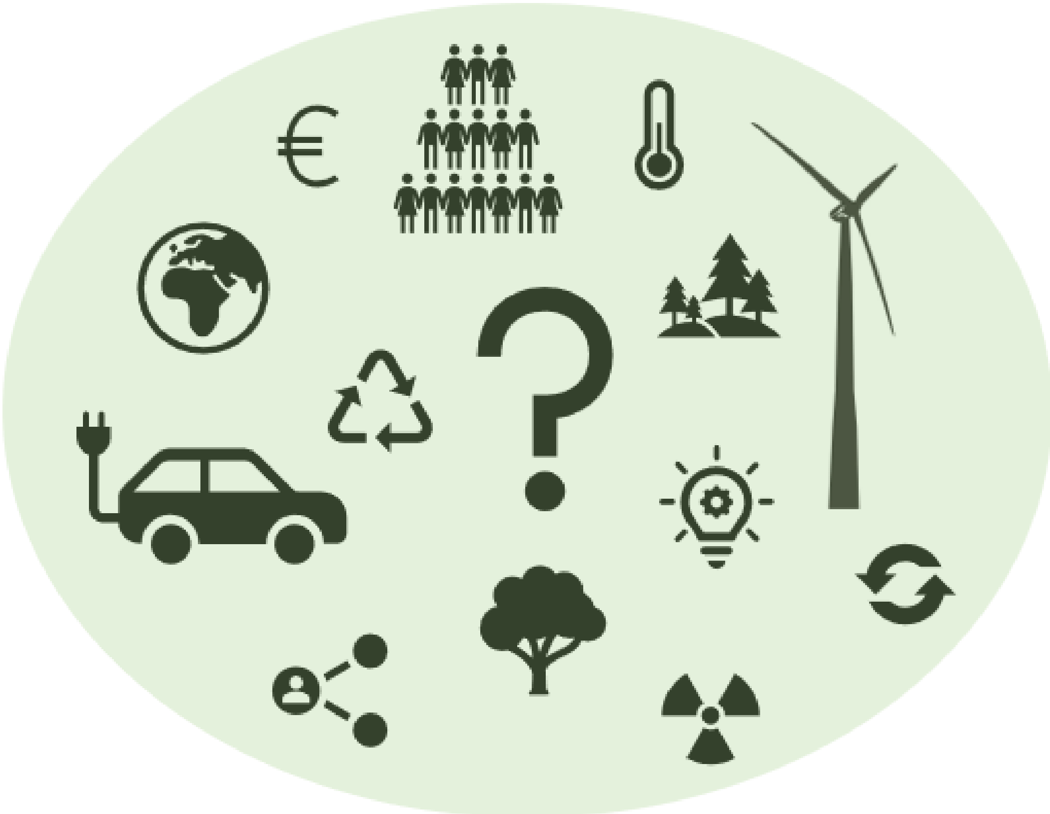
Electric Car Integration in the Danish Energy System

- a planning and institutional approach to technological change



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August 6th 2020

Title	Electric Car Integration in the Danish Energy System - a planning and institutional approach to technological change
Semester theme	Master's Thesis
Semester	4^{th} - Master's Programme in Urban, Energy and Environmental Planning with Specialisation in Sustainable Energy Planning and Management
Faculty	The Technical Faculty of IT and Design
Department	Department of Planning
Project period	3^{rd} of February 2020 to 6^{th} of August 2020
ECTS	30
Supervisor	Jakob Zinck Thellufsen
Author	Karina Hjeds
Pages, total	110
Appendices	2

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Abstract

In this Master's thesis, it is investigated how different scenarios with variations in the electric car share can affect the Danish energy system and the transition it is currently going through to become 100% fossil free in the year 2050. The methods applied in the thesis include scenario planning together with the energy system analysis tool EnergyPLAN. The methodology is applied in the first part of the analysis, which is carried out through a technical approach. The second part of the analysis has its point of departure in the theoretical framework of the thesis. This analysis investigates how external conditions influence on technological change and large technical systems. An approximation model for large technical systems is applied together with technological change theory, resulting in an institutional analysis of qualitative matter. Lastly, the findings from the two analyses are combined and discussed in relation to each other. In relation to the thesis scenarios, it can be concluded that the future transport sector should consist of a minimum of 50% electric cars for the biomass consumption not to exceed the critical limit, and that an increase in electric cars not requires an increase in wind capacity, but that the costs will increase in step with the electric car share and hydrogen usage. The thesis also concludes, that external conditions can affect technological change in different directions. Additionally, it is possible to perform adjustments within these conditions to influence technological change and to promote the desired scenario for the future energy system.

Referat

I dette afsluttende speciale er det undersøgt, hvordan variationer i andelen af elbiler kan påvirke det danske energisystem, som på nuværende tidspunkt undergår en omstilling fra et energisystem baseret på fossile brændsler, til et energisystem baseret udelukkende på vedvarende energi. Det danske folketing har vedtaget et energipolitisk mål, som omhandler en total omstilling af energisystemet, så det i år 2050 er fri for fossile brændsler. Dette betyder derfor, at energiforbruget i den danske transportsektor, som står for en betydelig andel i forbruget af fossile brændsler, ligeledes skal omstilles til vedvarende energi. Til dette vil elektricitet blive prioriteret højt på grund af den høje effektivitet forbundet med elbiler, samt de lave priser på denne form for energi. På nuværende tidspunkt har udviklingen i elbiler i Danmark ikke været som ønsket, og det er derfor både relevant og aktuelt at opstille scenarier, der illustrerer, hvordan forskellige andele i elbiler kan påvirke det danske energisystem.

Med udgangspunkt i IDAs energivision er tre forskellige scenarier med tilhørende underscenarier udformet for at belyse den usikkerhed, der er forbundet med elbiler i Danmark. Scenarierne er udformet på baggrund af en metode for scenarieplanlægning, og den praktiske udførsel er foretaget i EnergyPLAN, som er et simuleringsprogram anvendt til udførsel af energisystemanalyse. I specialet er der ydermere anvendt en overordnet forståelse for begrebet 'smart energisystem', som er denne form for energisystem der ønskes opnået i år 2050. Den teoretiske ramme for specialet omhandler teknologisk forandring, og her er der anvendt en model for, hvordan store tekniske systemer kan tilgås. Derudover er teori omhandlende teknologisk forandring anvendt for at give en forståelse for, hvordan ydre påvirkninger kan resultere i denne forandring. Denne del af analysen har en institutionel tilgang, og de to forskellige analyser er til sidst forbundet og diskuteret i relation til hinanden.

Det første scenarie i analysen indeholder lineær vækst, hvilket betyder, at den vækst som har gjort sig gældende for elbiler indtil i dag, er videreført til år 2050, hvilket giver en mindre andel i elbiler. Til dette scenarie er der udformet tre underscenarier, hvor den resterende del af bilflåden er erstattet med enten fossile brændsler, biobrændsel eller en kombination af biobrændsel og brint. Scenariet indeholdende fossile brændsler er uønsket i det fremtidige energisystem, da målet er at eliminere denne energiform. I det andet scenarie består bilflåden af 50% elbiler, og her indeholder den resterende del af bilflåden enten biobrændsel eller en kombination af biobrændsel og brint fordelt på to underscenarier. I det sidste scenarie er der anvendt en andel i elbiler på 90% af bilflåden, og her er den sidste andel biler erstattet af enten biobrændsel eller brint, ligeledes fordelt på to underscenarier.

Resultaterne af analysen indikerer, at den fremtidige transportsektor som absolut minimum skal bestå af 50% elbiler for ikke at overskride den kritiske biomassegrænse. Derudover viser scenarierne, at en øgning i antallet af elbiler ikke er ensbetydende med at vindkapaciteten skal udbygges tilsvarende, men at omkostningerne stiger i takt med andelen af elbiler

og brintforbruget. Derudover viser resultaterne, at teknologisk forandring skyldes ydre påvirkninger, og at det er muligt at justere disse betingelser, så de påvirker teknologien i den ønskede retning. Det kan konkluderes, at det især er politisk regulering, der kan have en effekt på udviklingen af elbiler, da det med disse initiativer er muligt at påvirke adfærden i samfundet. Ved hjælp af reguleringer er det derfor muligt at gøre elbiler mere attraktive og derved påvirke elbilsudviklingen i den ønskede retning.

Preface

This Master's thesis is the culmination of the two years Master's programme in Sustainable Energy Planning and Management at Aalborg University. The thesis was completed during the global COVID-19 pandemic, forcing Aalborg University to deny students campus access due to a society lock-down. Even though this thesis was composed by a single student, did the university lock-down affect the work intensity during a period of time, because of the work spaces at Aalborg University being unavailable. Though, the supervision meetings were still possible to attend online, which makes the consequences of the COVID-19 pandemic less significant seen in relation to the preparation of this thesis.

Reading Guide
The reference method used in the thesis is the Harvard method denounced as [author, publication year]. A nomenclature is placed in the beginning, including abbreviations, units and chemical formulas mentioned in the thesis. The thesis includes seven different chapters, which should be read chronologically. The thesis is initiated with an introduction functioning as a problem analysis and followed by a chapter with a presentation of the research question. Chapter 3 and 4, respectively, deal with the theories and methods applied in the thesis. Naturally, this leads to the analysis, which is divided into two chapters; one with a technical approach and one with an institutional approach. Chapter 7 consists of a discussion of the analysis results, which leads to the conclusion of the thesis. Appendices are attached in the end of the thesis and are mentioned with letters in the order that they are applied throughout the thesis.

Thanks...
Lastly, a great 'thank you' is directed at Jakob Zinck Thellufsen for being helpful during a semester under unusual conditions, and for providing great supervision throughout the process of writing this thesis.

Nomenclature

Abbreviations

EC	Electric Car
EV	Electric Vehicle
BEV	Battery Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
CEEP	Critical Excess Electricity Production
ICE	Internal Combustion Engine
RE	Renewable Energy
RES	Renewable Energy System
SES	Smart Energy System
CHP	Combined Heat and Power
BTL	Biomass-to-liquid
IDA	The Danish Society of Engineers
DEA	The Danish Energy Agency
BAU	Business As Usual
MEUR	Million Euros

Units

GJ	Gigajoule
PJ	Petajoule
MJ	Megajoule
MW	Megawatt
MWh	Megawatt hour
TWh	Terawatt hour
Mpkm	Million passenger-kilometer
Mt	Megaton

Chemical formulas

CO_2	Carbon dioxide
H_2O	Dihydrogen monoxide

Contents

Introduction 1

The Danish government has composed a goal with the aim to make Denmark independent of fossil fuels in the year 2050. The goal emerges from the fact that a new energy policy era has begun, which means that the so far accessible and cheap fossil fuels have to be replaced by other energy sources. An increase in the world's energy consumption has resulted in a pressure on the fossil fuel resources creating an energy race which the Danish government does not wish to be a part of. This is due to the fact, that the fuel prices rises and that the fossil fuel reserves often are located in countries that are political unstable, which makes the future of these energy sources uncertain. In an energy perspective, Denmark will obtain independence by eliminating fossil fuels. Political energy goals have therefore been composed with the purpose for Denmark to undergo a transition to renewable energy, which will also be the Danish contribution to reduce climate change [The Danish Government, 2011]. The Danish goal thereby also includes the transport sector, which is perceived a challenge in the green transition. The transport sector accounts for a large oil dependence and for that reason, renewable energy solutions and new technologies have to be integrated in the Danish energy system [Mathiesen et al., 2008].

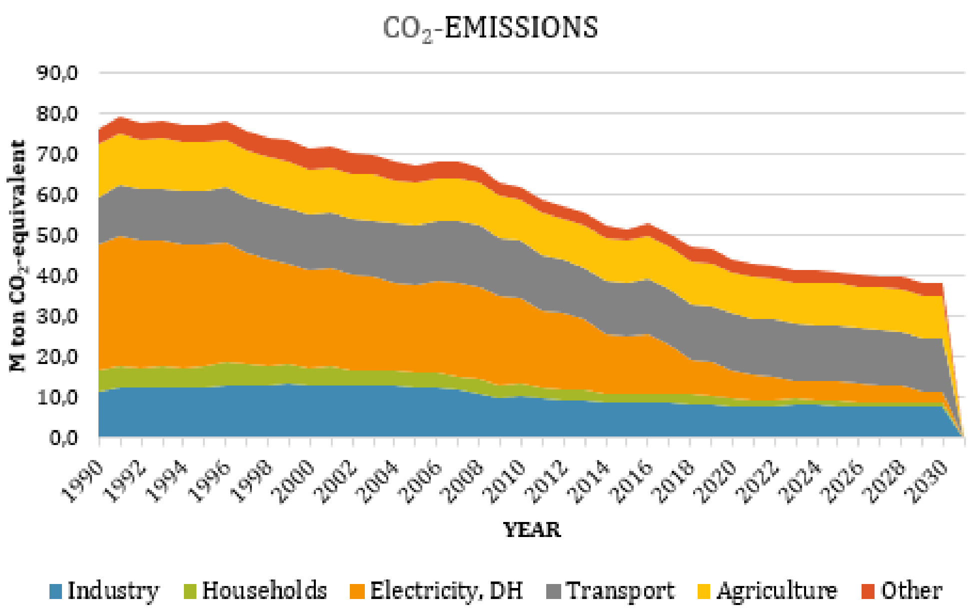

Figure 1.1: CO2-emissions distributed on sectors in Denmark [Energistyrelsen, 2019]

The transport sector is not only one of the sectors with the highest energy demand, but it is also the sector that currently, and in the future, emits the largest share of CO_2 [figure 1.1]. With electricity being an efficient and cheap energy resource, the majority of the transport sector is expected to be electrified [Mathiesen et al., 2015b]. This thesis investigates the consequences that occur, if the expected development within electric cars is not to be achieved. The effect on the energy system will be examined and alternative solutions that will ensure a fossil free society will be presented. Furthermore, is an analysis of technological change being conducted to achieve an understanding of how institutions can affect technological development.

1.1 Energy & Transport Demand

The current expectations for the global transport demand is that significant growth will be experienced in the years to come, which is due to many factors such as population and economic growth [International Transport Forum, 2019]. This is the case for Denmark as well, where recent projections show that the energy consumption for road transport will increase by approximately 0,1% annually towards 2030. In the same year, vans and passenger cars will constitute of 47% of the total energy consumption in the transport sector. Though, improved car technology efficiencies result in the energy consumption not increasing further [Energistyrelsen, 2019], even though the number in newly registered cars is growing [figure 1.2] due to private vehicles being the preferred travel mode on a world wide basis [International Transport Forum, 2019].

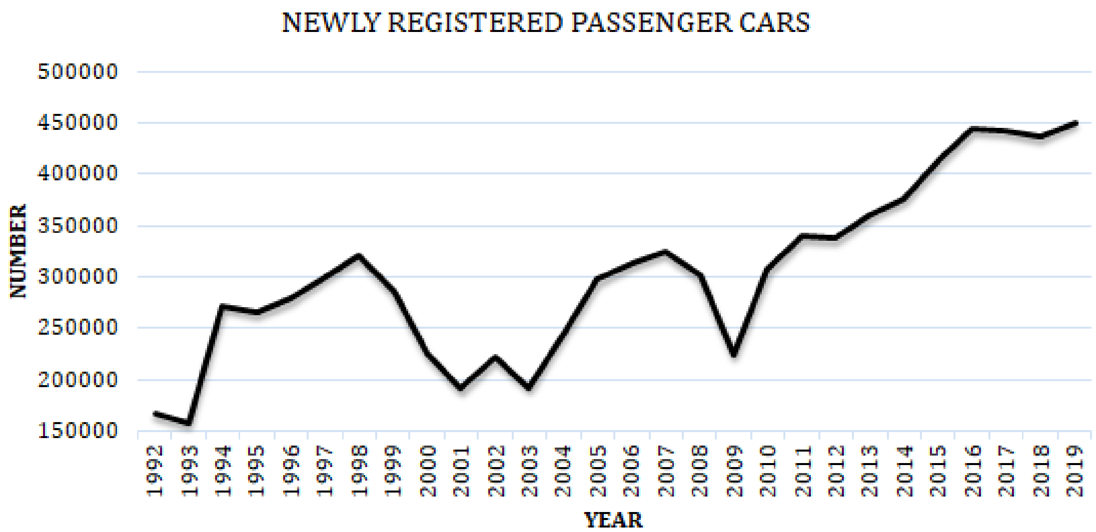

Figure 1.2: The distribution of newly registered passenger cars in Denmark from 1992-2019 [Danmarks Statistik, 2020a]

Figure 1.2 shows the purchasing number of new cars. The graph illustrates the development within newly registered passenger cars, which especially has been increasing over the past decade. This increase has thereby also resulted in a larger car fleet in Denmark, where more than 2,6 million passenger cars are to find on the Danish roads [figure 1.3].

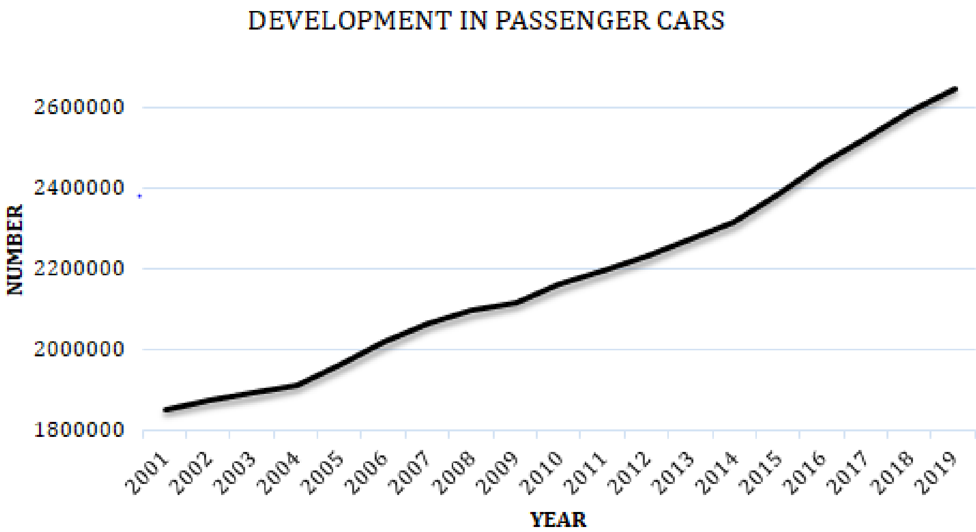

Figure 1.3: Number of passenger cars in Denmark from 2001-2019 [Danmarks Statistik, 2020b]

The increasing energy consumption used for transportation, together with an increase in the number of passenger cars, is making it more challenging to convert this sector to renewable energy. To convert the transport sector to renewable energy, there is no obvious solution, but studies show that electricity should have high priority in the equation, as this energy form is the cheapest and most efficient solution [Connolly et al., 2014b]. Other alternatives of renewable energy that can be used in the transport sector includes biomass, hydrogen, gas and electrofuels [Simonsen, 2016]. Though, challenges occur in the use of some energy sources. Biomass is a limited source [Lund, 2014b], because of the utilization of land in order to grow the plants for biomass. For this energy source, discussions about sustainability and emissions follow because of biomass only being considered CO_2-neutral if new plants are being planted to take up the emitted CO_2. Though, biomass is also a manageable source, meaning that it is not fluctuating and it is easy to store. This also means, that the biomass characteristics are similar to fossil fuels, which makes it the obvious alternative [Dansk Energi, n.d]. For cars that run on gas, the efficiency is lower than for ECs, which gives this technology a lower priority. Besides that, hydrogen is being converted from H_2O by an electrolysis process, which makes it a necessity to produce electricity for this process to happen. Storage of hydrogen can also be considered as storage of fluctuating energy, making the energy system more flexible[1]. But, transportation of hydrogen is also an expensive and complicated procedure, and safety issues are linked to the handling of the source [Energistyrelsen and Energinet, 2018]. These arguments are contributing to give electricity first priority in the transport sector, but it might also be necessary to include several different technologies as they can weigh up each other's weaknesses [Klimarådet, 2018].

[1]Flexibility in an energy system describes the system's ability to handle uncertainty and variability on both the demand and production side. It also includes that the system's reliability maintain a satisfactory level and with reasonable costs [Ma et al., 2013].

1.2 Electric Cars in the Danish Energy System

Several studies point at ECs being an important part of the solution in the process of making the transport sector fossil free. But today, ECs cannot be considered a zero-emission technology, both in relation to the fuel that is used and in a life cycle perspective, which is because of the emissions related to the production of the car. Currently, the resources used for production can derive from fossil fuels instead of renewable energy, which is also the case for the production of the electricity used as EC fuel. Though, this is expected to change in the future, where renewable energy replaces fossil fuels making both the production process and the technology zero-emitters.

Car	Diesel	Gas	Electric
Driving costs (euro/km)	0,193	0,188	0,145
Energy consumption (MJd/km)	1,91	1,98	0,53
Energy consumption (km/l gas-equiv)	17,2	16,6	62,2
Propellant cost total (euro/GJd)	22,12	23,08	22,89
Fuel cost (euro/km)	0,04	0,05	0,01
Vehicle efficiency	20,7%	19,5%	78,6%

Table 1.1: Comparison of technology characteristics [Energistyrelsen, 2016]

Today, ECs are in competition with fossil fuel driven cars, and it is thereby uncertain if people find ECs attractive with other alternatives available. ECs come with some advantages in comparison to fossil fuel driven cars in relation to efficiency, economy and environment [table 1.1], but cars running on fossil fuels do have other advantages such as lower cost prices and better range [Klimarådet, 2018]. In 2019, the sales of ECs made up 5,500 cars or 3,9% of the total car sale in Denmark [figure 1.4]. Currently, ECs account for approximately 15,500 cars or 1% of the Danish car fleet [Danmarks Statistik, 2019].

