trolyser MW	EH MW	Hydro Pump MW	Tur- bine MW	RES MW	Hy- dro MW	Geo- thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Stab- Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Imp Million EUR	Exp
January	6388	9	1114	0	2347	1613	15	1232	55	4	4776	689	795	252	151	0	0	4923	0	0	232	1003	479	100	818	793	0	793	48	15
February	6788	49	1114	0	2462	1710	15	1377	28	32	4690	713	855	437	131	0	0	4381	0	0	232	1072	449	100	1082	390	0	390	51	7
March	5993	69	1114	0	2414	1465	15	911	19	-14	4451	722	730	593	108	0	0	4016	0	0	232	1047	177	100	1377	245	0	245	62	5
April	5121	172	1114	0	2226	995	15	549	46	4	4067	687	533	135	121	0	0	4222	0	0	232	961	57	100	687	617	0	617	28	11
May	4108	192	1114	0	1679	634	15	393	76	5	4014	727	364	785	132	0	0	5059	0	0	232	715	34	100	611	629	0	629	21	11
June	1672	251	1114	0	146	6	15	364	73	-296	4136	713	42	177	88	0	0	4164	0	0	232	58	14	100	1190	502	0	502	32	4
July	1672	207	1114	0	77	3	15	364	128	-236	3921	704	44	530	143	0	0	4377	0	0	232	30	10	100	1259	567	0	567	21	3
August	1678	196	1114	0	155	3	15	364	71	-240	4208	711	38	473	86	0	0	3708	0	0	232	60	13	100	1809	307	0	307	40	3
September	2890	124	1114	0	804	3	15	371	89	369	4254	698	97	375	125	0	0	4037	0	0	232	316	21	100	1300	357	0	357	43	5
October	4044	65	1114	0	1696	320	15	406	34	395	4387	706	261	282	89	0	0	3303	0	0	232	723	200	100	1501	234	0	234	61	4
November	4871	20	1114	0	2125	1081	15	516	18	-19	4667	716	548	227	88	0	0	3790	0	0	232	921	344	100	1220	260	0	260	56	5
December	5155	11	1114	0	1673	1328	15	892	118	4	4650	697	650	653	192	0	0	5403	0	0	232	695	157	100	798	443	0	443	30	5
Average	4190	114	1114	0	1480	761	15	643	63	0	4351	707	412	412	121	0	0	4284	0	0	232	632	162	100	1138	446	0	446	Average price (EUR/MWh)	
Maximum	10170	1437	1114	0	2696	2115	15	6261	760	3584	6514	4470	1228	2454	910	0	0	11479	0	0	232	1239	2563	100	7105	5642	0	5642		
Minimum	1465	0	1114	0	26	0	15	364	0	-2857	2626	0	0	0	11	0	0	10	0	0	232	10	10	100	0	0	0	0	49	20
TWh/year	36,81	1,00	9,79	0,00	13,00	6,68	0,13	5,65	0,55	0,00	38,22	6,21	3,62	3,62	1,06	0,00	0,00	37,63	0,00	0,00	2,04	5,55	1,42		10,00	3,92	0,00	3,92	492	79

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon- version	Electro- Fuel	Wind	PV and CSP	Wind off Wave	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1,27	1,27	0,00	1,27	0,45	0,45
Oil	-	-	-	0,00	-	-	-	-	-	-	-	-	-	-	-	-	-	27,83	-	7,30	35,13	0,00	35,13	9,22	9,22
N.Gas	-	-	0,80	0,46	0,34	-	-	-	-	-	-5,42	-	-	-	-	-	-	0,06	5,85	9,09	11,17	0,00	11,17	2,29	2,29
Biomass	-	3,16	15,07	2,95	2,15	3,95	-	-	10,64	-	8,24	-	-	-	-	-	-	-	7,43	3,29	56,88	16,76	73,64	1,24	1,24
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	11,83	5,20	20,59	0,02	1,10	-	-	-	38,73	0,00	38,73	0,00	0,00
H2 etc.	-	0,00	0,00	0,00	0,00	0,00	-	-	-	-2,64	-	-	-	-	-	-	-	2,64	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-2,82	4,01	-	-	-	-	-	22,45	-	-	23,64	0,00	23,64	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	-	3,16	15,86	3,41	2,48	3,95	-	-	10,64	-2,64	-	4,01	11,83	5,20	20,59	0,02	1,10	52,98	13,28	20,95	166,81	16,76	183,57	13,20	13,20

Output specifications DK203070pct.txt — The EnergyPLAN model 15.0

District Heating Production

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW	Gr.2 District heating MW	Gr.2 Solar MW	Gr.2 CSHP MW	Gr.2 CHP MW	Gr.2 HP MW	Gr.2 ELT MW	Gr.2 Boiler MW	Gr.2 EH MW	Gr.2 Storage GW	Gr.2 Balance MW
January	0	0	0	0	2771	9	395	270	1610	0	482	1	22	4
February	0	0	0	0	2945	49	395	341	1707	0	418	2	15	32
March	0	0	0	0	2600	69	395	323	1462	0	364	2	13	-14
April	0	0	0	0	2222	172	395	286	992	0	364	2	24	11
May	0	0	0	0	1782	192	395	186	631	0	374	0	5	4
June	0	0	0	0	725	251	395	3	3	0	364	0	126	-290
July	0	0	0	0	725	207	395	0	0	0	364	0	304	-240
August	0	0	0	0	728	196	395	0	0	0	364	0	477	-227
September	0	0	0	0	1254	124	395	7	0	0	364	0	454	364
October	0	0	0	0	1754	65	395	188	317	0	403	0	83	386
November	0	0	0	0	2113	20	395	281	1079	0	364	0	24	-26
December	0	0	0	0	2236	11	395	132	1325	0	364	5	25	4
Average	0	0	0	0	1818	114	395	167	758	0	382	1	131	0
Maximum	0	0	0	0	4412	1437	395	571	2112	0	3409	489	562	3082
Minimum	0	0	0	0	635	0	395	0	0	0	364	0	0	-2419
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	15,97	1,00	3,47	1,47	6,66	0,00	3,36	0,01		0,00