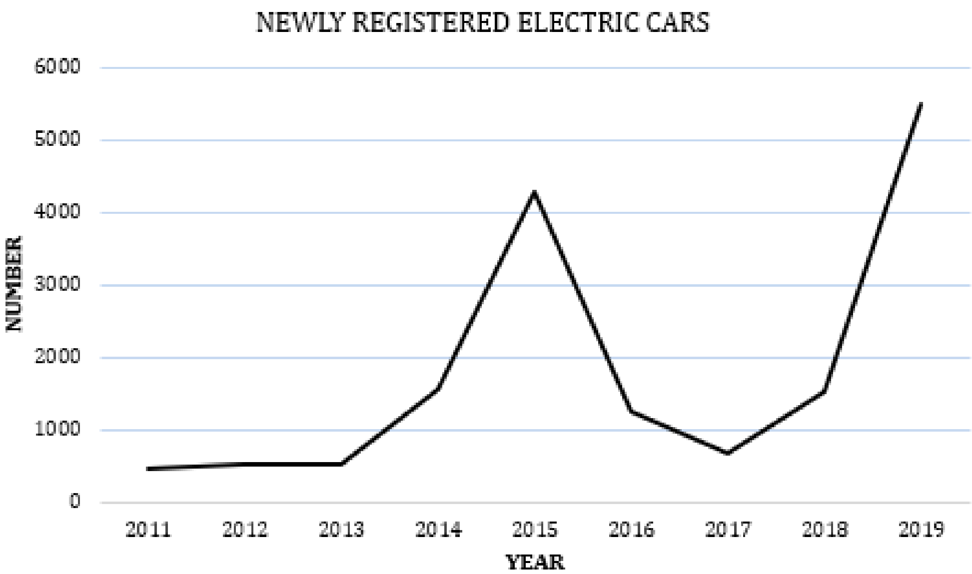

Figure 1.4: Newly registered electric cars in Denmark from 2011-2019 [Danmarks Statistik, 2020c]

The Danish Council on Climate Change suggests, on the background of socio-economic costs and the technology's potential to promote the green transition, that the number of ECs reaches 500,000 or 17% of the car fleet by 2030 [Klimarådet, 2018]. This means, that nearly 50,000 ECs will have to be sold every year for the next decade. Though, according to the DEA projections, the expected number of ECs in 2030 will only reach 300.000 [Energistyrelsen, 2019], which means that almost 30.000 ECs have to be sold every year.

1.3 Scenarios for the future Danish Energy System

Several scenarios have been composed to illustrate possible solutions to a fossil free energy system in 2050. The Danish Energy Agency has composed four different scenarios for a fossil free energy system in 2050:

- *Wind scenario* - This scenario contains a bioenergy consumption equal to what Denmark can deliver. Besides that, electrification of the transport sector is crucial and requires expansion of the offshore wind turbine capacity. There is a wish to keep the bioenergy consumption to a minimum, which is managed by using hydrogen for upgrading biogas and biomass
- *Biomass scenario* - This scenario does not contain hydrogen, but a higher bioenergy consumption that requires import of biomass
- *Bio+ scenario* - This scenario is similar to the energy system of today, as it is based on combustion. But, instead of fossil fuels, the energy source will be bioenergy. The scenario contains no use of hydrogen
- *Hydrogen scenario* - A small use of bioenergy is used in this scenario. Instead, hydrogen is the primarily energy source, and the wind capacity therefore has to be significantly expanded [Energistyrelsen, 2013]

In a report commissioned by IDA, composed by Aalborg University, another example of a renewable energy system is illustrated and compared to the DEA Wind scenario. In the IDA vision, the importance of cross-sectoral interaction is underlined. This means, that focus should be on the energy system as a whole instead of operating with the sectors individually [Mathiesen et al., 2015b].

Generally, the scenarios show, that a renewable energy system is a technical and economical possibility, but they are also an invitation to debate on how to reach a renewable energy system, because several possible scenarios can function as solutions [Mathiesen et al., 2015b].

In several of the 2050 scenarios there is widespread consensus about electrification of the transport sector being the most optimal solution [Energistyrelsen, 2013; Mathiesen et al., 2015b; Lund et al., 2011]. In the IDA vision, the passenger transport demand is 9% lower than for the DEA Wind scenario, though both scenarios operate with a higher demand for transport and an increase in the number of personal vehicles [Mathiesen et al., 2015b].

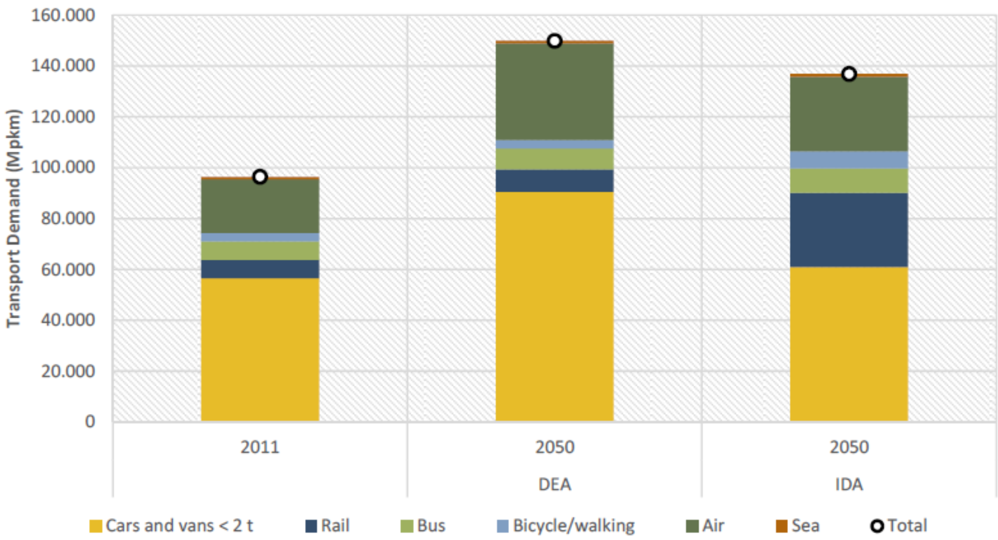

Figure 1.5: The past and future passenger demand (Mpkm) in different scenarios [Mathiesen et al., 2015b]

Figure 1.5 shows a difference in the transport demand for the two scenarios. Both scenarios agree on an increase in the demand for passenger transportation, but a great difference can be seen in the demand for 'cars and vans <2t' and 'rail', where the IDA vision operates with a lower demand in private vehicles because a large part of the passenger demand is relocated to public transportation [Mathiesen et al., 2015b].

In the IDA vision it is prioritized to use a minimum of biomass for fuel because of the limitation of the resource. Electrification has first priority, and the remaining demand is covered by electrofuels based on conversion from electricity. Besides that, does the IDA vision not contain gaseous fuels for the transport sector because a lower fuel demand from vehicles with higher efficiencies is prioritized. By using processes with higher efficiencies, the IDA vision has a lower energy demand in the transport sector than the DEA scenario [Mathiesen et al., 2015b]. In the DEA scenario, electric vehicles have first priority as well [Energistyrelsen, 2013], but the remaining demand is covered by BTL and hydrogen. This results in the biomass demand in the DEA scenario crossing the line for available biomass, which is 300 PJ [Mathiesen et al., 2015b].

The IDA vision operates with 75% of the transport demand for private cars being covered by BEVs, resulting in an electricity consumption of 21,7 PJ for 'cars and vans <2t'. In the same category, the electricity demand in the DEA scenario is 26,7 PJ due to the higher share of EVs in the scenario [Mathiesen et al., 2015b] where ECs account for 80% of the transport demand [Klimarådet, 2018].

Research Question 2

2.1 Problem Definition

The core problem of this thesis is identified by examining historical data of the EC development. It is given, that a prediction of the future number in ECs is difficult to determine, which is why there is reason to believe that the estimated number in ECs in 2050 comes with great uncertainty as well. Based on the thesis introduction, the transport sector accounts for a significant part of fossil fuel usage, and it can thereby be argued that this uncertainty might affect the Danish goal of a fossil free energy system. Therefore, it is considered important to investigate different solutions to how given quantities of ECs can constitute potential risks or opportunities in the future Danish energy system. Furthermore, the problem is considered to be of relevance today and in the future, as the actions of today are affecting the structure of the future energy system.
Based on the findings in the thesis introduction together with the problem definition, the following research question is established;

"How will different scenarios with variations in the electric car share, affect the transition of the Danish fossil fuel based energy system into a renewable energy system, and how can a technological understanding affect this development?"

The purpose of the research questions is to narrow down the problem definition in order for the thesis to be focused around what is desired to investigate. To be able to answer the research question, a set of sub-questions work as a division of the research question, which should bring structure to the thesis analysis. The formulations of the sub-questions are;

1. What are the potential environmental and economic effects of different shares in electric cars based on scenario preparation?
2. How can different perspectives affect the outcome of the future Danish energy system?
3. How are institutional settings preventing or promoting the future share in electric cars when analysed in a technological change perspective?

In addition to the sub-questions, a thesis scope is defined for the analysis to be focused as the desired investigation.

2.2 Scope

In this thesis, only one part of the transport sector is being touched upon. The thesis has a focus on passenger cars with a weight below two tonnes, which excludes other parts of the transport sector such as public transportation, sea and air. This division of the sector is natural and commonly used, which also is the case in the reference scenarios applied in the analysis. Besides that, only cars that run solely on electricity will be included in the analysis. This is chosen with the argument, that hybrid cars, which run on electricity in combination with another renewable energy source, have not been introduced to the market yet. In addition to that, it is assumed that hybrid cars in the future will run partly on biomass, which is an energy source that should be reduced to a minimum in the future because of it being a limited resource also used for food demands, biodiversity and different materials. This is also why it is not possible to cover the energy demand for transportation solely by using biomass [Lund, 2014b]. Besides that, it is difficult to estimate to which degree hybrid cars run on electricity or the supplementary energy source, which also is an argument to why ECs are in focus. Furthermore, analyses determining whether or not an expansion of the electricity grid is a necessity for some of the thesis scenarios to become a reality is not included. This means, that the thesis is based on the assumption that the Danish electricity grid does not require an expansion.
The purpose of the scope is to ensure that the focus of the thesis is maintained, and because of the limited space and time frame making it necessary to arrange a thesis delimitation.

2.3 Thesis Structure

The structure of the thesis is illustrated in figure 2.1 below. The figure shows the research question, the related sub-questions and the methods and theories that apply to each of these sub-questions.

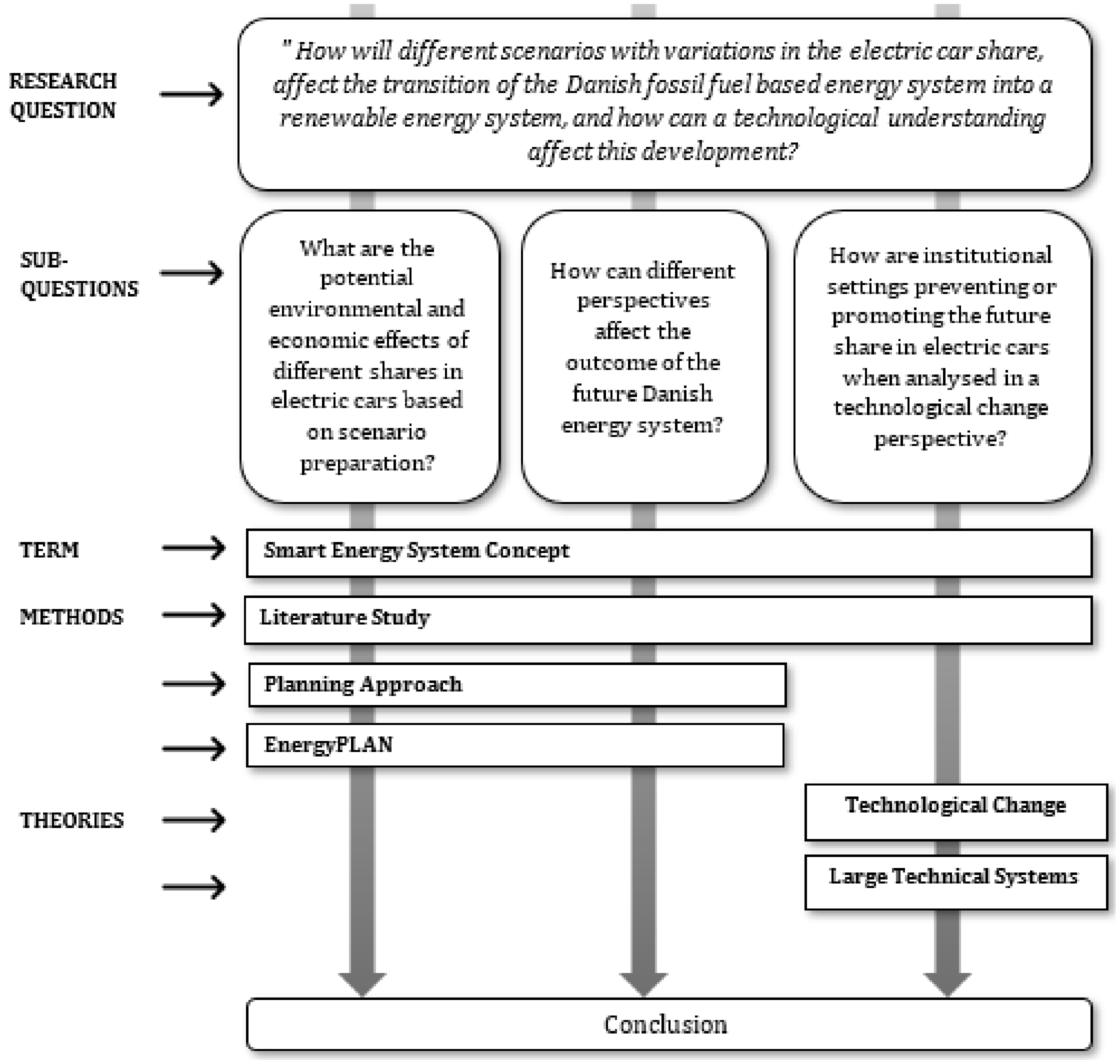

Figure 2.1: Overview of the thesis structure including questions, methods and theory, and how these lead to the conclusion

An overall understanding of a smart energy system is used throughout the entire thesis. This means, that the smart energy system might not be often mentioned, but the smart energy system concept is what the thesis aims to obtain in the future. The simulation tool EnergyPLAN is used to carry out the technical part of the analysis which is preparation of scenarios. For this analysis, the planning approach is used as an overall understanding of what scenario planning include and what risk and alternatives assessment comprise.

For the second part of the analysis, where the understanding of technology is analysed, it is the theoretical framework of the thesis that is applied. Theories dealing with technological change and large technical systems are used to identify the external factors influencing on the technological development.

In continuation of the analysis is a discussion where the findings from the two analyses are discussed in relation to each other. This means, that the findings only are partly discussed in the analysis, and that a more holistic view is applied in the discussion where both the technical and institutional findings are combined.

Theoretical Framework 3

The theoretical framework of this thesis includes theoretical approaches and concepts. These have the purpose to give a better understanding of individual technology and technological systems in relation to change, as well as the influencing factors that can have an impact on the ability to carry out given scenarios. Additionally, the theoretical framework is applied for analysing how external factors in form of institutions, can affect technological change and thereby also the realization of the thesis scenario.

3.1 The Smart Energy System Concept

The term 'smart energy system[1]' is of great importance in this thesis, as this approach to an energy system is the foundation of the analysis. In a SES, it is a necessity for the different sectors in the energy system to be connected in order to be able to make use of fluctuating energy sources. In this thesis, an understanding of a SES is important because ECs are one part of such a system. This theoretical approach thereby allows the results of the analysis to involve other parts of the energy system, because the transport sector being part of sector-coupling when using a SES approach. The scope of the thesis, which only includes ECs of the transport sector, should therefore only be seen in the light of the input of the analysis, as the holistic view in a SES requires the output to include the entire transport sector.

"[...] the Smart Energy System concept, [...] is a cross-sectoral approach that makes use of synergies between the various energy sub-sectors by identifying suitable and cost-effective renewable energy solutions for the future" [Mathiesen et al., 2015b] [p. 11].

The above definition and figure 3.1 are the ones applied in the IDA vision, which provide a natural argument for using the same definition in this thesis.

[1] A SES consists of bioenergy and fluctuating renewable energy sources as the primary energy forms. When using fluctuating energy sources, the production of energy can be unstable, which means that other intermittent energy sources have to accommodate for the missing production. For that reason, considerable expansions of fluctuating energy sources have to happen along with the possibility of storage or conversion of energy [Mathiesen et al., 2015b]

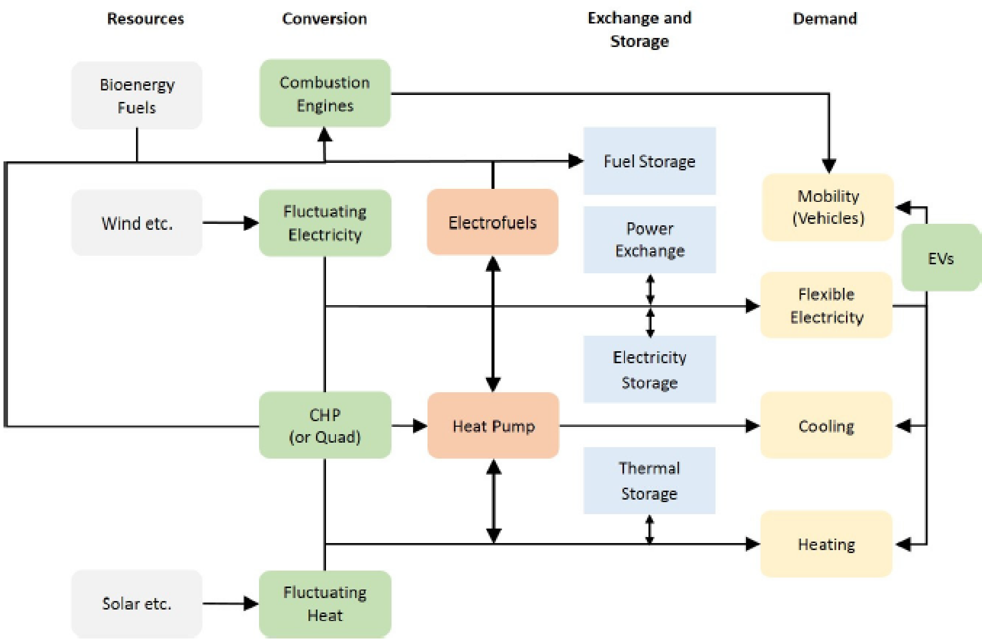

Figure 3.1: Overview of a Smart Energy System [Mathiesen et al., 2015b]

An approach that operates with the understanding that the different sub-sectors influence on one another is to be used in this thesis [Lund, 2014b]. This means, that even though this thesis revolves around the EC technology and one part of the transport sector, it is important to comprehend, that changes in one sector can affect other parts of the energy system as well. This is thereby also the overall understanding and approach that is used in the analysis, where it is analysed how changes in one sector can affect the energy system as a whole.

3.2 Technology & Change

The SES definition gives clarity about how one part of an energy system is able to affect other parts of the same system, which also can be understood as the energy system consisting of several sub-systems. The theoretical approach of this thesis is therefore extended with an understanding of these sub-systems as individual technologies in a larger technological system. One definition of technology is composed by Müller, who illustrates how technology consists of the four elements; *knowledge, organisation, technique and product* [Müller, 2011]. For every technology it applies, that the four elements are inseparable, and by describing the elements, it is possible to obtain knowledge about the technology structure. Besides that, an understanding of how the elements interact is important if technological change is desired as in this thesis, where the energy system and the EC technology can be conceived as technologies that undergo changes. If changes happen in one element, changes should also occur within the other elements, but if the other elements are not affected by the change, the initiative that was applied can be conceived as unsuccessful.

The main purpose of this perception is to approach technology through a holistic view, which makes it possible to determine the purpose of the technology, what problems or needs it is intended to solve and to understand that technology interacts with different societal processes [Müller, 2011].

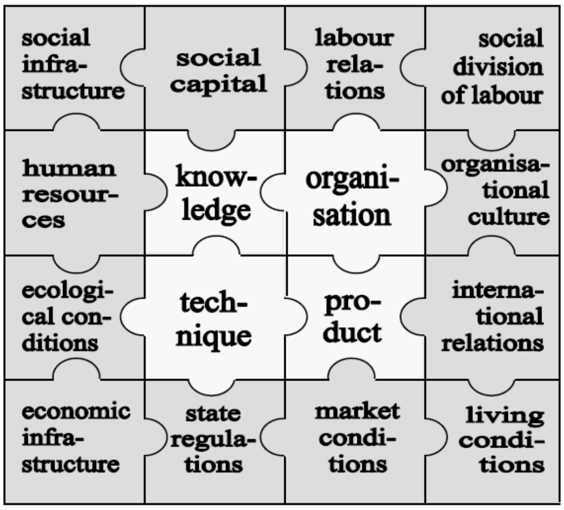

Figure 3.2: Figure showing the four elements of technology and the conditions that can result in changes [Müller, 2011]

Figure 3.2 shows some of the societal processes that interacts with technology. Whether technological change occurs is depending on the local conditions, which include the external economic, cultural and socio-political setting. As was the case for the four elements in technology, changes in one of the external elements [figure 3.2] will affect the other elements as well, and thereby also the technological setting [Müller, 2011].

"Technology does not drive choice; choice drives technology" [[Dicken, 2015], p. 75].

Technological change can be perceived as a learning form meaning that by using, doing and observing, it is possible to solve problems that are situated in environments that are highly changeable. Technological change is not exclusively inventions of new things, it is also depending on inventions transforming into innovations that are both usable and adoptable. Where technological change in an economic perspective works as an entrepreneurial process, it should on a long term basis work as an evolutionairy process [Dicken, 2015].

The elaboration of technology and how it changes is applied in the second part of the analysis. In relation to ECs as the technology and the Danish energy system as a technological system, it will be analysed how the external conditions can either promote or prevent the future development in ECs. The purpose of such an analysis is to be able to discuss possible solutions and to be able to be aware of how to ensure technological change, which can be used as a tool for reaching the desired number of ECs in 2050.

3.2.1 Approximation Models for Large Technical Systems

Besides an elaboration of the term 'technology', an understanding of a large technical system (LTS) is considered important to this thesis as well. In here, the Danish energy system is defined as an LTS, and it is a sector in such a system that the thesis revolves around. The term LTS is therefore being explained along with the factors that might affect the composition of it. Besides that, the definition of technological change will be touched upon, as an understanding of this term makes it possible to analyse which factors can affect technological change and thereby also future scenarios.