	Gr.3 District heating MW	Gr.3 Solar MW	Gr.3 CSHP MW	Gr.3 CHP MW	Gr.3 HP MW	Gr.3 ELT MW	Gr.3 Boiler MW	Gr.3 EH MW	Gr.3 Storage MW	Gr.3 Balance MW
January	3617	0	719	2077	3	15	750	54	61	0
February	3843	0	719	2121	3	15	959	26	3	0
March	3393	0	719	2091	3	15	547	17	33	0
April	2899	0	719	1939	3	15	185	45	4406	-7
May	2326	0	719	1494	3	15	19	76	7730	0
June	947	0	719	143	3	15	0	73	7800	-6
July	947	0	719	77	3	15	0	128	7686	4
August	950	0	719	155	3	15	0	71	7311	-13
September	1636	0	719	797	3	15	7	89	9615	6
October	2290	0	719	1507	3	15	3	34	8201	9
November	2758	0	719	1843	3	15	153	18	5531	7
December	2919	0	719	1540	3	15	529	113	4280	0
Average	2372	0	719	1313	3	15	261	62	5232	0
Maximum	5758	0	719	2124	3	15	3231	271	15700	2781
Minimum	829	0	719	26	0	15	0	0	0	-1890
Total for the whole year TWh/year	20,84	0,00	6,32	11,53	0,02	0,13	2,29	0,55		0,00

RES specification

	RES1 Wind MW	RES2 Offshoı MW	RES3 Photo \ MW	RES 4-7 ic MW	Total MW
January	1717	3094	110	2	4923
February	1528	2644	207	2	4381
March	1350	2085	579	2	4016
April	1130	2113	976	2	4222
May	1457	2637	963	2	5059
June	1061	2059	1044	1	4164
July	1178	2199	1000	1	4377
August	864	1915	929	1	3708
September	1033	2315	689	1	4037
October	965	1986	350	2	3303
November	1679	1952	156	2	3790
December	2198	3113	89	3	5403
Average	1347	2344	592	2	4284
Maximum	4800	4900	4900	3	11479
Minimum	1	0	0	1	10
Total for the whole year TWh/year	11,83	20,59	5,20	0,02	37,63

Own use of heat from industrial CHP: 0,00 TWh/year

ANNUAL COSTS (Million EUR)

Total Fuel ex Ngas exchange =		2902
Uranium =	0	
Coal =	13	
FuelOil =	197	
Gasoil/Diesel=	736	
Petrol/JP =	740	
Gas handling =	119	
Biomass =	1097	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		191
Marginal operation costs =		21
Total Electricity exchange =		411
Import =	492	
Export =	-79	
Bottleneck =	-1	
Fixed imp/ex=	0	
Total CO2 emission costs =		85
Total variable costs =		3611
Fixed operation costs =		4595
Annual Investment costs =		9794
TOTAL ANNUAL COSTS =		18000

NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Individual MW	Transport MW	Indu. Var. MW	Demand Sum MW	Biogas MW	Syngas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Storage MW	Sum MW	Import MW	Export MW
January	176	144	0	1109	7	1035	2470	617	0	0	0	0	582	1272	1272	0
February	198	147	0	1187	7	1035	2573	617	0	0	0	0	685	1272	1272	0
March	130	145	0	1028	7	1035	2344	617	0	0	0	0	455	1272	1272	0
April	77	134	0	849	7	1035	2102	617	0	0	0	0	213	1272	1272	0
May	54	103	0	645	7	1035	1844	617	0	0	0	0	-44	1272	1272	0
June	50	10	0	158	7	1035	1259	617	0	0	0	0	-629	1272	1272	0
July	50	5	0	159	7	1035	1256	617	0	0	0	0	-633	1272	1272	0
August	50	11	0	161	7	1035	1263	617	0	0	0	0	-626	1272	1272	0
September	51	55	0	405	7	1035	1553	617	0	0	0	0	-336	1272	1272	0
October	56	104	0	638	7	1035	1840	617	0	0	0	0	-49	1272	1272	0
November	72	127	0	805	7	1035	2047	617	0	0	0	0	158	1272	1272	0
December	127	107	0	863	7	1035	2138	617	0	0	0	0	249	1272	1272	0
Average	91	91	0	666	7	1035	1889	617	0	0	0	0	0	1272	1272	0
Maximum	885	147	0	2216	7	1035	4269	617	0	0	0	0	2381	1272	1272	0
Minimum	50	2	0	127	7	1035	1220	617	0	0	0	0	-669	1272	1272	0
Total for the whole year TWh/year	0,80	0,80	0,00	5,85	0,06	9,09	16,59	5,42	0,00	0,00	0,00	0,00	0,00	11,17	11,17	0,00

RES Share: 57,3 Percent of Primary Energy 94,5 Percent of Electricity 45,9 TWh electricity from RES

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