A characterization of an LTS, is that its scope and structure are of a global nature. The meaning of a global scope is that some of the time, most people are affected by LTSs. A global structure means, that the dynamics and structures of a given situation or process is shaped by several factors. The two types of globalness are being combined in an LTS, which also can be identified through its four different phases:

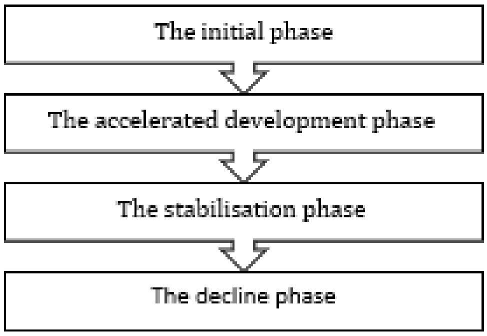

Figure 3.3: The four phases of a large technical system

The *initial phase* is characterized by being a phase with no overall plan for the development of the LTS, and a phase with debate of how the LTS can benefit the society in comparison with the existing LTS. In the *accelerated development phase*, the LTS is recognized because of it being superior and useful, and this phase also includes the LTS developing in compliance to a plan. Furthermore, the period can contain sub-periods that follow economic and political events. In the *stabilization phase*, the development rate of the LTS will decrease, which also results in a stagnation of the economic activities in relation to the LTS. The fourth phase is the *decline phase*, where the importance of an extension of the LTS diminishes along with its activity involvement. The last phase can also be determined by an LTS being replaced by a new LTS. In the two last phases, there is a chance that the old LTS is adopting some of the new LTS's characteristics, when this is going through the initial phase. However, this is not a revitalization of the old LTS as it is an affirmation of the new LTS. It also works as a sign that the new LTS is beginning it's domination over the old LTS, and thereby is using the old system as testing ground [Gökalp, 1992].

What is typical for an LTS, is that often there is a correlation between the industrial society development and the LTS. In addition, another characteristic feature is that there exists a close correlation between political and ideological views and the LTS.

The developer of the American radio technology, Hugh Aitken, argues that the rate and direction that the system will develop at, are determined by the socioeconomic[2]

[2]The socioeconomic position of an individual or group refers to the given society's economic ranking in relation to resource access such as wealth, income and education [Ball and Crawford, 2010]

context that the technology operates in. In addition to that, he composed three different approximation models to a technological system, where the one relevant to this thesis is presented. He considered science, economics and technology as the spheres of human action, and with approximations he was able to identify different types of interactions between the three spheres and thereby also how changes in one sphere affects the two others [Gökalp, 1992].

One of the approximation models accounts for the three spheres as not being unidirectional, and that there can be several kinds of interaction between these. The model presents, that there are two kinds of interaction, which happens between science and technology, and between technology and economy.

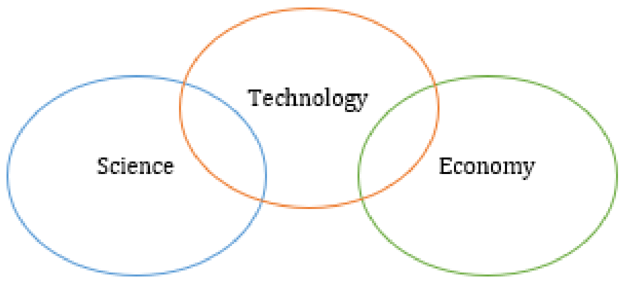

Figure 3.4: The interaction between the three spheres in one approximation model

As figure 3.4 shows, the spheres overlap and in these two areas the interactions that are most productive take place. In this model, feedback between the spheres exists in form of reverse flows, which could consist of information [Gökalp, 1992]. In the thesis analysis, the three spheres are discussed in relation to the technology jigsaw [section 3.2] together with the possibility of identifying a connection between the two spheres of science and economy.

In this thesis, the understanding of technological change and LTSs is applied in the second part of the analysis. The role of these terms is to be able to comprehend that ECs both function as a technology themselves, but also that they are part of an undergoing process in a larger system. ECs are therefore perceived individually together with how they operate in a system. The purpose is to give an understanding of the phase that the current system is going through and also to identify how external factors can affect the desired progress.

Methodology 4

4.1 Data Collection

The data that is used for the analysis in this thesis, is solely collected through literature studies. In the introduction, knowledge about ECs was acquired through scientific articles and official statistics. This part of the thesis led to an overall problem definition and thereby also a question to answer through an analysis. The first part of the analysis has a technical approach with data collected mainly from the governmental administration DEA and the IDA vision. Here, the collected data, and the results of the analysis, is of quantitative matter because of the measurable numbers that form the input and output of the modelling tool. The theoretical framework of the thesis is used for the second part of the analysis, where the literature study has been the main method for establishing the framework. This part of the analysis is qualitative, because of the difficulty of quantifying the results of the applied theories.

4.2 Planning Approach, Risks & Alternatives

Different approaches to planning can be employed, but in this thesis *scenario planning* is preferred. Scenario planning differs from *strategic planning* by instead of predicting the future, it is possible to arrange multiple potential outcomes and with that knowledge, to select a preferred path for the future. It is problematic to make use of forecasting when wanting to predict something with a long-term time frame, so instead of relying on a guess on what is the most likely outcome, scenario planning can be used to construct many possible outcomes [Enzmann et al., 2011].

"Scenarios are not intended to be exactly predictive of the future, but rather, it creates plausible futures that offer a diverse scope to better capture eventual reality" [[Enzmann et al., 2011], p. 176.]

In this thesis, scenario planning can also be defined as a probabilistic prediction process, meaning that the prepared scenarios do not contain worst or best case scenarios, but instead different alternatives to an uncertain future [Enzmann et al., 2011]. Uncertainty is a key word in this relation, because several different forces influence on how the EC fleet and the future energy system will be structured which makes it hard to predict. This also means, that the scenarios presented in this thesis are not definitive results, but only a few out of several possible solutions. Scenarios are therefore not a consensus view, but forces that are expected to affect the outcome of the future can be known and the most uncertain and important forces can be in focus [Enzmann et al., 2011]. In this thesis, it is evaluated that the most important forces in relation to the EC development are *politics*, *technology development* and *climate focus*. How the different forces can affect the future, will be presented in the analysis. Following the scenario building, it is natural to analyse the outcome of these. In relation to the research question of the thesis, it is of interest to determine some of the risks that occur if the EC fleet develops differently, but also which alternatives are present in order to reach the political goal of a fossil free society in 2050. To do so, an understanding of the terms risk and alternative assessment have been applied.

For many years, *risk assessment* has been widely used by governments for instance. The purpose of risk assessment can, in an energy context, be to analyse possible damages to the environment in a given scenario [O'Brien, 2000]. In this thesis, the risks following different numbers in ECs are presented. Besides a presentation of the risks, the method of *alternative assessment* is applied as well. Alternative assessment is an extension of risk assessment, which includes to present alternatives of how damage can be minimized or avoided when wanting to achieve a given societal goal [O'Brien, 2000]. Alternative assessment is considered to be relevant in this thesis, because alternative solutions to the existing 2050-scenarios in relation to ECs can become a necessity in the future. It is still of interest to reach the national goal of a fossil free society in 2050, even though the EC development will move at another pace than what has been presented in the IDA vision. The analysis will therefore be approached with the purpose to be able to present advantages and disadvantages of the scenarios. Though, it should be noted that an advantage can vary depending on the perspective that the scenarios are seen from, meaning that if a scenario contains an economic advantage it does not necessarily mean that it comes with environmental advantages as well.

4.3 Energy System Analysis

For the purpose of the analysis in this thesis, an energy system modelling tool is considered to be an optimal method, because a simulation of the Danish energy system is necessary to answer the research question properly. To be able to decide on the most optimal modelling tool for this purpose, the overall objectives of the thesis are established. The objectives are;

- *To identify how a given share in electric cars in 2050 will affect the Danish energy system*
- *To identify what the most optimal solutions in an energy system, with a given share in electric cars, are in relation to different parameters*

By identifying the objectives, it makes it easier to determine which modelling tools that are able to fulfill these objectives [Connolly, 2015]. For this thesis, the purpose of using a modelling tool is to create scenarios and solutions for a Danish energy system with a different EC share than what is currently proposed. The changes will occur in the transport sector, but because of the need of a SES with cross-sectoral interactions in the future, focusing on an individual sector is not considered an optimal approach. It is assumed, that changes in the transport sector affect other sections of the energy system, and when wanting to consider the energy system as a whole, it is a criteria that the modelling tool makes use of the same approach.

The modelling tool that has is considered to contain the needed characteristics, is the EnergyPLAN tool. The arguments for using the EnergyPLAN tool, are that the tool is used in a simulation for a Danish 100% renewable energy system before [Connolly, 2015]. This also means, that the tool is able to simulate energy systems on a national level, which is a requirement in this thesis. In 2050, a major part of the energy system consists of fluctuating energy sources, why it is important to create a flexible energy system. This flexibility can be obtained by using technologies such as electric vehicles, hydrogen and heat pumps in the integration of the heat, electricity and transport sector, which is a possibility when modelling in EnergyPLAN. To make sure, that EnergyPLAN is able to model the application of the thesis, a historical year can be used as a reference model [Connolly, 2015]. In this report, the reference model is already existing as the IDA 2050 scenario. For this scenario, the EnergyPLAN tool is used for the simulation, which also is an argument for choosing this tool for the thesis.

4.3.1 What is EnergyPLAN?

For the energy system analysis of this thesis, the modelling tool EnergyPLAN is applied, and this section contains an elaboration of the tool's attributes that are needed in order for the thesis analysis to be carried out.

EnergyPLAN has a focus on evaluating and designing renewable energy systems with a high level of fluctuating energy sources and energy storage alternatives to improve the flexibility of the system. The model makes it possible to design energy strategies that are based on economic and technical consequence analyses of the implementation of certain investments or energy systems. EnergyPLAN is an input/output simulation tool, that can model both regional and national energy systems over a one year time period by the use of hourly simulations. The user of the model is defining the inputs that can both be of technical and economic matter [figure 4.1] [Lund, 2014b]. For the purpose of this thesis, the user input definitions are an important attribute, because changes within the technical and cost related parameters are a necessity to be able to establish scenarios for a different number in ECs.

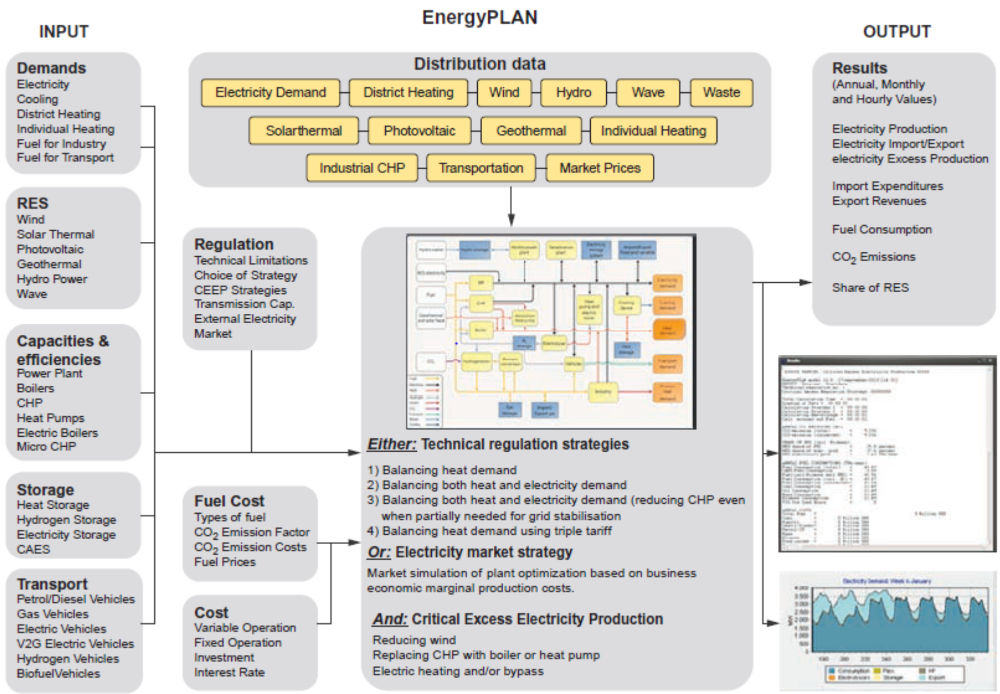

Figure 4.1: Overview of the inputs and outputs in the EnergyPLAN model [Lund, 2014b]

Furthermore, the tool operates on a cross-sectoral basis with the purpose to create synergy between these. Besides modelling the hourly balance of sub-sectors such as cooling, electricity and district heating, the tool also includes technologies such as CHP-plants and heat pumps, but also ECs [Lund, 2014b], which is the primary technology in this thesis.

4.3.2 EnergyPLAN and the Transport Sector

In EnergyPLAN, the transport sector is handled by allowing one to determine the energy consumption in relation to the different forms of energy that are used within the sector [figure 4.2].

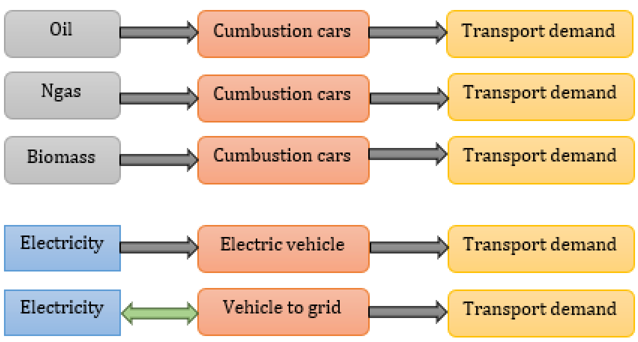

Figure 4.2: Overview of particular parts of the transport sector

In EnergyPLAN, it is possible to determine the efficiencies for given car types, and the part of the transport sector that runs on electricity has specific parameters to operate with, as seen in figure 4.3. In this thesis, it is mainly the parameters within electric vehicles that are adjusted to fit the scenarios in the analysis. Some values are provided by EnergyPLAN, but these are considered and changed in cases where they do not match the data applied to the thesis analysis. Besides the possibility to change the electricity consumption for the transport sector, it is also possible to define the grid to battery capacity, which is a definition for the charging stations needed for a given amount of ECs [figure 4.3].

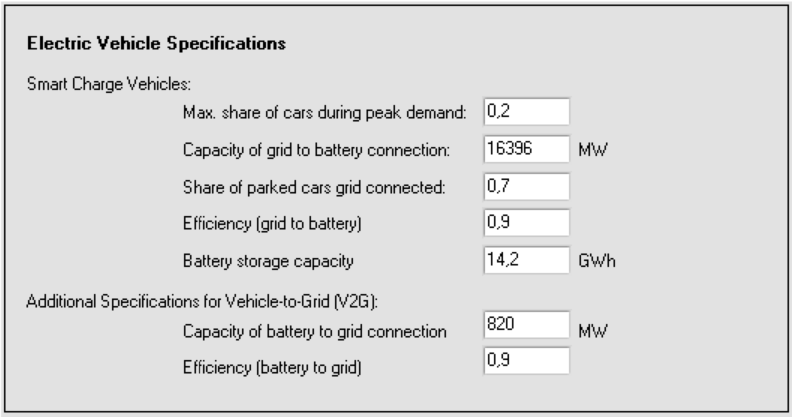

Figure 4.3: Input parameters for the electrified part of the transport sector with values from the IDA vision

The parameter which concerns charging stations is considered to be important in an economy perspective, but also for being able to meet the electricity demand, which is divided into smart charge and dump charge. The smart charge parameter is used as a way to bring down the business-economic costs in relation to electricity purchasing for being able to meet the demand. This means, that smart charge improves the flexibility of the energy system and makes it possible to achieve the lowest prices on the market [Lund, 2014a]. In this thesis, wind energy is given first priority, and since this is a fluctuating energy source, it is important to have a flexible system, where it is possible to cover the demand during low production periods. In the IDA vision, this is partly performed by using smart charge for the EC fleet, and this method is also used in this thesis. This means, that the total EC fleet is specified as smart charge.

Besides electricity, it is also possible to handle energy sources such as electrofuels, biofuels, gases and fossil fuels in the EnergyPLAN transport tab sheet [Lund, 2014a]. Changes within other fuel types are important to consider as alternatives to electricity or fossil fuel, to be able to compose scenarios for the entire car fleet. The scenarios composed in this thesis, contain alternatives that include biomass and hydrogen for fuel use. Here, biopetrol is chosen over biodiesel in spite of biodiesel being more commonly used in Denmark today. Biodiesel used in Denmark is mostly based on oils, but EnergyPLAN only allows a specification of biodiesel output from dry biomass. Besides that, biopetrol has a higher efficiency than biodiesel from dry biomass [Energistyrelsen and Energinet, 2020a], and for that reason biopetrol is prioritized to give a more representative illustration of the energy system, together with a lower biomass consumption. By making use of biopetrol, the bi-product distillers' dried grains (DDG) is produced and can be used as animal food or for export and is mentioned as food income in EnergyPLAN. Furthermore, the efficiencies and costs, in relation to biopetrol, are updated from the values used in the IDA vision to match recent data from the DEA. This change makes the efficiency slightly higher in this thesis, but the DDG production lower.

In order to carry out a true comparison of the IDA vision and the scenarios composed in this thesis, the investments and efficiencies, in relation to the passenger transport sector, are changed if more recent data is available. The parameters subjected to changes are shown in table 4.1 below, and the results from the EnergyPLAN simulation can be seen in section B.1 in appendix B.

Parameter	IDA vision	Thesis	Unit
EC efficiency	5	5,1	km/kWh
EC investment	18,1	28	MEUR pr. 1000 vehicles
Charging station lifetime	10	30	Years
Charging station investment cost	745	1242	Euro
Grid to battery efficiency	0,9	0,82	Percentage
BioPetrol plant investment	0,44	0,66	MEUR pr. MW-bio
BioPetrol plant lifetime	20	25	Years
BioPetrol plant O&M	7,68	9,2	% of investment
BioPetrol efficiency	0,4	0,47	Percentage
Food bi-product efficiency	0,5	0,25	Percentage
Investment cost biofuel cars	-	22,8	MEUR pr. 1000
Electrolyser investment	0,28	0,4	MEUR pr. MW-e
Electrolyser lifetime	15	30	Years
Hydrogen efficiency	73	79	Percentage
Hydrogen storage investment	20	21	MEUR pr. GWh
Hydrogen storage O&M	0,5	0,6	% of investment
Investment cost hydrogen cars	-	28,1	MEUR pr. 1000 vehicles

Table 4.1: Parameters changed in EnergyPLAN based on updated data for the year 2050 [Energistyrelsen and Energinet, 2020a], [Energistyrelsen and Energinet, 2020b]

The changes include updated cost and efficiency data for the different vehicle types and technologies. This also include the production of biopetrol, electrolysers and hydrogen storage. The electrolysers used in this thesis are similar to the ones used in the IDA vision. The technology used is the solid oxide electrolyser cells (SOED), which have a higher efficiency than other types of electrolyser [Mathiesen et al., 2015b]. For the sake of simplicity, the above mentioned parameters are mentioned here because of them being applied in every scenario of the analysis.

4.4 Reference Scenario

For the analysis in this thesis, IDA's Energy Vision 2050 is used as a reference scenario. The IDA vision is one of several 2050 scenarios, but this particular scenario is chosen to function as point of departure for the analysis. The IDA vision is an addition to two previous plans composed by IDA, and is based on inputs and contributions from IDA's networks and researchers in energy system analysis from Aalborg University [Mathiesen et al., 2015b]. The scenario is chosen as reference because of the focus on a minimal biomass use, and because the scenario already being modeled in EnergyPLAN [Mathiesen et al., 2015b]. Some of the outputs from the IDA vision can be seen in table 4.2.

IDA Energy Vision 2050	Result (TWh)
Onshore electricity	16,2
Offshore electricity	63,76
CEEP	2,99
Biomass consumption	47,91
Smart transport electricity	6,46
Electrolysers	40,93

Table 4.2: Selected results from the IDA vision [Mathiesen et al., 2015b]

With the reference scenario already modeled, it is not a necessity to do so in this thesis. The main changes in the reference scenario appear in the transport sector, because of the thesis' focus on ECs. The IDA vision operates with 75% of the passenger car demand running solely or partly on electricity by 2050, which is a result of different criteria to the transport sector:

1. A minimal use of biomass for fuel
2. Electrification has first priority - remaining demand is covered by electrofuels
3. Prioritization of low fuel demand from high efficiency vehicles
4. No gaseous fuels for transportation

[Mathiesen et al., 2015b]

Besides the above-mentioned criteria, the results of the IDA vision are due to the technical optimisation used for modeling the scenario.

4.4.1 Optimisation

The two kinds of optimisations that the EnergyPLAN tool is able to carry out, are a *technical* optimisation and a *market economic* optimisation. When using the technical optimisation, the consumption of fossil fuels is minimised, and with a market economic optimisation, the operation costs of the system are minimised. The components of the energy system, and the technical abilities of these are the basis of the technical optimisation. This means, that only in situations where the demand cannot be met by the power producing units, power will be imported from external markets, and if production of excess energy is present, this energy is exported. The demand is thereby met by the power producing units as long as these are capable of doing so. The design of the market economic optimisation is not to prioritize a minimum fuel consumption, but to meet the demand and supply at the lowest cost [Connolly, 2010]. With this optimisation, energy might be imported if the cost of this functions as the cheapest solution. The risk of the market optimisation therefore is, that energy produced by fossil fuels can be given first priority because of a low cost. In this thesis, the main priority is to avoid the use of fossil fuels and thereby obtain a CO_2-neutral society, which is why the technical optimisation is chosen for the energy system analysis.

4.4.2 Scenario Input & Energy System Criteria

For the scenario analysis in this thesis, different arguments are used as foundation for establishing the scenario criteria. The criteria are primarily based on the criteria applied in the IDA vision, which means that the use of biomass continuously is limited to a minimum. A biomass level higher than the projected might be available in 2050, but because of the uncertainty in regards to this, a low level of biomass is applied. The scenario results are considered to be unusable if the available biomass resources becomes lower than expected for the future. The biomass level used in this thesis, is the level applied in the IDA vision. This level is based on the assumption, that the food production and agricultural structure match the one that is seen today. This means, that the biomass level is a maximum of 250 PJ, but a level close to or below 200 PJ is preferable due to environmental and economic risks [Mathiesen et al., 2015b], and a biomass level at maximum 200 PJ is therefore also the aim in this thesis.

Besides that, wind energy is being prioritized in situations where a scenario requires more or less renewable energy in the system. In a report composed by Energinet, the socioeconomic potential of expanding onshore wind turbines is compared to a corresponding offshore wind turbine expansion. The potential for onshore wind was thereby found to be 12000 MW, because of this being a cheaper solution than an expansion of offshore wind turbines. The reason for this, is that compensation to neighbors, together with a purchase of the adjacent properties for an amount that is 50% higher than the value of the property is more profitable. The analysis in the report has its point of departure in the support tool from the Danish Nature Agency, which is a tool also applied by municipalities in the planning of wind turbines [Energinet, 2015]. In the IDA vision, a capacity of 5000 MW onshore wind is applied, but it is assumed that scenarios operating with a higher number of electric vehicles might require an expansion in renewable energy production. Potential expansion of renewable energy will in this thesis be obtained by expansion of both onshore and offshore wind turbines, where an expansion of onshore wind is considered to be possible based on Energinet's report.

In an renewable energy based system, there is a high probability of experiencing CEEP[1]. In the analysis of this thesis, the aim is not to exceed a CEEP level higher than the one from the IDA vision results of 2,99 TWh/year [Mathiesen et al., 2015a]. A CEEP level of 2,99 TWh/year deviates from the level of 0,1 that is used in the official IDA vision report. The reason for this is, that the scenario in the IDA report is simulated with a market optimisation, but the scenario with a technical optimisation has a CEEP level of 2,99 TWh/year in EnergyPLAN. Since the technical optimisation is the one used in this thesis, a CEEP level of 2,99 TWh/year will therefore be applied here as well. The lowest possible quantity of CEEP is desired to avoid the energy from being dumped or for the electricity grid being to be unbalanced. A SES with a combination of different renewable sources together with storage of energy, can help to correct the CEEP level, but as more fluctuating energy sources come into the system, it is more difficult to control [Lund, 2014b].

[1] The term CEEP is used when the produced electricity exceeds the demand, but also the capacity that can be exported by transmission lines to external markets. CEEP should therefore be low to avoid a collapse of the electricity system [Lund, 2014b]

Scenario Preparation 5

5.1 Introduction

The purpose with this analysis is to identify how different shares in ECs in 2050 can affect the Danish energy system. The first part of the analysis has a technical approach, and it is thereby in this part that the thesis planning approach is carried out through the modelling tool EnergyPLAN. In the technical part of the analysis, the potential environmental and economic risks or benefits are emphasized through an energy system analysis. Besides that, it is presented how alternative energy system solutions can be constructed if the EC share deviates from the expected. The technical analysis consists of three scenarios with different EC developments [figure 5.1] than what is projected in the IDA vision as the reference scenario.

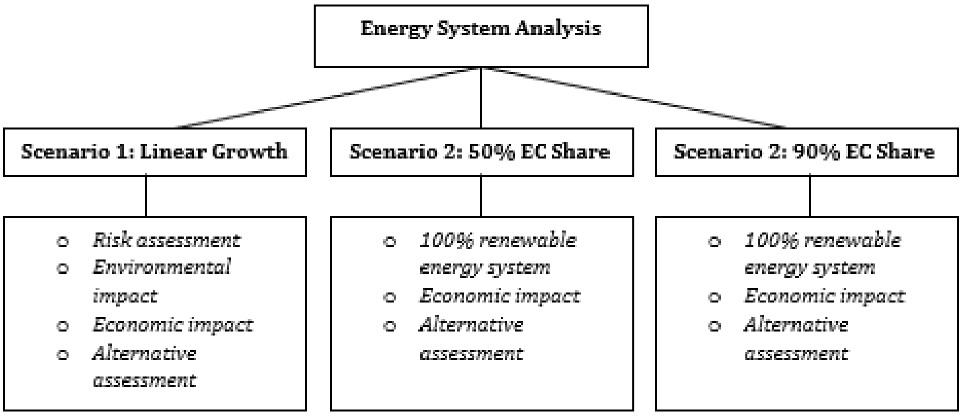

Figure 5.1: Scenario overview with the applied methods used for analysis

The first scenario which is analysed, is a scenario containing linear growth. A linear growth scenario has its point of departure in the existing knowledge about the EC development and with the presumption that the development continues along the same path. This scenario has the purpose to present the possible environmental risks that the current development has on the future energy system. This scenario is therefore also the only scenario where the energy consumption for the remaining part of the car fleet is replaced by fossil fuels. For the two remaining scenarios, which consist of the EC share being 50% and 90% respectively, the IDA vision is used as point of departure. The IDA vision already contains a suggestion of electricity based cars having a share of 75% of the passenger car fleet, but this share consists of both ICE hybrid vehicles, ICE PHEVs and ECs. Because of the scope [section

2.2] in this thesis, the BEV technology included in the analysis are cars that run solely on electricity. Exact numbers for the future car fleet are not to be found in the IDA vision, and the numbers that are applied from this derive from an appendix figure [Mathiesen et al., 2015a]. When reading from a figure, it can result in the numbers being imprecise to some extent. In this thesis, the imprecision is acceptable because scenario planning [section 4.2] is one of the overall approaches to the analysis, and imprecision is therefore not considered a barrier for composing relevant scenarios.

Based on a car fleet of 2,200,000 cars in 2050, ECs will account for 61,4% or 1,300,000 cars according to the IDA vision. The scenarios in this thesis operates with different shares in ECs, because it is considered of interest to investigate how these affect the energy system [table 5.1].

Scenario	Cars (M)	EC fleet
IDA Vision	2,2	61,4%
Scenario 1	2,2	8,3%
Scenario 2	2,2	50%
Scenario 3	2,2	90%

Table 5.1: Total number in cars and EC shares for the scenarios

So far, the EC fleet has not increased as desired [Klimarådet, 2018], which means that there might be a potential risk that this continues in the future. Deviations that are both lower and higher than what is projected in the IDA vision, makes the analysis operate with outcomes that fall on both sides of the IDA vision. Common to all three of the scenarios, is that the same approach for calculating the energy consumption is used with the following points in mind:

1. The average kilometer number for Danish people is determined
2. The average of the EC efficiency for the years up until 2050 is determined
3. The number in kilometers is converted to energy consumption with the efficiency taken into account
4. The number in charging points is considered in relation to the EC number
5. The capacity in wind turbines is considered in relation to the given scenario

Several of the above mentioned parameters vary depending on the year that they are applied to [Energistyrelsen, 2016]. This means, that prices and efficiencies are variables when operating with a long-term time frame, why the average of the parameters is used in the calculations. In appendix A, vehicle specifications are shown in relation to a given year.

Common to all of the scenarios, is that the calculations are based on values relevant to a given year from a data sheet composed by the DEA regarding vehicles and alternative fuels. In this thesis, the analysis has a focus on ECs, but as one scenario examines the risks of a car fleet with a share of fossil fuel driven cars, these values are shown in the appendix as well. Additionally, do the alternatives assessments contain shares of cars driven by biofuel or hydrogen why these are shown in appendix as well A.

The DEA data sheet operates with different values for the years 2020, 2035 and 2050 [Energistyrelsen, 2016], but since the lifetime for each of the car types are stated to be 16 years, the cars in 2050 will be from 2034 at the earliest. This means, that the car fleet in 2050 only operates with consumption and efficiency values valid to the period from 2034-2050. It is expected, that the production years of the cars affect the outcome of the scenarios, because the efficiency of the car influences on the consumption. The average energy consumption for cars with different fuel types is illustrated in table 5.2 below.

Car type	MWh/year
Electric	3,9
Diesel	12,5
Gasoline	13
Biofuel	12,5
Hydrogen	8,2

Table 5.2: Table showing the consumption for different fuel types

Besides the electricity consumption for ECs, the consumption for other fuel types are also shown, and the same method is used for calculating the average consumption for these as well. According to the IDA vision, the transport demand for passenger cars in 2050 is estimated to be 27,680 pkm/year, and this number is thereby also part of the consumption calculations in table 5.2. The values seen in the table are the ones applied to every scenario in the analysis.

It should be noted, that the same amount of electricity consumption per vehicle is applied in the IDA vision and in the DEA scenarios. But, when the IDA vision was composed, it was not possible to determine how the DEA differentiated between ECs and hybrid plug-in cars, and thereby also how large of an amount of electricity was used for the two types of cars. This means, that the IDA vision operates with all of the EVs as BEVs [Mathiesen et al., 2015b], which in this thesis are denoted as ECs. The electricity consumption will therefore not differ depending on the different types of BEVs, which also is an argument for not differentiate between these in this thesis.
In addition to that, a part of the electricity consumption in the transportation sector in the IDA vision is left for the scenarios in this thesis. This is because a part of the electricity for transportation is used in other vehicle categories than cars and vans < 2 t, which is the group focused on in this thesis. This is also the case for electrofuels, which means that electrofuels used for cars and vans < 2 t in the IDA vision will be subtracted in such a way that the remaining demand only covers the parts of the transport sector that are not a part of the scope in this thesis. By using this method, it is possible to model the relevant part of the sector from scratch, but with the whole transport sector still being included in the scenarios. The demand remaining is determined as shown in table 5.3.

Electricity (TWh)	IDA vision	Thesis scenarios
Total for transportation	8,83	
Cars and vans < 2 t	6,03	
Fixed demand for scenarios		2,8
Electrofuels (TWh)	**IDA vision**	**Thesis scenarios**
Total for transportation	20,86	
Cars and vans < 2 t	3,11	
Fixed demand for scenarios		17,75

Table 5.3: Table showing the demand divided into total demand and cars and vans $<$ 2 t in the IDA vision together with the remaining demand used in this thesis

As the above indicates, 2,8 TWh electricity and 17,75 TWh electrofuels are used as fixed numbers in the transport sector, as this amount of energy is used in the part of the transport sector that is delimited from in this thesis. This method has the purpose to give a more realistic view on the energy system, because the whole transport sector is a part of the result in spite of the whole sector not being adjusted in the scenarios.

The share of cars that are parked and driving during peak hours constitute a fixed share for all the forthcoming scenarios. The maximum share of cars during peak demand is set to be 20%, which means that the remaining 80% of the cars are parked with the possibility to be connected to the grid [Lund and Kempton, 2008]. This division of the car fleet was relevant in the year 2008 and is used in the IDA vision as well. An argument for using the same shares for 2050, is that the demand for passenger transport in the future shifts from private to public transportation. This also means, that the car fleet is decreasing, reaching a lower share of cars in 2050 than what is seen today [Mathiesen et al., 2015b]. Lastly, the number of charging stations is determined on background of the method used in the IDA vision, where the number is defined by calculating with two charging stations per EC vehicle [Mathiesen et al., 2015b].

5.2 Scenario 1: Linear Growth

The initiating scenario in the analysis is based on the principle of frozen policy[1] in relation to ECs, which is why this scenario contains a linear EC growth. In 2019, 15,500 ECs were to be found in Denmark and 5,500 of these were newly registered. For the linear development, 2019 will therefore be used as the reference year, as this year has experienced the highest increase in ECs so far. In figure 5.2, the linear development is shown.

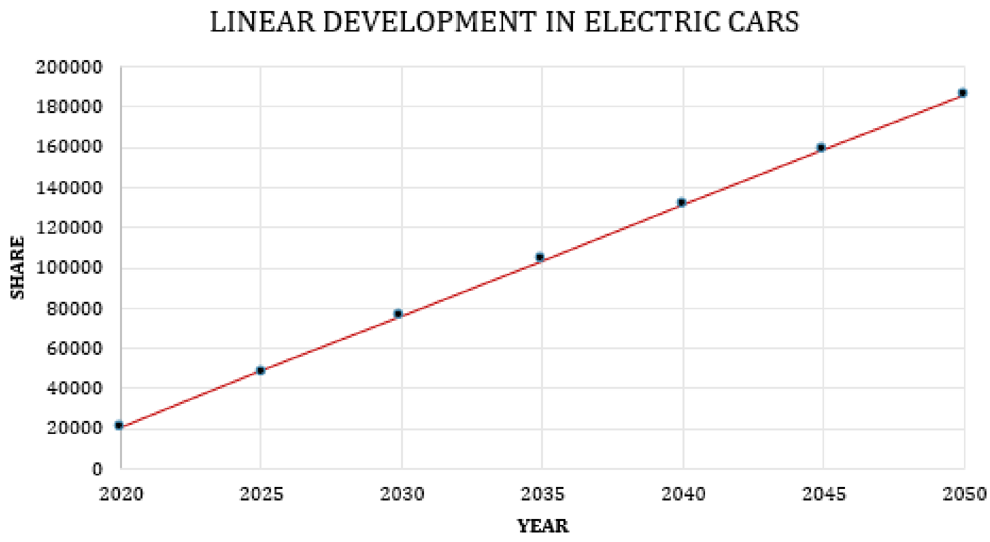

Figure 5.2: Graph showing a linear development in electric cars

The linear development is based on the premise that owners of ECs continuously will procure an EC, meaning that when the car's life time of 16 years [Energistyrelsen, 2016] has passed, the car owner will acquire an EC again. If a linear development occurs, 186,000 ECs are to be found in Denmark by 2050. In the IDA vision, the Danish car fleet will in 2050 consist of approximately 2,2 million passenger cars [Mathiesen et al., 2015a], which will result in ECs accounting for 8,3 % of the car fleet if a linear development takes place. In projections from the DEA, ECs are expected to account for 9 % of the Danish car fleet in 2030 [Energistyrelsen, 2019], so if the transport sector has to be fossil free by 2050, a linear development is not to be preferred. The consequences of a linear growth rate are assumed to both be of environmental and economic matter. This is because it is expected to be necessary to make use of either fossil fuels or other more expensive renewable energy technologies than wind to cover the demand. Based on these assumptions, the scenario with a linear development is structured as seen in figure 5.3.

[1] Frozen policy is a term used for scenarios, where there is no introduction of new policies. The policies of today that are present throughout the entire time frame of the scenario [Energistyrelsen, n.da].

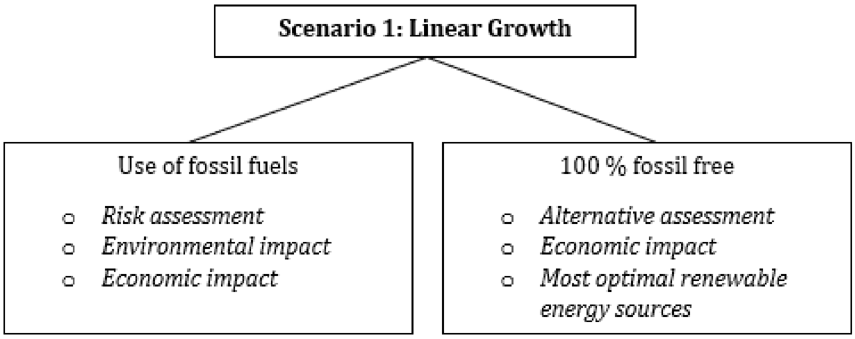

Figure 5.3: Focus points in scenario 1: Linear growth

As the figure shows, the linear growth scenario results in a compilation of several different sub-scenarios, which function as risk and alternative assessments of a linear growth rate. These assessments are carried out because it is assumed that a scenario with a notably lower EC fleet both can result in the remaining transport demand to be covered by fossil fuels or renewable energy.

In this scenario, the EC fleet in 2050 will consist of 186,000 cars, but because of the uncertainty about the distribution of car sizes and efficiencies in the future, a mean of the consumption is used. The same method is used when determining the consumption of fossil fuel driven cars, which only occur in this scenario. This method is used to produce, what is assumed to be, the most exact results in relation to energy consumption and economy, because of the difficulty in relation to determining when the ECs are being procured.

5.2.1 Risk Assessment

The first scenario prepared based on a linear growth functions as a BAU-scenario, where the rest of the transport sector is covered by fossil fuels. It is thereby this part of the scenario that contains a risk assessment of this development's environmental impact. In this scenario, the year 2050 has 1,114,000 fewer ECs than what is suggested in the IDA vision. With a determination of the energy consumption for one EC of 3,9 MWh/year, it is possible to calculate the overall consumption for the EC fleet in 2050, which will be of 0,718 TWh/year. Fossil fuel driven cars constitute the remaining car fleet, which is 2,014,000 cars. Based on data from the IDA 2035 scenario, where fossil fuels are still part of the energy system, diesel cars account for 60,5%, while gasoline cars account for 39,5% [Mathiesen et al., 2015b]. Because fossil fuels are not part of the IDA vision, numbers from the year 2035 is used, and the share of the two fuel types is transferred to 2050. The individual and total consumption of fossil fuel driven cars can be seen in the table 5.4.

Year/fuel type	Gasoline	Diesel	Unit
2035	48,7	46,8	GJ/year
2050	44,6	42,9	GJ/year
Mean (one car)	46,6	44,8	GJ/year
Total (TWh/year)	**10,3**	**15,2**	TWh/year

Table 5.4: Table showing the consumption of fossil fuel driven cars divided into fuel type, with a total consumption based on the car fleet share

As hybrid cars are not a part of the analysis in this thesis [2.2], the risk assessment of a linear growth scenario is based on a car fleet with a given EC share together with a share of gasoline cars and diesel cars. Though, the number of hybrid cars in the car fleet is not subtracted from the total number of cars but eliminated instead, meaning that the total car fleet consists of the same amount of passenger cars as in the IDA vision. This means, that the electricity demand for cars is modelled, but the additional fossil fuel consumption is added to the consumption from the IDA vision.

For ECs, the average efficiency is 78,5%, while the average efficiency for fossil fuel driven cars is 21,9%, making the efficiency for ECs approximately 3,6 times higher, why this will be corrected in EnergyPLAN.

Parameters	IDA vision	Linear growth	Unit
Electricity demand	6,03	0,72	TWh/year
Diesel	0	15,2	TWh/year
Gasoline	0	10,3	TWh/year
Conventional cars (total)	0	46322	MEUR
Dump charge	2,64	2,64	TWh/year
Smart charge	6,46	0,72	TWh/year
Electric cars (total)	61600	5208	MEUR
Charging stations (total)	4347	462	MEUR
Capacity of grid to battery connection	16396	2300	MW
Capacity of battery to grid connection	820	105	MW
Battery storage capacity	14,2	1,8	GWh
Biofuel cars (total)	0	45919	MEUR
Hydrogen cars (total)	0	34113	MEUR

Table 5.5: Table showing the parameters that are changed in EnergyPLAN, from the values in the IDA vision to the values relevant to the linear growth scenario

As table 5.5 shows, the demand for electricity is lowered, but the demand for fossil fuels has increased in comparison to the IDA vision. Furthermore, the biomass consumption is lowered because of the eliminated share of hybrid cars. The biomass demand decreases with 5 TWh based on data from the IDA vision showing how different shares of EVs are affecting the biomass supply [Mathiesen et al., 2015b].

As expected, the scenario with a linear growth rate results in higher emissions of CO_2 and a lower RES share due to a lower EC share and a fossil fuel replacement for the remaining car fleet. As seen in table 5.6, the scenario composition results in slightly higher annual costs and a noticeably amount of CO_2 emission costs, which are non-existing in the IDA vision.

Results – Scenario 1: Linear Growth

Parameter	IDA vision	Linear growth	Unit
Annual investment costs	20268	19143	MEUR
Total annual costs	29642	29793	MEUR
CEEP	2,99	2,97	TWh/year
Oil usage	0	25,5	TWh/year
Offshore wind capacity	14000	13150	MW
RES share	100	85,2	%
CO2 emission	0	6,25	Mt
Total CO2 emission costs	0	263	MEUR

Table 5.6: Results from the linear growth scenario in comparison with the IDA vision

The scenario has a slightly lower CEEP level than the IDA vision, which is because of a lower share of fluctuating energy in the system due to the reduced number in ECs. The offshore wind capacity is reduced because of the higher investment costs that are related to offshore wind in comparison to onshore wind [Energistyrelsen and Energinet, 2020c]. However, a scenario containing use of fossil fuels does increase the costs related to CO_2 emissions and prevents Denmark from producing energy that covers the Danish demand if there is a need to important fossil fuels [Energistyrelsen, n.db]. Overall, it is an indication that a frozen politics scenario has a negative effect on the growth in EC share and thereby also on the possibility of reaching the 2050 goal. The scenario gives an understanding of the importance of changes in politics that are in favour of ECs if the national goal should be reached. Furthermore, does the scenario contain climatic risks, and such a scenario is therefore not preferable in relation to the national goal of a fossil free Denmark in 2050. The results from the EnergyPLAN simulation can be seen in section B.1 in appendix B.

5.2.2 Alternatives Assessment

The risks of a linear growth rate with a replacement of renewable energy with fossil fuels are determined, but if a linear growth is to happen, alternative solutions for the car fleet are necessary if the 2050 goal should be reached. In this thesis, an alternative solution consists of a similar EC share as in the risk assessment, but with the remaining car fleet consisting of renewable energy sources instead of fossil fuels. It is expected that this scenario influences the economy, because of the potential need of expensive technologies or a increase in import in order to maintain the costs at a level similar to what can be seen in the IDA vision.

For the alternatives assessment, it is investigated if it is possible to replace the fossil fuels from the risk assessment with renewable energy sources, so that it is possible to reach the 2050 goal despite of a lower EC share. Additionally, it is investigated if it is possible to make use of biomass as an substitute in relation to the preference of keeping biomass at an acceptable level. Previously, an acceptable biomass consumption was noted to not exceed 250 PJ, but that a consumption close to 200 PJ or below is preferable 4.4.2. In the IDA vision, the annual biomass consumption equals 47,91 TWh/year or 172,48 PJ, leaving little room for an increase in biomass in the thesis scenarios. The fossil fuel consumption stands for 25,5 TWh/year. If this share is replaced by biofuel, the result is as seen in the table 5.7 below.

Results – Scenario 1: Linear Growth (biofuel)

Parameter	IDA vision	Linear growth (risk ass.)	Linear growth (alternative ass.)	Unit
Annual investment costs	20268	19143	19156	MEUR
Total annual costs	29642	29793	15501	MEUR
CEEP	2,99	2,97	0,87	TWh/year
Oil usage	0	25,5	0	TWh/year
Offshore wind capacity	14000	13150	11400	MW
Biomass consumption	47,91	42,87	81,36	TWh/year
RES share	100	85,2	100	%
CO2 emission	0	6,25	0	Mt
Total CO2 emission costs	0	263	0	MEUR

Table 5.7: Results from the alternative assessment including biomass in comparison with the IDA vision and risk assessment

In a linear growth scenario where fossil fuels are replaced by biomass for transportation, the biomass consumption increases to 81,36 TWh/year, which is equal to 292,72 PJ/year. This scenario is thereby not desirable in the case where a biomass consumption below 250 PJ is preferred. Though, there is the possibility to import the remaining biomass demand when the 250 PJ limit is reached. But this method brings issues, such as a reduction in the security of supply that follows when energy is imported [Bran and Chipurici, 2015]. In addition to that, discussions regarding the use of biomass as a CO_2-neutral energy source is also worth bearing in mind. Biomass functions as a good substitute to fossil fuels, but CO_2 is still emitted during the incineration of biomass and new trees therefore have to be planted in order for them to bind the emitted CO_2. For this to be successful, planting of new trees has to be carefully supervised, but when trees are planted years have to go by for them to reach a CO_2-uptake equal to the level seen before the shedding [Johnston and van Kooten, 2015]. These arguments are worth considering when wanting to determine the share of biomass in the energy system. This also means, that a solution where biomass covers the remaining car fleet is not to be preferred. A third solution thereby has to be proposed in order for the scenario to meet the criteria in relation to the use of biomass, and in relation to the 2050-goal concerning fossil fuels. The results from the EnergyPLAN simulation can be seen in section B.2 in appendix B.

A third alternative to use as fuel for transportation is hydrogen produced by an electrolysis process. By using hydrogen for transportation, it is possible to lower the biomass consumption. The criteria for the two car types are as seen in table A.1 in appendix A, and the results from the EnergyPLAN simulation can be seen in section B.3 in appendix B.

For this scenario, the biofuel cars account for 800,000 cars or 36% of the car fleet, while hydrogen cars account for 55% or 1,214,000 cars. This distribution is used in order for the biomass consumption to be lowered to a level of 208,5 PJ, which is an acceptable level in relation to the scenario criteria even though it still exceeds the preferred level of 200 PJ. The scenario results can be seen in table 5.8 below.

Results – Scenario 1: Linear Growth (biofuel/hydrogen)

Parameter	IDA vision	Linear growth (biofuel/hydrogen)	Unit
Annual investment costs	20268	20199	MEUR
Total annual costs	29642	23047	MEUR
Onshore wind capacity	5000	6250	MW
Offshore wind capacity	14000	14000	MW
CEEP	2,99	0,71	TWh/year
Biomass consumption	47,91	57,93	TWh/year
RES share	100	100	%
Electrolyser capacity	9009	12500	MW-e
Hydrogen storage	552	800	GWh

Table 5.8: Results from the alternative assessment including biofuel and hydrogen in comparison with the IDA vision

The production process of hydrogen requires conversion of electricity and because of an energy loss during electrolysis and when driving the vehicle, the use of hydrogen requires a higher wind capacity [Connolly et al., 2014a]. For that reason, the onshore wind capacity is increased as seen in table 5.8. Electrolysis is currently a more expensive alternative than e.g. biomass and electricity used directly for ECs [Connolly et al., 2014a]. Though, it is more efficient and a solution for storing electricity as hydrogen, why it is also contributing to a more flexible energy system [Lund, 2014b]. Additionally, the increased flexibility affects the share of CEEP which is 0,71 TWh/year because of the improved energy storage facilities. In comparison to the updated IDA vision values, this alternative has lower costs, which makes this alternative attractive in an economic perspective. Though, cars for biofuel and hydrogen have a significantly lower efficiencies and higher energy consumption than ECs, which is one indication pointing towards ECs being the more obvious choice of technology for the future transport sector. For that reason, the following two scenarios consist of higher EC shares in order to examine how such scenarios affect the energy system.

5.3 Scenario 2: 50% Electric Car Share

This scenario does not follow a particular growth rate as the scenario is based on the end-result of a 50 % EC share, and not how the EC fleet develops. This scenario thereby consists of uncertainty in regards to when the ECs are added to the car fleet, which also comes with uncertainty about different factors in the calculations such as efficiencies and fuel consumption. In figure 5.4, the scenario is shown as a linear function, because of the uncertainty about the growth rate.

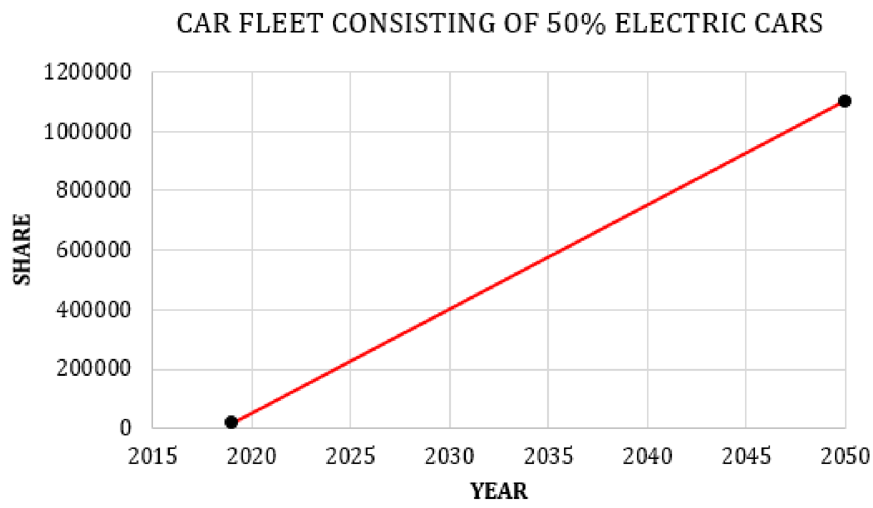

Figure 5.4: Development in a scenario consisting of a car fleet with 50% ECs

Because of the uncertainty about when car owners procure the technology, the average of the different EC values is used as in the previous scenario. This scenario does not contain a risk assessment as in the first scenario, because the negative effects of having fossil fuels in the energy system and because a 100% renewable energy system in 2050 is preferred.

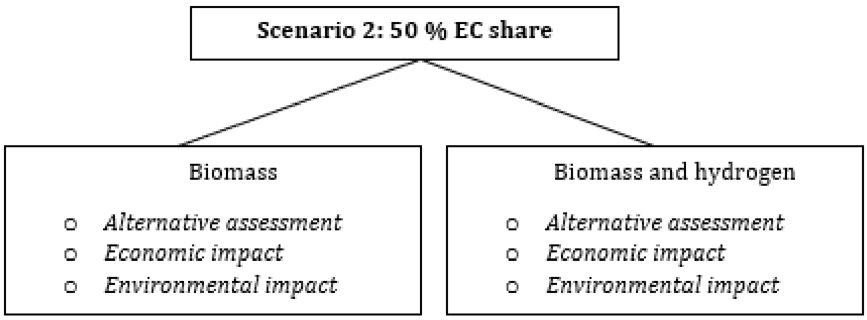

Figure 5.5: Focus points in scenario 2: 50% EC share

The above figure illustrates what the alternatives assessments consist of in this scenario. Similar to the previous scenario, one alternative consists of a biomass replacement, and the second alternative is a combination of biomass and hydrogen for the remaining 50% of the car fleet. For this scenario, the share of ECs is significantly higher, which results in a lower share of cars that are to be covered by alternatives fuel, than what was the case in scenario 1.

5.3.1 Alternatives Assessment

With 50% of the car fleet consisting of ECs, the remaining 50% account for 1,100,000 cars. Where the alternatives assessment in the previous scenario contains alternatives to the use of fossil fuels, this scenario operates with alternatives to the IDA vision because solutions operating with different shares of ECs might be useful when forming the future energy system. With point of departure in the values from section 5.1, the corrections in EnergyPLAN for this scenario are as shown in table 5.9 below.

Parameters	IDA vision	50 % scenario	Unit
Electricity demand	6,03	4,3	TWh/year
Dump charge	2,64	2,08	TWh/year
Smart charge	6,46	4,3	TWh/year
Electric cars (total)	61600	30800	MEUR
Charging stations	4347	2732,4	MEUR
Capacity of grid to battery connection	16396	11496	MW
Capacity of battery to grid connection	820	580	MW
Battery storage capacity	14,2	10	GWh
Offshore wind capacity	14000	11850	MW
Biofuel	0	13,7	TWh/year
Biofuel cars (total)	0	25080	MEUR

Table 5.9: Table showing the parameters that are changed in EnergyPLAN, from the values of the IDA vision to the values relevant to the linear growth scenario

As mentioned, the first scenario does not include hydrogen cars, which means that 50% of the car fleet runs on biofuel in the first simulation, and the scenario results are shown in table 5.10, and the results from the EnergyPLAN simulation can be seen in section B.4 in appendix B.

Results - Scenario 2: 50% (biofuel)

Parameter	IDA vision	50 % scenario	Unit
Annual investment costs	20268	19596	MEUR
Total annual costs	29642	21950	MEUR
Onshore wind capacity	5000	5000	MW
Offshore wind capacity	14000	11850	MW
CEEP	2,99	0,71	TWh/year
Biomass consumption	47,91	68,53	TWh/year
RES share	100	100	%

Table 5.10: Table showing the results for a passenger car fleet consisting of 50% electricity and 50% biofuel

By using biofuel as an alternative to the remaining half of the car fleet, the scenario costs decrease in comparison to the IDA vision. With a 50% EC share, it is possible to lower the offshore wind capacity, resulting in a lower share of fluctuating energy in the system and thereby a reduced CEEP value.

The annual investment costs do not vary much from the IDA vision, but the difference in the total annual costs is considerable and is assumed to occur due to lower operation and maintenance costs associated with the technologies applied in this scenario. Furthermore, the biomass consumption in this scenario is 247,4 PJ, which is just below the critical limit of a sustainable use of biomass, but also a significant level above the preferred 200 PJ. In a situation where biomass below 250 PJ is acceptable, this scenario could function as an alternative to the IDA vision if the EC fleet reaches 50% in 2050. The scenario has decreased CEEP and a lower offshore wind capacity, but it could be argued that it is more optimal to utilize the level of wind capacity utilized in the IDA vision because of wind energy being a renewable and zero-emitter energy source in comparison with biomass. In relation to exploring the option of utilizing the wind capacity, an alternative assessment with electricity, biofuel and hydrogen is composed. The changes from the previous scenario are shown in table 5.11 below, and the results from the EnergyPLAN simulation can be seen in section B.5 in appendix B.

Parameter	50 % (biofuel)	50 % (biofuel & hydrogen)	Unit
Biofuel	13,7	6,9	TWh/year
Hydrogen	0	4,5	TWh/year
Electrolyser capacity	9009	10810	MW-e
Hydrogen storage	593	712	GWh
Offshore wind capacity	11850	13100	MW

Table 5.11: Table showing the parameters that are changed in EnergyPLAN, from the values of the alternative with biofuel to an alternative consisting of biofuel and hydrogen

In this alternative, the biomass consumption is reduced by adding hydrogen to the transport sector. The scenario therefore consists of 50% ECs, 25% biofuel and 25% hydrogen, which makes the distribution of the car fleet as follows:

- 1,100,000 electric cars
- 550,000 biofuel cars
- 550,000 hydrogen cars

The results for this alternative are shown in table 5.12, and the results from the EnergyPLAN simulation can be seen in section B.2 in appendix B. By including hydrogen, the total annual costs increases, and the biomass consumption is reduced to 213,4 PJ, which is considered acceptable but above the proposed level of 200 PJ in the IDA vision.

Results - Scenario 2: 50%

Parameter	IDA vision	50 % scenario (biofuel)	50 % scenario (biofuel & hydrogen)	Unit
Annual investment costs	20268	19596	20013	MEUR
Total annual costs	29642	21950	25250	MEUR
Offshore wind capacity	14000	11850	13100	MW
CEEP	2,99	0,69	0,27	TWh/year
Biomass consumption	47,91	68,53	58,29	TWh/year
RES share	100	100	100	%
Electrolyser capacity	9009	9009	10810	MW-e
Hydrogen storage	552	552	662	GWh

Table 5.12: Table showing the results for a passenger car fleet consisting of 50% electricity, 25% biofuel and 25% hydrogen

Furthermore, by being able to store the electricity from the increased wind capacity, the CEEP level is lowered to 0,27 TWh/year. As earlier mentioned, electrification has first priority, and this scenario confirms why it should be prioritized to aim for an EC fleet above 50%. With an increase in the EC fleet, the demand for biomass can be lowered which results in a more sustainable solution. For that reason, a scenario including a passenger car fleet with a 90% EC share is composed.

5.4 Scenario 3: 90% Electric Car Share

Because of the inaccurate predictions of the development in ECs so far, a scenario operating with an EC share of 90% is chosen as one scenario in this thesis. It is assumed, that a higher EC share, than what has been suggested in the IDA vision, also is a possible outcome in the future.

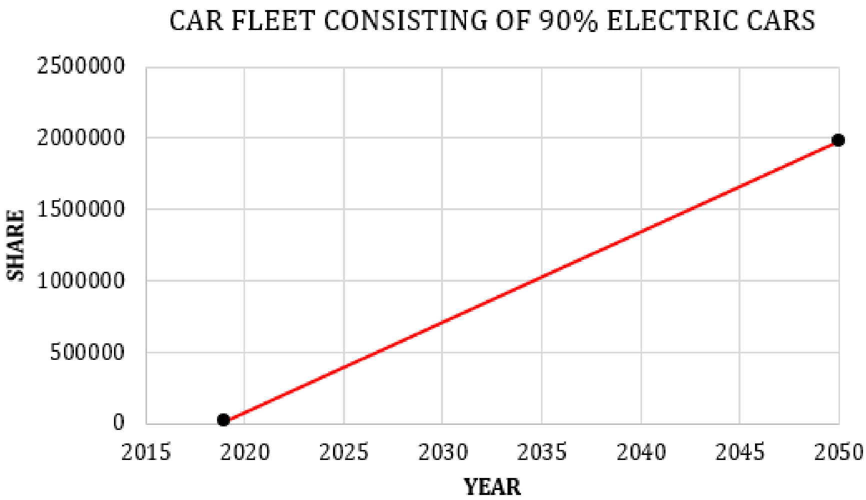

Figure 5.6: Development in a scenario consisting of a car fleet with 90% ECs

A scenario operating with a transport sector having an EC share of 100% is considered to be unlikely due to the fact that other renewable transport technologies are already existing. However, due to the efficiencies and thereby lower energy consumption for ECs in comparison with other vehicle types in 2050, it is assumed a possibility that this technology has high priority among car manufacturers and car buyers, and that a higher EC share than what the IDA vision projects is a possibility in the future.

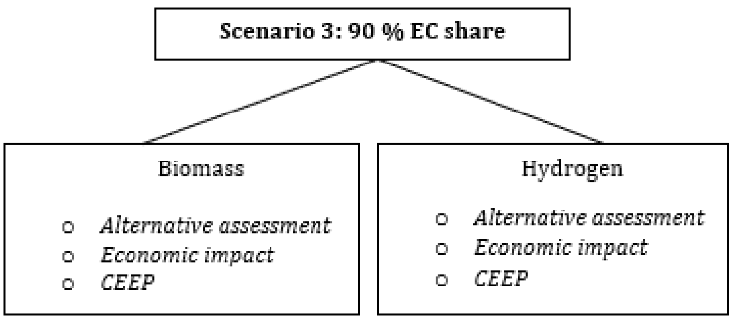

Figure 5.7: Focus points in scenario 3: 90% EC share

As figure 5.7 shows, two alternatives are composed with a 90% EC share. For this scenario, it is chosen to replace the remaining 10% of the car fleet by either biomass or hydrogen. This means, that they differ from the previous scenarios where biomass and hydrogen are combined. For the simplicity of the scenario, a combination of biomass and hydrogen is not included, as the remaining 10% make up for a minor share of the car fleet.

5.4.1 Alternatives Assessment

Two scenarios are composed including the remaining 10% of the car fleet to be driven by biomass and hydrogen, respectively. For these scenarios, it is expected for the wind capacity to be expanded due to the higher EC share. Though, the CEEP level is not expected to increase, because of the higher share of smart charge than applied in the IDA vision. The scenarios are consisting of a 90% EC share corresponding to 1,980,000 cars, which makes the remaining part of the car fleet consist of 220,000 cars. The parameters in EnergyPLAN are changed as seen in table 5.13 below, and the results from the EnergyPLAN simulation can be seen in section B.6 in appendix B.

Parameters	IDA vision	90 % scenario	Unit
Electricity demand	6,03	7,72	TWh/year
Dump charge	2,64	2,08	TWh/year
Smart charge	6,46	7,72	TWh/year
Electric cars (total)	61600	55440	MEUR
Charging stations (total)	4347	4919	MEUR
Capacity of grid to battery connection	16396	17660	MW
Capacity of battery to grid connection	820	884	MW
Battery storage capacity	14,2	15,3	GWh
Biofuel	0	2,72	TWh/year
Biofuel cars (total)	0	5016	MEUR
Hydrogen	4,99	6,79	TWh/year
Hydrogen cars (total)	0	6182	MEUR

Table 5.13: Table showing the parameters that are changed in EnergyPLAN. From the updated IDA vision values to the values relevant to a scenario with a 90% EC share

By changing the values in energy plan, the third scenario results in two different alternatives consisting of one with a combination of ECs and biomass, and one with ECs and hydrogen. The results show, that the costs of the three scenarios are similar to each other but also that the two scenarios in this thesis have a lower offshore wind capacity in comparison with the IDA vision. The lower wind capacity deviates from the expected increase in capacity but is assumed to be because of a high share of smart charge, which explains the low CEEP values as well. Additionally, can the lower wind capacity be a result of a higher EC share consisting of higher efficiencies than the electrofuels included in the IDA vision.

Results - Scenario 3: 90%

Parameter	IDA vision	90 % scenario (biomass)	90 % scenario (hydrogen)	Unit
Annual investment costs	20268	20191	20311	MEUR
Total annual costs	29642	28932	29420	MEUR
Offshore wind capacity	14000	12300	12800	MW
CEEP	2,99	0,04	0,09	TWh/year
Biomass consumption	47,91	41,15	36,23	TWh/year
RES share	100	100	100	%
Electrolyser capacity	9009	9009	10810	MW-e
Hydrogen storage	552	552	662	GWh

Table 5.14: Table showing the results of scenario 3 in comparison with the IDA vision

From the biomass scenario to the hydrogen scenario, the offshore wind capacity increases because of the need for electricity in an electrolysis process [table 5.14]. Additionally, the CEEP level decreases considerably in both of the 90% EC scenarios because of the higher EC share in combination with a lower wind capacity. The hydrogen scenario was expected to have the lowest CEEP level, but because of an increase in the wind capacity from the biomass scenario, the CEEP level is slightly higher. Besides that, the biomass consumption is lowered in the thesis scenarios in comparison with the IDA vision. This is because of an replacement of electrofuels with biopetrol, which results in higher efficiency. This means, that the biomass level from these scenarios still are within the preferred 200 PJ. The results from this scenarios EnergyPLAN simulation can be seen in section B.7 in appendix B.

5.4.2 Results

Based on the scenarios composed in this thesis, climate and economy perspectives are analysed in relation to the future car fleet and the energy system. Three scenarios withholding sub-scenarios are established, compared to the IDA vision and to one another.

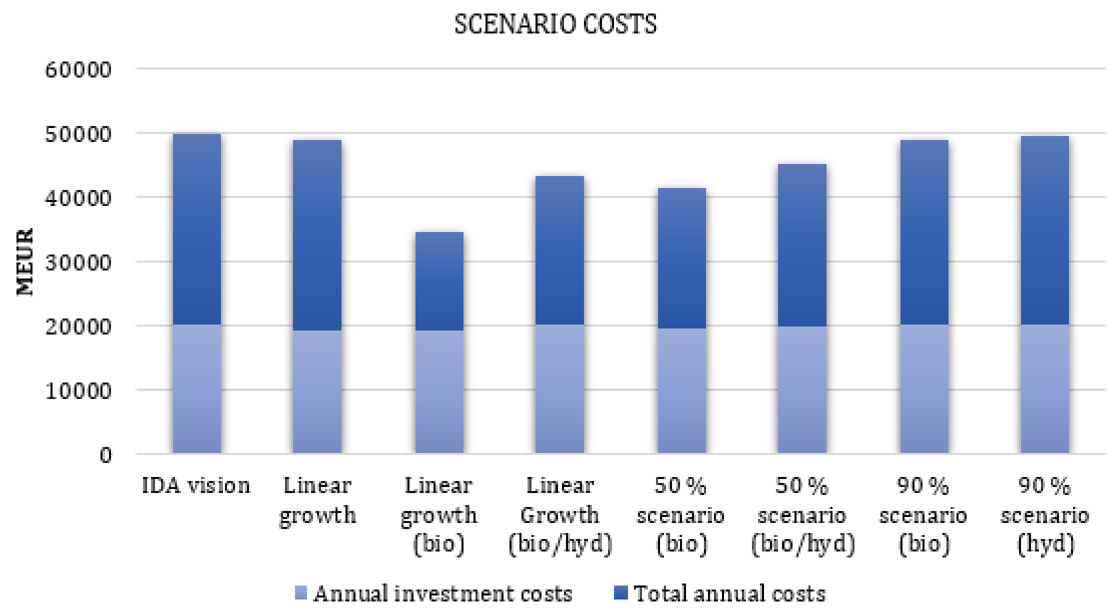

Figure 5.8: Results for scenario costs

Figure 5.8 shows a comparison of the costs in the different scenarios. The annual investment costs are nearly the same for all of the scenarios, but differences occur in the total annual costs. Here, the IDA vision and the two scenarios with a 90% EC share are the scenarios with the highest total annual costs. The 50% (biofuel) scenario is the scenario with the lowest costs, because of the lower operation and maintenance costs on biofuel cars in combination with the lower investment costs related to biopetrol in comparison with hydrogen. The same arguments can support the results of the linear growth (biofuel) scenario where the costs are low despite a significantly lower EC share. This means, that low costs are related to the use of biomass, and that the costs increases in step with a higher EC share and the integration of hydrogen.

Besides the costs, other factors vary depending on the scenario as well. Figure 5.9 illustrates the biomass consumption and CEEP level for the scenarios. The scenarios in this thesis all have lower CEEP levels than the 2,99 TWh presented in the IDA vision. Of the thesis scenarios, the linear growth scenario accounts for the highest CEEP level, which is because of the low EC share with smart charge and the absence of hydrogen. Furthermore, does this scenario contain a high wind capacity in relation to the low EC share. The offshore wind capacity for this scenario is increased to the highest capacity possible without exceeding a CEEP level of 2,99 TWh. This increases the RES share as much as possible even though the scenario contains fossil fuels.

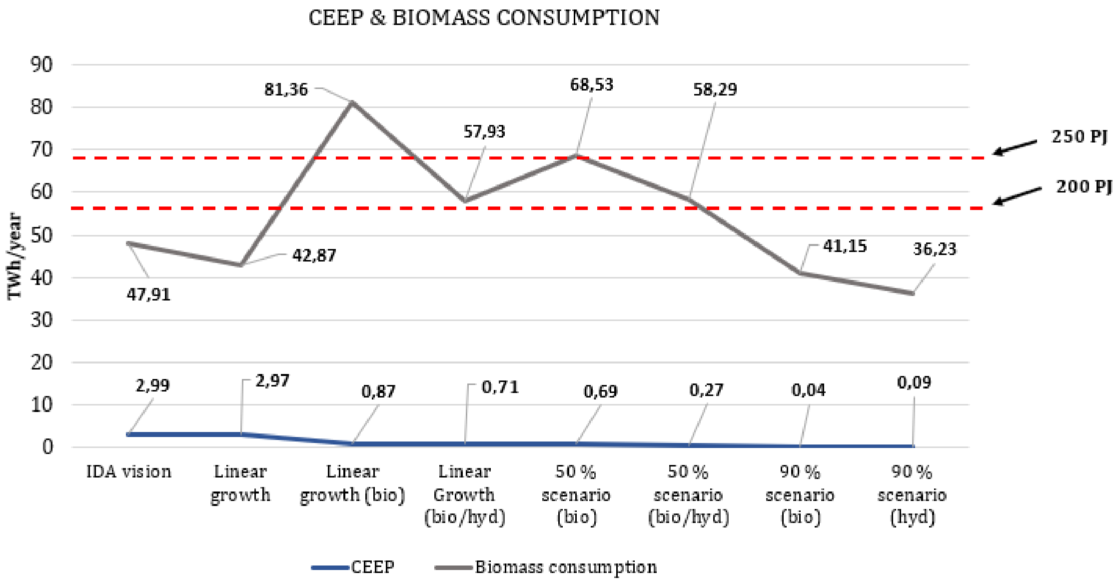

Figure 5.9: Results for scenario CEEP level and biomass consumption

Besides the CEEP level, does one graph in figure 5.9 illustrate the biomass consumption in the scenarios. Four scenarios contain a higher usage of biomass in comparison with the IDA vision, which means that these scenarios exceed the preferred 200 PJ. The scenarios show, that low biomass usage increases the costs, because of the necessity to utilize more expensive technologies such as electrolysers. Though, no thesis scenario exceeds the costs of the IDA vision. In relation to the criteria of a biomass usage below 200 PJ and no use of fossil fuels, only the two 90% scenarios meet the requirements.

In relation to figure 5.10, all three of the linear growth scenarios have relatively high wind capacities in comparison to the remaining scenarios which consist of higher EC shares and hydrogen usage. The highest wind capacity is experienced in the linear growth (biofuel/hydrogen) scenario, where the max capacity in offshore wind turbines is reached with a need to expand the onshore wind capacity as well [section 5.2.2]. The reason for this, is that the electricity produced by wind covers the demand outside the transport sector in order for the scenarios to still contain the highest possible RES share.

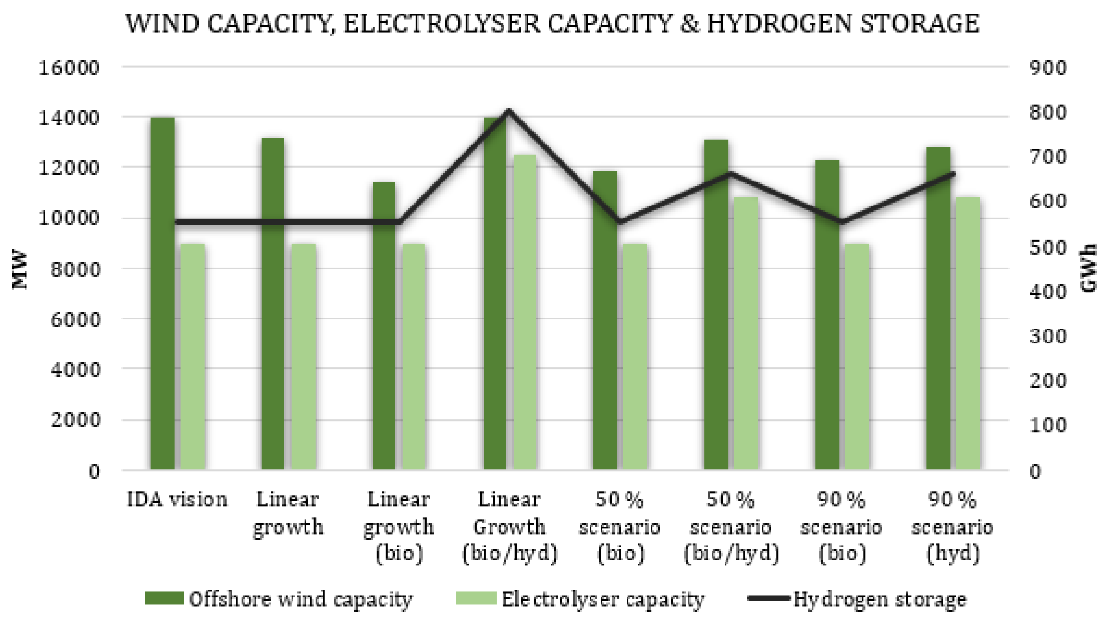

Figure 5.10: Results for offshore wind capacity (MW), electrolyser capacity (MW-e) and hydrogen storage (GWh)

The reason for the linear growth scenario to contain a higher wind capacity than the linear growth (biofuel) scenario, is that the scenario with biofuel reaches a 100% RES share with a offshore wind capacity of 11400 MW. In the linear growth scenario, it is the remaining part of the transport sector that is replaced by fossil fuels, and because of the delimitation of the thesis, no other sector in the energy system has been adjusted [section 2.2]. Besides that, does the figure show a relation between hydrogen storage and the need for an increase in wind capacity. Non of the thesis scenarios have higher offshore wind capacities than the IDA vision, which is a result of higher biomass usage and the higher efficiencies for ECs in comparison with electrofuels. This means, that even though the EC share increases does it not necessarily mean that there is a need for an increase in wind capacity.

The Role of Technology 6

6.1 Technology Structure

With point of departure in the theoretical framework in section 3.2, a qualitative analysis of technological change is composed in relation to ECs in the Danish energy system and the scenarios produced in this thesis. With figure 6.1 as background, it is analysed how the external setting can promote or prevent the EC development. Even though most of the external conditions changes if one of these undergo change, the analysis is not examining all of the conditions, but the ones that are found most relevant to the theme of this thesis. The conditions are evaluated in relation to their direct influence on the EC development, and the ones considered are market at figure 6.1. Though, an analysis of certain conditions does not indicate that changes within the remaining conditions are not possible, but these changes are not considered of relevance in this thesis.

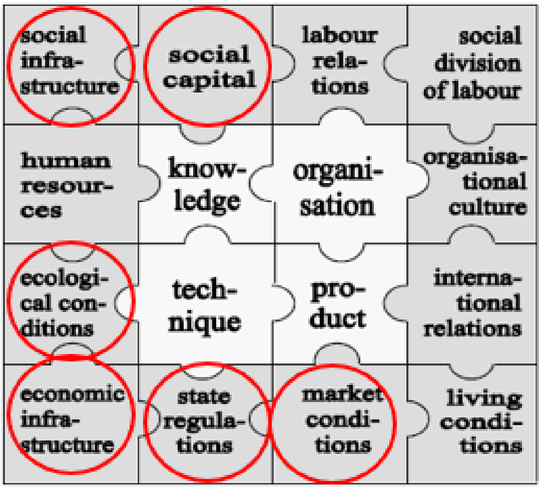

Figure 6.1: Figure highlighting the conditions relevant to technological change within electric cars [Müller, 2011]

Social infrastructure has the purpose to reproduce society's labour force, and it therefore includes health facilities, recreational facilities, educational organisations etc. [Müller, 2011]. Social infrastructure can thereby be defined as spaces, where social services can be accessed by the community [Queensland Government, 2020]. In this thesis, the external condition of social infrastructure does not include all of the facilities, but only focus on educational organisations because they are considered to influence on the EC development. Social infrastructure and *social capital* are terms that are closely related to the constituent of 'knowledge' in the technology concept. A general definition to the term 'social capital' does not exist, but in this thesis social capital is defined as being the resources that are available to the collective and the individual through the social relationships of these. Additionally, the term can be divided into a structural and cognitive dimension, where the structural dimension refers to what people do, whereas the cognitive dimension refers to how people feel in their social relations [Han, 2019]. In this thesis, both of the dimensions are, to some extent, important, and the social capital condition is related to social infrastructure why these are discussed together.

Social infrastructure as educational organisations is considered to be important in relation to the EC development, because of the correlation between ECs and climate. The purpose of integrating ECs in the Danish energy system is to eliminate fossil fuels from passenger transportation due to their negative effect to the climate. Today, studies are claiming ECs to emit more CO_2 than fossil fuel driven cars seen in a life cycle perspective, because of the emissions related to the production of ECs [Klimarådet, 2018]. For that reason, it is considered important that educational organisations take responsibility to pass on knowledge about how the production of ECs can become CO_2 neutral in the future. It is not possible for the EC production to become completely CO_2 neutral before the energy system is made up entirely by renewable energy sources. It is therefore necessary for society to be informed about the importance of perceiving the energy system as a whole, and to understand that a green transition is a long-term process. The importance of education should be seen in connection with misinformation being an obstacle when consumers decide whether or not they want to procure an EC.

The social infrastructure is related to social capital because of the necessity for mankind to have a shared understanding of the climate crisis and which initiatives are needed for the crisis to be averted. The structural dimension is referred to as being what people do, and the cognitive dimension is how people feel. Both of these dimensions can be linked to educational organisations in the social infrastructure, because of peoples' knowledge often being a driver for how they act [Funke, 2017]. Though, it is not solely the social infrastructure that influences on the social capital, but also economic conditions are driving the purchasing power.

State regulations, market conditions and *economic infrastructure* are also conditions that affect the EC development. State regulations in relation to ECs have already been applied by the Danish government to promote the EC sale. These initiatives have worked as short-term solutions, which has resulted in the EC fleet of today not to be of the desired extend. The regulations have resulted in short-term effects because of the government's decision of phasing out the regulative benefits in relation to ECs [Klimarådet, 2018]. This is an example of how important long-term regulations are if it should be possible to obtain a fossil free society. Today, ECs are a more expensive alternative than fossil fuel driven cars, which also prevent many people from buying an EC [Thøgersen and Ebsen, 2019]. At the same time has the Danish government lowered the registration taxation for fossil fuel cars, which has made it possible for people to buy 'more car' for the same amount of money [Skatteministeriet, 2018]. These initiatives from the government are conflicting, as a lowering of both the EC taxation and fossil fuel car taxation can be assumed not to have a notably effect. In a social capital perspective, the credibility of the government can be impaired because of them not giving people a real option to procure an expensive EC even though they are willing to help the climate. This is closely related to the market conditions of the EC market. Because of ECs being a relatively new technology for the public, the prices are higher and not many used ECs are available at the market in comparison with fossil fuel cars. Though, the price of ECs are expected to decrease in step with the technology becoming more mature and widespread. But, the social capital that is present among car owners and the EC technology also has to be strengthened. The technology experiences some lack in trust in relation to the technology being able to fulfill the demands of car users [Klimarådet, 2018]. Here, the economic infrastructure should be mentioned as well. This term covers the physical system of a nation or a business, including electric systems or transport systems, which are the ones most important to this thesis. It is a necessity for these systems to function in order for the national economy to develop and for the nation's functioning [Chappelow, 2020]. The transport and electricity systems are important to maintain in order for the EC fleet to increase as well. In Denmark, the security of supply is high, which is crucial to maintain in order for the car users to trust the technology and thereby procure an EC. Today, one reason for people not procuring ECs, is that they do not trust the technology to be able to fulfill the needs that a fossil fuel car can [Thøgersen and Ebsen, 2019]. At some points, that is the truth, and that is why the EC development is depending on how the technology develops and navigates at the market as well.

The last condition from the technological change jigsaw with relevance to this thesis, is the *ecological conditions*. The meaning of this is not defined by Müller, but in this thesis the understanding of ecological conditions is discussed in relation to the availability of the resources needed to produce or run a given technology, and how this affects the environment and technological change.

Today, the majority of passenger cars are driven by fossil fuels, which is a scarce resource. This means, that changes within vehicle technology has to occur eventually, because the fossil fuel resources are fully exploited a a given time in the future [Society, 2019]. Though, because of the Paris Agreement[1], greenhouse gas emissions are to be reduced, which is why technological change within vehicles is now initiated, as the transport sector is responsible for a significant part of greenhouse gas emissions [chapter 1]. In relation to climate change, it can be considered responsible to force technological change within the car industry, as long-term security of supply not can be obtained with fossil fuels usage. By implementing vehicles that are driven by electricity from wind turbines, the resource is both renewable and CO_2 neutral. As earlier mentioned, it is possible for the production of ECs to be carried out by the use of renewable energy, but the production also includes use of metals that experience an increase in demand in step with ECs becoming a more widespread technology. This is therefore an examined problem today, as the metals used to produce ECs is increasing and therefore also might be a scarce resource in the future. In such a scenario, the EC technology will experience some challenges, forcing the manufacturers to reconsider the technology structure which is currently experienced by examining possible replacements of critical metals by the so-called strategic metals [Iglesias-Émbil et al., 2020]. Though, the EC industry emits less CO_2 than fossil fuel driven cars, it is still a possibility

[1]In 2015, 196 parties adopted the Paris Agreement comprising worldwide sustainable development with a goal to limit global warming. This means, that the temperature, in comparison with the pre-industrial level, should not exceed 1.5-2 degrees Celsius [United Nations, n.d]

that this industry will meet similar problems to the ones related to fossil fuels when it comes to security of supply. Also, fossil fuels are still available today, giving competition to ECs from fossil fuel driven cars as a more convenient and cheap alternative. Overall, the EC technology functions as a good alternative to fossil fuel cars in relation to the environmental impacts, but obstacles with the production of ECs might still occur in the future, why one could say that the technology is not fully developed at this point. Additionally, from an institutional perspective, several regulative challenges are present and should be considered for the EC industry to develop as desired. This clarifies how changes in one condition can influence on technological change, but also that the conditions are connected in one way or another and that several of the conditions overlap by covering parts of the same area.

6.1.1 Electric Cars in Large Technical Systems

ECs can be perceived as an individual technology, but also as one part of an LTS. In this thesis, the LTS that is being considered is the Danish energy system. The EC technology is situated in the transport sector of the energy system and because of the SES concept, connecting sectors of the energy system strengthens the system's flexibility [section 3.1].

As presented in section 3.2.1, an LTS is characterized by being of global nature meaning that most people are affected by the LTS some of the time. This is an exact indication that the energy system can be defined as an LTS, as most people, businesses and sectors are depending on the energy system to function. In this thesis, the Danish energy system is approached as an LTS currently situated in the accelerated development phase, placing the energy system in the second of four phases. This means, that the old energy system based on fossil fuels is placed in the decline phase, because of the importance of an extension of this system is diminishing and because of an energy system based on renewable energy is prioritized.

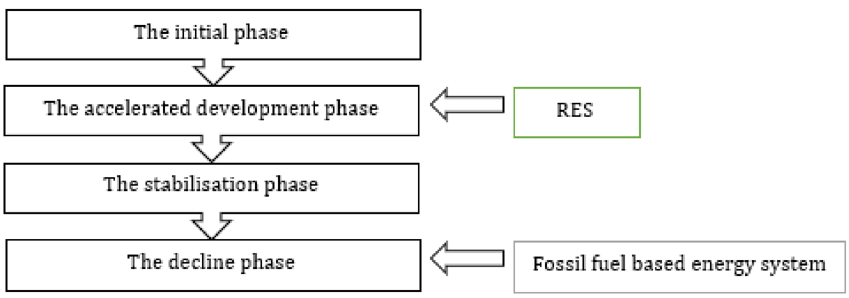

Figure 6.2: The Danish energy system undergoing changes, situating the current fossil fuel based system in the decline phase and the future 100% RES in the accelerating development phase

The new energy system, that is also illustrated in the thesis scenarios, has passed the initial phase, where the LTS does not yet undergo a plan. The initial phase also includes debates on how the new LTS can benefit the society, which has already happened by concluding that renewable energy sources give security of supply together with them not affecting the climate in a negative manner. The Danish energy system of today is thereby situated in the accelerated development phase because of it developing in compliance to the plan of the energy system becoming fossil free in 2050. This development is a long-term process, meaning that the fossil fuel based system is situated in the decline phase and will continue to be for years to come. This also means that the linear growth scenario, including fossil fuels from the previous part of the analysis, is situated in the decline phase. Additionally, an EU memo stated that renewable energy sources made up for 37% of the energy usage in Denmark in 2018. This argues that the stabilisation phase has not yet been reached, because of fossil fuels still being the dominating energy source in the system.

How the energy system is situated in the phases can be transferred to the EC development as well, where the EC technology can be said to have passed the initial phase, but not yet be in the stabilisation phase. Additionally, a close correlation between ideological and political views and the LTS can be experienced. This is manifested in the political initiatives that are adopted in order for both the EC technology and the energy system to develop, as political regulation seeks to promote the green transition. The rate and direction that the system develops at are, according to Hugh Aitken, determined by socioeconomic contexts of the given technology [Gökalp, 1992]. In Denmark, the socioeconomic position is considered to be high due to the country being a welfare state with resources such as high income level, free education and healthcare. Hugh Aitken's statement is therefore considered correct in relation to the Danish energy system moving towards a completely renewable energy system. On the contrary, does the statement not match to the EC technology because of it developing at a slow pace compared to other countries with a similar socioeconomic position. EC promoting initiatives have produced positive results in Norway, leaving the country with the world's highest EC share. Though, Norway has made use of several initiatives to promote ECs including free parking, free fairy rides and exemption from registration taxation [Bjerkan et al., 2016]. With the Norwegian EC strategy in mind, the importance of long-term EC promoting initiatives are important in order for the population to adopt the technology.

The above-mentioned leads to an investigation of the three spheres in Aitken's second approximation model, and how these influence on the Danish energy system as an LTS. It is discussed in relation to the EC technology and how the spheres are affecting this as well. In this thesis, the three spheres are considered to have the same approach to technology as the four elements of technology and the conditions that surround these. An argument for this, is that the two approaches consider either technology or an LTS from a holistic view, meaning that the technology itself does not undergo change without external influence, and that changes within the technology affects the external conditions.

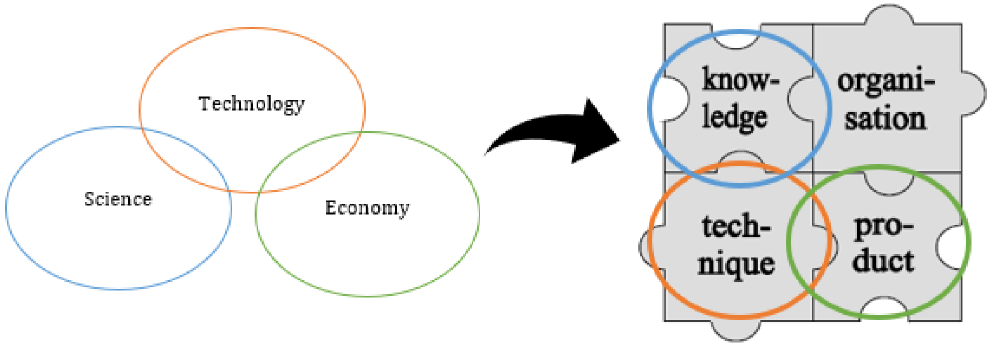

Figure 6.3: The three spheres from Aitken's approximation model transferred to Müller's four elements of technology

In figure 6.3, it is illustrated how there is a correlation between Aitken's approximation model and Müller's four elements of technology. This is shown by transferring the three spheres to the jigsaw of technology, where knowledge, technique and product functions as the three spheres leaving only organisation as an extra element of technology.

In the approximation model, the three spheres are not all related though it, in this thesis, is argued that a relation between science and economy can be found as well. This is based on how the economy influences on the possibility to carry out proper research. Research requires financial resources, and in Denmark such funds are distributed to research with the purpose to accelerate the green transition [Energistyrelsen, 2020b]. It can therefore be argued that the economy that the given LTS is located in, affects the pace in which the LTS develops and thereby connects science and economy in the approximation model. Additionally, this observation makes it possible to argue that science affects the economy as well. By being able to carry out research, the economy can be strengthened because of an increase in employment and the ability to be innovative [Loiseau et al., 2016]. Though, the relation that goes from science to economy can be argued to pass through the technology sphere because of the necessity of the research to produce technology that can enter the concerned market to create profit. This means, that science is affecting the technological development because of the generation of technological devices that occurs with assistance from science. As mentioned, innovative technological development affects the economy, but likewise does the sphere of economy have the power to affect technology directly. In this thesis, this can be experienced in a regulation perspective where political initiatives are able to promote technology. This does not mean that the development of the technology is affected directly, but that the spreading of the technology increases because of it obtaining a higher market share. In addition to that, the higher market share can be assumed to naturally result in the technology to develop because of an increased interest for the product.

6.1.2 Technological Change in Practice

This section includes examples of how an understanding of technological change functions in practice. Here, the theoretical framework is applied to the scenario composed in this thesis. Examples of how the external conditions are able to influence on technological change are countless. Most often do changes in one condition generate change in other conditions, which means that technological change should be perceived from many perspectives and in coherence. As earlier mentioned, have the most relevant conditions to this thesis been emphasized, but this is not synonymous with the other conditions being completely without relevance. Figure 6.4 illustrates examples of how the conditions can affect the outcome of the future energy system.

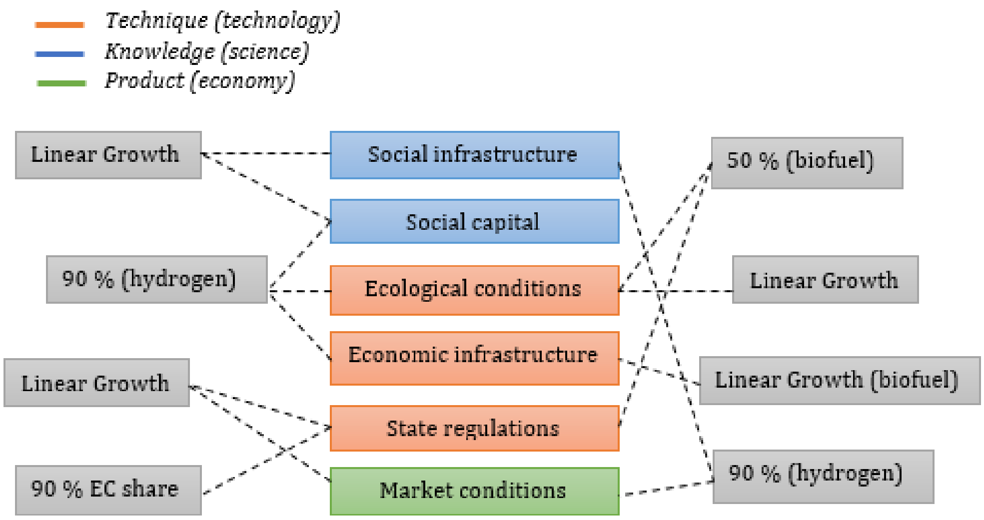

Figure 6.4: Examples of how technological conditions are related to the thesis scenarios. The colors of the conditions indicate the concerned elements of technology and the three approximation model spheres

The figure is not exhaustive, meaning that these are only few out of many possible influencing factors. The figure shows that changes in social infrastructure and social capital are able to result in the linear growth scenario becoming a possibility. This means, that if the general perception of climate change turns out in favour of fossil fuels, then the EC share develops into a scenario with linear growth. Likewise, it is possible for the linear growth scenario to be affected by market conditions and state regulations. This means, that if car taxation is regulated in favour of fossil fuel cars and if the EC technology does not mature as desired, then ECs do not become as widely distributed as is the case within the remaining scenarios. On the contrary, the same conditions can affect the EC development in the opposite direction. This can be seen in relation to the 90% EC scenarios, where state regulations are able to promote the EC development and where the right market conditions can result in a widely distributed technology.

The economic perspective is important for technological change as well. Here, the figure illustrates connections between the linear growth (biofuel) scenario and the 90% (hydrogen) scenario, respectively. In this thesis, the economic infrastructure covers elements as security of supply which can affect the future energy system in two ways. If the security of electricity supply in Denmark is reduced, a linear growth scenario is more likely to occur, but if the security of supply is maintained at the current level, a significant growth in ECs is expected. The market conditions are relevant to mention in relation to economy, as the market dictates the prices and thereby consumers' ability to purchase. In addition to that, the market conditions are affecting the scenario that unfolds in Denmark, as declining prices strengthens the consumers' purchasing power. Contrary to this, will the purchasing power decrease in step with increaseing prices.

The ecological conditions are affecting the outcome of the scenario as well, depending on the resources available in the future. If limited resources are available for the production of ECs, linear growth and 50% EC scenarios are more likely to occur while the possibility of 90% scenarios decreases. Additionally, the ecological conditions in relation to biomass are also affecting the scenario outcome. If biomass resources become more available in the future, then scenarios including high shares of biomass, such as linear growth (biofuel) and 50% (biofuel), more likely to occur - especially because of the economic benefits related to biomass.

The coupling conducted between the theoretical framework and the technical analysis, illustrates the several external conditions that affect technological change in different directions. Once again, it should be stressed that this illustration is not complete and that a full elaboration of every condition, together with their positive and negative effects on technological change, not is possible to conduct in this thesis. Though, this illustration gives an understanding of the complexity that technological change is, and that changes in one condition result in other conditions to change as well. Furthermore, it exemplifies that changes in the conditions can result in different outcomes, meaning that no absolute answer exists when analysing technological change.

6.1.3 Summary

To summarize the findings in this chapter, table 6.1 contains the emphasized conditions from the technology jigsaw. The table explains what the mentioned conditions withhold, seen in a perspective where an increase in the sales of ECs is desired.

Condition	Factor	Content
Social infrastructure	Educational organisations	Responsibility to pass on correct knowledge Information about climate change, CO_2 and the energy system
Social capital	Shared understanding	Perception of climate change Knowledge drives actions Personal finances equals purchasing power
State regulations	Political initiatives	Exemption from taxation Making other alternatives less attractive
Market conditions	Technology maturity	Strengthening of the technology reliability Lowering of cost prices
Economic infrastructure	Physical systems	Security of electricity supply
Ecological conditions	Resources	Alternatives to critical metals Focus on strategic metals Technology structure reconsideration

Table 6.1: The six conditions from the technology jigsaw with importance to the electric car technology

What was found, was that political regulation has a significant role in promoting ECs, especially because of the existence of fossil fuel cars, which is a competitive technology and for many also a more attractive alternative. In addition to that, the regulations that

have been adopted so far have worked on a limited time frame, which is conflicting with the actual goals for Denmark, as these operate on a long-term time frame. At the same time, have regulations on the EC technology happened in step with regulations being applied to fossil fuel cars, where both of the regulations have the purpose to make the technologies more attractive. These initiatives are contradictory to each other and makes the government appear inconsistent in the attempt to promote green technology.
In the case where the governmental regulations do not have the desired effect, the consumers are given the ability to choose from different technologies, which especially makes the other conditions important. These consist, to a high degree, of factors that are affecting the consumers willingness to procure an EC. This concerns people's knowledge about climate change together with their shared understanding of what is necessary to carry out in other to achieve sustainability. Besides that, do doubt among the consumers prevent them from buying ECs, but with developing the technology structure, this doubt should hopefully phase out.

Besides the EC technology being analysed individually, the Danish energy system as an LTS was analysed too. Here, it was determined that the future renewable energy system is currently situated in the accelerated development phase, whereas the current fossil fuel based energy system is situated in the decline phase. Aitken's approximation model to an LTS was applied to be able to determine where the most productive interactions take place, giving the LTS the needed tools to accelerate. An extension of the model was found by determining a unidirectional connection between economy and science. Additionally, a relation between the technology jigsaw and the approximation model was identified together with the possibility to influence on the LTS acceleration through the three spheres; technology, science and economy.

The correlation between changes in the external conditions and the outcome of the thesis scenarios is shown in section 6.1.2. Here, it is found that each of the conditions are able to affect how the energy system unfolds, both in a positive and negative direction given the perspective. In addition to that, if the effect of the external conditions are known, then it is possible to make adjustments in the conditions to promote technological change.

In the forthcoming chapter, the findings connected to the scenarios and the technological change analysis are discussed in relation to each other.

Discussion 7

This chapter includes discussions in relation to the possibility of the thesis scenarios to become a reality, how to combine the results from the two analyses and to what extent the approach used in this thesis fulfilled what was desired to investigate. The purpose of the discussion is to determine, which initiatives the future shall withhold in order for the Danish energy system to become renewable and what consequences are related to a reduced EC share in the future.

7.1 Scenario Possibility & Considerations

In relation to the first part of the thesis analysis, the possibility of the scenarios becoming a reality is discussed. Besides that, it is discussed which of the scenarios that should be prioritized in the future based on the information and analyses that are presented in this thesis.

As mentioned in section 4.2, predicting long-term processes are difficult, which is why scenario planning can be applied instead to create several possible outcomes, and thereby be able to choose the preferred path. Figure 7.1 shows the cone of possibility, which illustrates how the method of scenario planning includes several possible outcomes for the future. Additionally, the cone illustrates how the possibilities of the future covers a significantly larger area than the present, and that a prediction of the future covers a small area of what possibly will occur [Enzmann et al., 2011].

Furthermore, figure 7.1 illustrates how the possibility of scenario 2 and scenario 3 are approximately the same. This assumption is made because of the existing 2050-goal of obtaining a fossil free society. An assumption is that the government is persistent to reach the goal, why a future energy system containing fossil fuels is unlikely to unfold. Though, the development within the EC share is difficult to predict, leaving both scenario 2 and 3 as possible future outcomes. It is assumed, that the EC development can, to some extent, be influenced by political initiatives which also has been the case so far [section 6.1]. Though, many factors play a role in how the EC technology develops, as it is dependent on the consumers that are to procure the technology.

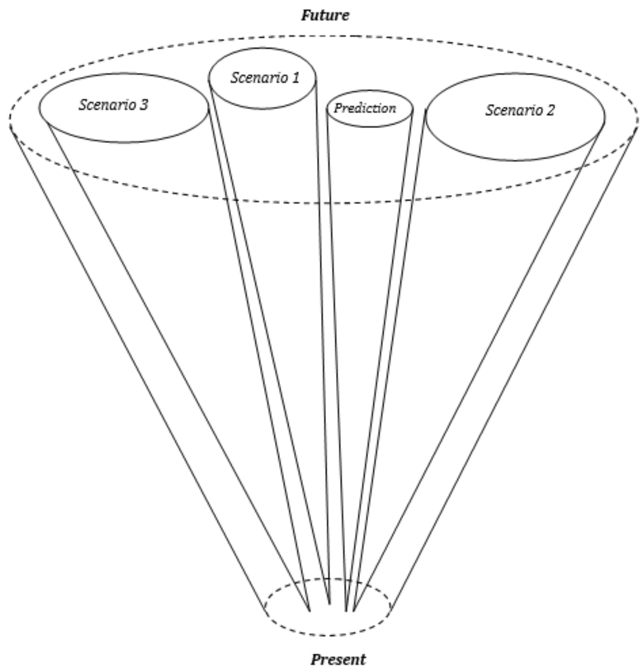

Figure 7.1: The cone of possibility [Enzmann et al., 2011]

As shown in figure 7.1, scenario 1: linear growth is considered to be the one least likely of the three scenarios in this thesis, which is due to the use of fossil fuels. Though, the linear growth scenario is assumed to be most likely to occur *if* no political initiatives in favour of ECs are implemented, and if the technology does not experience any noticeable improvements in the future. A linear development is assumed to be unlikely due to an increased focus on climate, technology improvement and possible changes in politics in regards to ECs. With policies that are in favour of ECs, it is assumed that the development will be different. So far, the sales in ECs have been fluctuating, and one reason for this is because of the taxation on this type of car. Notices of a phase-in of the so far exempted registration taxation has earlier proven to be a reason for an increase in the sales of ECs [Klimarådet, 2018]. Studies have also shown, that reasons for people not wanting to buy an EC include uncertainties about the technology, price, the range not being suitable for peoples' needs and the practicality of owning an EC being difficult [Thøgersen and Ebsen, 2019]. Based on the fact that ECs as a technology are getting more mature, that the prices will decrease over time and that policy measures are assumed to be in favour of ECs over time, makes it unlikely for the growth in ECs to be linear. Instead, it is assumed that the EC fleet will experience a growth that is more likely to be exponential in some way.

7.1.1 Determining the Future Path

Based on the findings in the thesis, this section discusses how the scenarios match the future 2050-goal. Though, there are no criteria to determine the exact path to reaching the goals, and it is therefore discussed in relation to the IDA vision and the results from the analysis.

The linear growth scenario is not perceived as a possibility for the future energy system, because the use of fossil fuels is contrary to future national goal. This leaves the scenarios including a 50% and 90% EC fleet as possible proposals for the future car fleet. As earlier presented, the 50% (biofuel) scenario contains one of the highest biomass shares of all of the scenarios. The biomass share does not exceed the limit of 250 PJ, but since a biomass share below 200 PJ is preferred, other scenarios should have higher priority. Depending on the extent of the costs, both the 50% (biofuel and hydrogen) and the 90% EC share scenarios are preferred in relation to CEEP, but for the 50% (biofuel and hydrogen) scenario, the biomass consumption exceeds the limit of 200 PJ with approximately 10 PJ. The 90% (hydrogen) scenario is much in line with the costs of the IDA vision, and the scenario has a significantly lower biomass consumption and CEEP level. However, if lower costs are preferred, the 90% (biofuel) scenario and the 50% (biofuel and hydrogen) scenario are the remaining alternatives. The 50% (biofuel and hydrogen) scenario contains a higher biomass consumption than the IDA vision. This leaves the biomass consumption at an acceptable level, but not below 200 PJ. Though, the combination of biofuel and hydrogen results in a considerably lower CEEP value than what can be seen in the IDA vision. This is the case for the 90% (biofuel) scenario as well, as this scenario holds the lowest CEEP level out of all of the scenarios. Though, the 90% (hydrogen) scenario contain the lowest biomass consumption, making this scenario attractive in relation to the environmental issues related to biomass.

Based on the findings made in the thesis analysis and the execution of this, a car fleet with a 50% EC should be an absolute minimum to aim for. In relation to the biomass consumption in the scenarios, the EC fleet should exceed 50% in order for the biomass limit not to be crossed. Though, a 50% EC can be a possibility if the hydrogen usage is increased and the biomass consumption is lowered. In relation to the scenarios composed in this thesis, the 90% (biofuel) scenario is the most favorable. In an energy and economic perspective, this proposal is based on the low biomass consumption of 148 PJ, a low CEEP level and minor cost savings in relation to the IDA vision. In relation to the theoretical framework in this thesis, the EC technology experiences some institutional obstacles. This is also an argument for aiming for a solution with a 90% EC share, as this means that fewer technologies have to be obtained in the society together with the infrastructure needing expansion for as few technologies as possible.

Several scenarios are possible to implement in the future, and the ones presented in this thesis are only few out of many possibilities. It will therefore be beneficial for the Danish government to prioritize which of the criteria are more important in the future energy system. By assigning some criteria higher priority than others, it is possible to eliminate several scenarios and thereby narrowing down the possibilities. For example, the biomass criteria used in this thesis originates from the IDA vision, which is based on calculations of the available biomass resources in the future and which is considered in an energy perspective. Though, it is possible to still obtain a fossil free energy system in spite of other criteria being of higher priority. This could contain limits for investment costs and annual costs or limits for wind capacity. In a political view, it is assumed that the economic perspective is of importance, which can direct the energy system ion a path where the use of biomass is high and the costs are low [section 5.4.2]. Such a solution results in a fossil fuel free energy system as well, but the discussions related to the use of biomass makes this solution questionable in an energy perspective. Additionally, if wanting an energy system with a limited use of biomass, the economy related to this resource is something for the government to consider as well, as it is currently a profitable resource to utilize. Today, subsidies are given when utilizing biomass in heat and electricity production together with the resource being exempted from taxation [Energistyrelsen, 2020a]. In a case where the government wishes to limit the biomass usage, it should be considered how this energy source is regulated. Though, it is difficult to foresee if such a regulation is necessary in the future, as the biomass prices can be expected to increase if the demand for the energy source increases as well. Biomass functions well as a substitute to fossil fuels because of it containing the same characteristics and the ability for it to be CO_2-neutral. Though, a significant increase in the use of biomass can result in the resource not maintaining its CO_2-neutrality, and for Denmark it also affects the ability to obtain self-sufficiency. This means, that one solution for the biomass consumption to decrease is to make the source unattractive to consumers, which can be executed by an increase in taxes.

7.2 Incorporating ECs into the Danish Energy System

In the previous section, the discussion was primarily focused on the thesis scenarios and the energy system as a whole in connection to the political choices related to obtaining the 2050-goal. In this section, it is discussed how the EC development can affect the 2050-goal.

Though, the purpose of this thesis is not to illustrate exactly how a Danish renewable energy system should be constructed, likewise it is not the purpose to determine which of the prepared scenarios that function best in reality. The purpose is to prepare different possible outcomes and on that background, to consider which of these few scenarios are the optimal solution when evaluated in different perspectives. In addition to that, this thesis is neither an analysis of whether or not the Danish government is aiming for a renewable energy system. The goal of a fossil free Denmark in 2050 is already composed, why this thesis has its point of departure in this goal with the assumption that the government is aiming to achieve an energy system on renewable energy. This means, that the purpose is to illustrate possible outcomes, but also the risks in particular. The thesis points out the insufficiency in solely composing a long-term goal and the importance of connecting the several factors that are affecting how and when a certain goal can be obtained.

To this discussion, the linear growth scenario is crucial to consider as a risk for the future energy system. It functions as a BAU-scenario and presents a possible future outcome in a case where frozen politics are dominating. Not only will this scenario prevent the 2050-goal to be reached, but the costs of a BAU-scenario are much in line with the scenarios aiming for a 100% renewable energy system. Seen in an energy perspective, this means that the risks related to the CO_2-emissions in the linear growth scenario can be used as an argument for why it is important to aim for a renewable energy system. On the other hand, do the costs of a linear growth scenario not deviate considerably compared to the remaining scenarios which, in an economic perspective, can be considered a strong argument for implementing a 100% renewable energy system. This is thereby also the reason for this scenario to function as a risk assessment, because this scenario is the only one which constitutes a potential risk to the climate when seen in relation to the 2050-goal. Though, it could be argued that other of the thesis scenarios constitute risks as well in relation to their use of biomass.

Besides an assessment of the potential risks connected to a BAU-scenario, do the remaining scenarios illustrate potential alternatives to avoid fossil fuel usage. The count of possible alternatives to an energy system are close to endless, which is why only few are composed with EC shares different to the IDA vision. Though, the thesis scenarios deviate from the result in the IDA vision. In this thesis, scenarios are presented with lower costs, lower CEEP levels and a lower biomass consumption in comparison to the IDA vision, raising the question why these differences occur, and why IDA has not chosen to operate with similar solutions to the ones in this thesis. The major differences are, of course, the EC share which deviates with 29,6% and 11,4%, respectively, in relation to the 61,4% EC share in the IDA vision. Though, if one thesis scenario was prepared with the same EC share as in the IDA vision, the costs of such scenario are still expected to be lower in the thesis scenario. This means, that the fuel choices are affecting the costs, as the IDA vision makes use of electrofuels and bioelectrofuels, whereas hydrogen and biofuel are prioritized in this thesis. As earlier mentioned, biopetrol is preferred over biodiesel in this thesis because of the higher efficiencies and thereby lower costs, which has affected the costs of the scenarios. Likewise, an increase in hydrogen storage is also prioritized in this thesis, which lowers the demand for offshore wind turbines and the costs related to these. Additionally, higher efficiencies occur for hydrogen than for the electrofuels used in the IDA vision, which also can affect the electricity and biomass demand in transportation. Also, a part of the dump charge demand is replaced by smart charge, giving the thesis scenarios more flexibility. It should be noted though, that the choices made in this thesis, to a great extent, are made on the basis of available renewable energy technologies and the costs related to these. This means, that potential restrictions in relation to for example area and technology development not are taken into account as might be the case in the IDA vision. It is therefore not possible to conclude which of the scenarios are more realistic, as numerous factors are in play and the predictions for costs in the future might vary as well.

7.2.1 Institutions and Technological Development

This section discusses the findings from the second part of the analysis, where it is analysed which parameters it is possible to influence on to promote the EC development. As the first part of the analysis concerned the technical aspects, the second part includes the institutional aspects in relation to technology. These aspects are considered important, as they give an understanding of several factors that affect technological development. Furthermore, this perspective of the analysis is included to emphasize that technological change is an important part of EC integration as well. This means, that technological change does not occur by itself, but by changes in the external factors that surround technology. The external factors are creating technological change, making the theoretical framework crucial for obtaining an understanding of technological foundation.

In relation to technological change in this thesis, the political aspect should be emphasized in particular. This is because it makes it possible to regulate people's behaviour directly, and especially if other alternatives are excluded as options. It is also possible to affect several aspects in relation to social life including the perception of ECs and the understanding of climate change. Though, several aspects are difficult to change seen in a Danish perspective. This includes the technology production and maturity, and thereby the resources used for this as well. In this thesis, regulations are considered to be the most effective mean when wanting to promote the EC technology, but it requires that other technological alternatives are made less attractive for it to have an effect. As with the technical analysis, it should here be mentioned that the political aspect has been superficially touched upon, because a more thorough assessment of this would have required a different direction of the thesis. This means, that different factors within the political aspect are left out, As an example, this means that the influence of international is not included. It is known, that EU-law prevents the Danish government from banning fossil fuel cars, because it is conflicting with EU and its law for internal market [Svansø, 2019]. This is affecting the political initiatives in Denmark, and a ban therefore requires changes in EU law. Though, this obstacle should not hinder the EC development, as other regulations are possible to adopt - just as they have been so far. The missing in-depth analysis of the political aspect is thereby a reason for possible political obstacles to be left out. But, because of the previous and existing regulations in relation to the EC technology, it is assumed to be possible to continue these regulations in the future and thereby affect the EC development. The overall purpose of this part of the analysis is to emphasize some of the factors that are possible to adjust to achieve a 100% renewable energy system. Furthermore, it shows that events of today are affecting the development of a new technical system, and that long-term goals not should be fulfilled by applying short-term initiatives.

7.3 Thesis Approach

The research question in this thesis is investigated in an energy and climate perspective with the economic costs in mind. This approach is assumed to produce results that might vary from an approach where political or economic perspectives are dominating. The methodological approach used in the thesis, and the results generated through the analysis, come with several uncertainties in relation to the structure of the future Danish energy system. The purpose of the thesis is not to produce one exact result as it was to illustrate possible outcomes. The thesis scenarios function as examples, yet there is a possibility for them to come with uncertainties, meaning that if one scenario is chosen as a solution, the scenario might not unfold exactly as presented in this thesis. It is possible for the economic and technological conditions not to develop as today's data anticipates. For the second part of the analysis, where the theoretical framework of the thesis was applied, the findings are more certain. This means, that even with a long-term time frame, external conditions are still able to affect the technological development.

The methodology successfully assisted to produce an answer to the research question, and thereby strengthen the validity of the thesis. The findings include giving an understanding of the possibilities and factors that can affect the future outcome of an energy system. Though, it is not possible to directly generalize the thesis results to other cases, because of the thesis being directed at the Danish energy system and the goals applied to this. This means, that factors such as costs and technology availability might vary in relation to a different energy system. In addition to that, it is possible to apply the methodology and theoretical framework to other cases, which will, in combination with relevant data, give the ability to produce results that are relevant to the given energy system.

Lastly, the data including future costs do come with uncertainties that can affect the outcome of the scenarios. Sensitivity analyses are generally applied as a method to illustrate how such uncertainties affect the result. These are not applied to this thesis, because of the scenario analysis already functioning as a sensitivity analysis. Though, if one scenario is chosen as a final solution, it is possible to perform a sensitivity analysis for this particular scenario.

Conclusion 8

The initiating part of the thesis led to an understanding of the environmental issues the transport sector creates by having a significant fossil fuel consumption. If the Danish government should succeed in reaching their goal of a fossil free energy system in 2050, it is crucial that alternatives to fossil fuel driven cars are integrated in the transport sector. Electric cars are currently a technology in development, with an expectation of the technology to be dominating in the passenger car category. The problem definition of the thesis led to the research question:

"How will different scenarios with variations in the electric car share, affect the transition of the Danish fossil fuel based energy system into a renewable energy system, and how can a technological understanding affect this development?"

Two analyses were conducted, where the first consists of scenario planning with a technical approach, and the second includes an institutional perspective with an examination of technological change. By combining the analyses, an answer to the research question was found.

From the technical analysis, it can be concluded that a correlation exists between low system costs and the use of biomass in the transport sector, where low biomass consumption increases the costs of the system due to more expensive technologies being integrated instead. It can also be concluded, that the CEEP level decreases in step with an increase in the electric car share together with an increase in hydrogen usage. Furthermore, an increase in electric cars does not necessarily equals an expansion of wind capacity, due to the possibility to use smart charging for electric cars.

With the IDA vision as reference, a biomass consumption below 200 PJ is preferred, but in the thesis scenarios the biomass requirement is only kept by one linear growth scenario and scenarios including a 90% electric car share. One scenario containing linear growth includes usage of fossil fuels, why such a scenario is not an option in relation to the 2050-goal. It can be concluded, that a scenario consisting of a 90% electric car share and 10% biofuel car share is the most favorable scenario in this thesis, seen in an energy and economic perspective. This is due to a biomass consumption of 148 PJ and minor cost savings in comparison with the reference scenario. In relation to the scenarios composed in this thesis, the future EC fleet in Denmark should account for an absolute minimum of 50% for the biomass consumption not to exceed 200 PJ.

From the second part of the analysis, it can be concluded that the current Danish energy system is situated in a decline phase, while the future renewable energy system currently is situated in an accelerated development phase, which applies for the electric car technology as well. Furthermore, it was found that changes in external conditions result in technological change, meaning that several initiatives are possible for the Danish government to execute to promote the development within electric cars. It is concluded that economy, market and social factors are some institutional conditions affecting at what pace and how technological development unfolds. Though, it can be concluded that the most effective condition to change is state regulations due to the ability to influence on behaviour in favour of electric cars. Additionally, the political regulations that have been applied for electric cars up until today, have not had the desired effect due to them being of a short-term time frame when aiming to obtain a long-term goal. Finally, the external institutional conditions influence on the outcome of the thesis scenarios as well. This means, that when the effects of external change is known, it is possible to adjust these changes to obtain technological change.

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Appendix A

A.1 Vehicle Specifications

Parameter & Type	2035	2050	Unit
Cars lifetime	16	16	Years
Distance (one car)	0,032	0,028	Mpkm/year
EC - small battery	**2035**	**2050**	**Unit**
Cost price	193304	189401	DKK
Efficiency	79	81,6	%
Energy consumption	0,49	0,45	MJd/km
EC - large battery	**2035**	**2050**	**Unit**
Cost price	241192	229806	DKK
Efficiency	75,5	77,9	%
Energy consumption	0,56	0,51	MJd/km
Gasoline	**2035**	**2050**	**Unit**
Cost price	155116	155116	DKK
Efficiency	20,8	21,6	%
Energy consumption	1,76	1,61	MJd/km
Diesel	**2035**	**2050**	**Unit**
Cost price	170976	170976	DKK
Efficiency	22,2	23	%
Energy consumption	1,69	1,55	MJd/km
Biofuel	**2035**	**2050**	**Unit**
Cost price	170976	170976	DKK
Efficiency	22,2	23	%
Energy consumption	1,69	1,55	MJd/km
Hydrogen	**2035**	**2050**	**Unit**
Cost price	210569	210374	DKK
Efficiency	39,3	41	%
Energy consumption	1,11	1,01	MJd/km
Charging stations	**2035**	**2050**	**Unit**
Capacity	9	9	GJ/year
Cost price	9314	9314	DKK
Lifetime	30	30	Year
Conversion efficiency	80,2	80,2	%

Table A.1: Parameters considered in relation to fuel type for the years 2035 and 2050, respectively [Energistyrelsen, 2016], [Energistyrelsen, 2018], [Mathiesen et al., 2015a]

Appendix B

B.1 IDA vision - thesis version (updated values)

Input Ida 2050 updated.txt

The EnergyPLAN model 13.0

Electricity demand (TWh/year):		Flexible demand	3,44
Fixed demand	33,17	Fixed imp/exp.	0,00
Electric heating + HP	2,44	Transportation	9,10
Electric cooling	1,55	Total	49,71

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,00	12,94	22,30	35,24
Solar Thermal	0,00	1,75	0,60	2,35
Industrial CHP (CSHP)	0,00	0,00	0,00	0,00
Demand after solar and CSHP	0,00	11,19	21,70	32,89

Wind	5000	MW	16,20	TWh/year	0,00	Grid
Offshore Wind	14000	MW	63,76	TWh/year	0,00	stabili-
Photo Voltaic	5000	MW	6,35	TWh/year	0,00	sation
River Hydro	0	MW	1,35	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	1500	1125	0,52	0,39	
Heat Pump	300	1050			3,50
Boiler		4400		0,95	
Group 3:					
CHP	3500	2625	0,52	0,39	
Heat Pump	400	1400			3,50
Boiler		7600		0,95	
Condensing	4500		0,61		

Heatstorage: gr.2: 56 GWh gr.3: 56 GWh
Fixed Boiler: gr.2: 0,5 Per cent gr.3: 0,5 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	1,20	0,00
Gr.3:	0,00	1,89

Regulation Strategy:	Technical regulation no. 3	
CEEP regulation	234580000	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	0	MW

Di:Nord_pool_system_2013_EUR.TXT

Addition factor	1,00	EUR/MWh
Multiplication factor	2,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	77	EUR/MWh
Gas Storage	6000	GWh
Syngas capacity	2184	MW
Biogas max to grid	1721	MW

Fuel Price level:

	Capacities MW-e	Storage GWh	Efficiencies elec.	Efficiencies Ther.
Hydro Pump:	0	0	0,80	
Hydro Turbine:	0		0,90	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	9009	552	0,79	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	0,00	0,00	0,00
Household	0,00	0,00	0,00	1,59
Industry	0,00	0,00	0,00	3,41
Various	0,00	0,00	8,41	0,00

Output WARNING!!: (1) Critical Excess; (3) PP/Import problem

	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	6005	103	2333	0	1019	1878	0	459	208	4	4504	1439	1061	5175	208	0	0	10422	0	0	352	1359	351	100	23	121	121	0	2	5
February	6126	218	2343	0	1207	1750	0	465	137	6	4388	1405	1019	4108	137	0	0	8753	0	0	352	1610	372	100	23	52	52	0	1	2
March	5328	247	2251	0	703	1878	0	167	145	-62	4222	1419	957	5730	145	0	0	11677	0	0	352	937	231	100	0	724	724	0	0	26
April	4417	384	2100	0	707	1205	0	23	11	-13	3846	1435	647	5075	11	0	0	9756	0	0	352	943	342	100	0	378	378	0	0	14
May	3626	408	1910	0	407	881	0	1	2	18	3577	1431	470	4412	2	0	0	8773	0	0	352	542	352	100	0	128	128	0	0	4
June	2048	371	1790	0	103	174	0	0	1	-392	3637	1421	113	4969	1	0	0	9776	0	0	352	138	423	100	0	547	547	0	0	13
July	2048	419	1746	0	135	100	0	0	0	-353	3541	1423	87	3151	0	0	0	6951	0	0	352	180	855	100	0	136	136	0	0	3
August	2048	393	1766	0	99	153	0	0	0	-363	3776	1450	114	4629	0	0	0	9110	0	0	352	133	694	100	0	320	320	0	0	9
September	2747	291	1873	0	325	349	0	1	1	-92	3764	1412	249	4144	1	0	0	8348	0	0	352	434	721	100	0	283	283	0	0	9
October	3730	187	1998	0	273	1282	0	1	14	-26	3901	1443	640	6324	14	0	0	12081	0	0	352	364	124	100	0	599	599	0	0	22
November	4663	117	2152	0	539	1671	0	84	91	10	4134	1442	862	5253	91	0	0	10829	0	0	352	719	206	100	0	323	323	0	0	11
December	5423	70	2270	0	372	2086	0	310	277	38	4158	1428	1061	6710	277	0	0	13161	0	0	352	496	88	100	0	463	463	0	0	16
Average	4012	267	2043	0	488	1117	0	125	74	-102	3953	1429	606	4979	74	0	0	9980	0	0	352	650	396	100	4	341	341	0	Average price	
Maximum	9949	2281	2936	0	3750	2450	0	4643	900	2500	6099	11132	1623	9397	900	0	0	22255	0	0	352	5000	4500	100	2024	6500	6500	0	(EUR/MWh)	
Minimum	1886	0	1558	0	0	20	0	0	0	-1499	2428	-539	6	83	0	0	0	9	0	0	352	0	0	100	0	0	0	0	100	44
TWh/year	35,24	2,35	17,95	0,00	4,28	9,81	0,00	1,10	0,65	-0,90	34,72	12,55	5,32	43,74	0,65	0,00	0,00	87,66	0,00	0,00	3,09	5,71	3,48		0,03	2,99	2,99	0,00	3	133

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon- version	Electro- Fuel	Wind	Offsh.	PV	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Imp/Exp Corrected Net	CO2 emission (Mt): Total	CO2 emission (Mt): Net
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
N.Gas	-	5,76	5,22	-	-	5,66	-	-	-	-	-23,66	-3,48	-	-	-	-	-	-	-	8,41	-2,09	-4,81	-6,90	-0,43	-1,41
Biomass	-	-	-	0,95	0,21	-	-	-	7,30	-	34,72	-	-	-	-	-	-	-	1,32	3,41	47,91	0,00	47,91	0,00	0,00
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	16,20	63,76	6,35	-	4,59	-	-	-	92,25	0,00	92,25	0,00	0,00
H2 etc.	-	0,00	0,00	-	0,00	0,00	-	-	-	-32,81	-10,63	38,46	-	-	-	-	-	4,99	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-31,13	-	-	-	-	-	31,13	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	-	5,76	5,22	0,95	0,21	5,66	-	-	7,30	-32,81	0,42	3,85	16,20	63,76	6,35	-	4,59	36,12	1,32	11,82	138,07	-4,81	133,26	-0,43	-1,41

Output specifications Ida 2050 updated.txt The EnergyPLAN model 13.0

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 MW	Gr.2 Balance MW
January	0	0	0	0	2205	77	354	401	902	0	353	113	17946	4
February	0	0	0	0	2249	163	357	471	850	0	338	65	17047	6
March	0	0	0	0	1957	184	335	333	857	0	148	112	12344	-12
April	0	0	0	0	1622	285	300	365	644	0	22	11	13634	-6
May	0	0	0	0	1332	304	256	249	494	0	1	2	16522	26
June	0	0	0	0	752	277	228	103	161	0	0	1	16261	-18
July	0	0	0	0	752	310	218	135	87	0	0	0	16342	2
August	0	0	0	0	752	296	222	99	140	0	0	0	17085	-6
September	0	0	0	0	1009	216	247	275	262	0	1	1	16283	7
October	0	0	0	0	1370	140	276	166	785	0	1	14	20133	-14
November	0	0	0	0	1712	87	312	314	817	0	83	89	17677	10
December	0	0	0	0	1991	52	340	174	952	0	286	186	18478	1
Average	0	0	0	0	1473	199	287	256	579	0	102	50	16651	0
Maximum	0	0	0	0	3653	1624	495	1125	1050	0	2182	300	35988	801
Minimum	0	0	0	0	692	0	174	0	7	0	0	0	0	-757
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	12,94	1,75	2,52	2,25	5,09	0,00	0,90	0,44		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	RES1 Wind MW	RES2 Offshoı MW	RES3 Photo \ MW	RES 4-7 ic MW	Total MW
January	3800	26	1979	618	975	0	106	95	15689	0	1958	8159	149	156	10422
February	3876	56	1986	736	899	0	127	72	26938	0	1435	6771	318	229	8753
March	3372	63	1916	370	1021	0	19	33	21087	-50	2304	8348	844	181	11677
April	2795	99	1800	342	561	0	1	0	39776	-7	1984	6539	1112	121	9756
May	2295	104	1654	158	387	0	0	0	40409	-8	1527	5947	1183	116	8773
June	1296	94	1562	0	13	0	0	0	40410	-373	1755	6737	1177	108	9776
July	1296	109	1529	0	13	0	0	0	40417	-355	1160	4431	1267	93	6951
August	1296	97	1543	0	13	0	0	0	40417	-357	1587	6317	1081	125	9110
September	1739	75	1626	50	87	0	0	0	40417	-99	1375	6007	810	156	8348
October	2360	47	1722	107	497	0	0	0	40941	-12	2194	9283	407	197	12081
November	2951	30	1840	225	854	0	1	1	39873	0	1956	8458	214	201	10829
December	3432	18	1930	197	1133	0	24	91	35656	37	2863	10033	100	166	13161
Average	2539	68	1756	232	537	0	23	24	35160	-102	1845	7259	723	154	9980
Maximum	6296	841	2441	2625	1400	0	2462	600	56000	1972	4954	13840	4388	300	22255
Minimum	1193	0	1384	0	13	0	0	0	0	-1456	0	0	0	5	9
Total for the whole year TWh/year	22,30	0,60	15,43	2,04	4,72	0,00	0,20	0,21		-0,90	16,20	63,76	6,35	1,35	87,66

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

ANNUAL COSTS (Million EUR)

Total Fuel ex Ngas exchange =		1082
Uranium =	0	
Coal =	0	
FuelOil =	0	
Gasoil/Diesel=	291	
Petrol/JP =	11	
Gas handling =	28	
Biomass =	752	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		-62
Marginal operation costs =		46
Total Electricity exchange =		3
Import =	3	
Export =	-133	
Bottleneck =	133	
Fixed imp/ex=	0	
Total CO2 emission costs =		-18
Total variable costs =		1051
Fixed operation costs =		8323
Annual Investment costs =		20268
TOTAL ANNUAL COSTS =		29642

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	0	2613	570	0	0	957	4141	1721	973	2281	1778	-3544	1170	-238	0	238
February	0	3095	605	0	0	957	4657	1721	973	1625	1778	-3544	2342	-238	0	238
March	0	1802	375	0	0	957	3135	1721	973	2646	1778	-3544	-202	-238	0	238
April	0	1814	557	0	0	957	3328	1721	973	2228	1778	-3544	410	-238	0	238
May	0	1043	572	0	0	957	2572	1721	973	1784	1778	-3544	98	-238	0	238
June	0	264	687	0	0	957	1909	1721	973	2198	1778	-3544	-979	-238	0	238
July	0	346	1390	0	0	957	2694	1721	973	1433	1778	-3544	570	-238	0	238
August	0	255	1129	0	0	957	2341	1721	973	1518	1778	-3544	133	-238	0	238
September	0	834	1172	0	0	957	2963	1721	973	1663	1778	-3544	610	-238	0	238
October	0	700	201	0	0	957	1859	1721	973	2964	1778	-3544	-1796	-238	0	238
November	0	1382	335	0	0	957	2674	1721	973	2332	1778	-3544	-348	-238	0	238
December	0	953	144	0	0	957	2054	1721	973	3231	1778	-3544	-1867	-238	0	238
Average	0	1250	644	0	0	957	2852	1721	973	2162	1778	-3544	0	-238	0	238
Maximum	0	9615	7317	0	0	957	12199	1721	973	5333	1778	-3544	10367	-238	0	238
Minimum	0	0	0	0	0	957	957	1721	973	1141	1778	-3544	-5066	-238	0	238
Total for the whole year TWh/year	0,00	10,98	5,66	0,00	0,00	8,41	25,06	15,12	8,55	18,99	15,62	-31,13	0,00	-2,09	0,00	2,09

RES Share: 101,5 Percent of Primary Energy 96,4 Percent of Electricity 89,6 TWh electricity from RES

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B.2 Scenario 1: Linear Growth (BAU)

Input Linear.txt

The EnergyPLAN model 13.0

Electricity demand (TWh/year):		Flexible demand	3,44
Fixed demand	33,12	Fixed imp/exp.	0,00
Electric heating + HP	2,44	Transportation	2,80
Electric cooling	1,55	Total	43,35

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,00	12,94	22,30	35,24
Solar Thermal	0,00	1,75	0,60	2,35
Industrial CHP (CSHP)	0,00	0,00	0,00	0,00
Demand after solar and CSHP	0,00	11,19	21,70	32,89

Wind	5000 MW	16,20	TWh/year	0,00	Grid
Offshore Wind	13150 MW	59,89	TWh/year	0,00	stabili-
Photo Voltaic	5000 MW	6,35	TWh/year	0,00	sation
River Hydro	0 MW	1,35	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	1500	1125	0,52	0,39	
Heat Pump	300	1050			3,50
Boiler		4400		0,95	
Group 3:					
CHP	3500	2625	0,52	0,39	
Heat Pump	400	1400			3,50
Boiler		7600		0,95	
Condensing	4500		0,61		

Heatstorage: gr.2: 56 GWh gr.3: 56 GWh
Fixed Boiler: gr.2: 0,5 Per cent gr.3: 0,5 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	1,20	0,00
Gr.3:	0,00	1,89

Regulation Strategy:	Technical regulation no. 3	
CEEP regulation	234580000	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	0	MW

Di:Nord_pool_system_2013_EUR.TXT		
Addition factor	1,00	EUR/MWh
Multiplication factor	2,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	77	EUR/MWh
Gas Storage	6000	GWh
Syngas capacity	1709	MW
Biogas max to grid	1721	MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Ther.
Hydro Pump:	0	0	0,80	
Hydro Turbine:	0		0,90	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	9009	552	0,73	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	25,50	0,00	0,00
Household	0,00	0,00	0,00	1,59
Industry	0,00	0,00	0,00	3,41
Various	0,00	0,00	8,41	0,00

Output WARNING!!: (1) Critical Excess; (3) PP/Import problem

	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	6005	103	2276	0	1112	1845	0	453	210	4	4498	721	1052	5276	210	0	0	9927	0	0	352	1483	83	100	16	103	103	0	1	5
February	6126	218	2286	0	1308	1698	0	471	138	6	4382	694	1004	4310	138	0	0	8342	0	0	352	1744	119	100	12	41	41	0	1	2
March	5328	247	2194	0	781	1841	0	143	172	-51	4216	714	946	5852	172	0	0	11170	0	0	352	1042	29	100	0	693	693	0	0	28
April	4417	384	2043	0	779	1195	0	19	13	-16	3840	717	644	5206	13	0	0	9359	0	0	352	1038	47	100	0	376	376	0	0	15
May	3626	408	1853	0	473	871	0	1	2	20	3571	695	467	4595	2	0	0	8412	0	0	352	630	73	100	0	137	137	0	0	5
June	2048	371	1733	0	109	168	0	0	1	-333	3630	721	111	5006	1	0	0	9367	0	0	352	145	163	100	0	558	558	0	0	15
July	2048	419	1689	0	141	95	0	0	0	-296	3535	705	84	3108	0	0	0	6682	0	0	352	187	383	100	0	172	172	0	0	5
August	2048	393	1709	0	106	146	0	0	0	-306	3770	713	111	4549	0	0	0	8727	0	0	352	142	278	100	0	355	355	0	0	11
September	2747	291	1816	0	360	348	0	1	1	-69	3758	713	248	4103	1	0	0	7983	0	0	352	481	305	100	0	297	297	0	0	10
October	3730	187	1941	0	327	1279	0	1	15	-21	3895	708	638	6494	15	0	0	11518	0	0	352	437	28	100	0	584	584	0	0	23
November	4663	117	2095	0	643	1631	0	69	99	10	4128	724	851	5453	99	0	0	10316	0	0	352	857	39	100	0	309	309	0	0	11
December	5423	70	2213	0	427	2085	0	307	302	18	4152	708	1061	6846	302	0	0	12552	0	0	352	569	15	100	0	419	419	0	0	15
Average	4012	267	1986	0	544	1100	0	121	80	-86	3947	711	601	5072	80	0	0	9539	0	0	352	725	130	100	2	338	338	0	Average price	
Maximum	9949	2281	2879	0	3750	2450	0	4677	900	2385	6093	3173	1623	9382	900	0	0	21419	0	0	352	5000	3370	100	1458	5593	5593	0	(EUR/MWh)	
Minimum	1886	0	1501	0	0	20	0	0	0	-1442	2421	-67	6	83	0	0	0	9	0	0	352	0	0	100	0	0	0	0	111	48
TWh/year	35,24	2,35	17,45	0,00	4,78	9,66	0,00	1,07	0,70	-0,76	34,67	6,25	5,28	44,55	0,70	0,00	0,00	83,79	0,00	0,00	3,09	6,37	1,14		0,02	2,97	2,97	0,00	2	143

FUEL BALANCE (TWh/year):	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	Offsh.	PV	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25,50	-	-	25,50	0,00	25,50	6,79	6,79
N.Gas	-	6,22	6,03	-	-	1,86	-	-	-	-	-19,50	-5,66	-	-	-	-	-	-	-	8,41	-2,64	-4,80	-7,44	-0,54	-1,52
Biomass	-	-	-	0,89	0,23	-	-	-	7,30	-	29,72	-	-	-	-	-	-	-	1,32	3,41	42,87	0,00	42,87	0,00	0,00
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	16,20	59,89	6,35	-	4,59	-	-	-	88,38	0,00	88,38	0,00	0,00
H2 etc.	-	0,00	0,00	0,00	0,00	0,00	-	-	-	-31,57	-10,63	37,22	-	-	-	-	-	4,99	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-27,87	-	-	-	-	-	27,87	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	-	6,22	6,03	0,89	0,23	1,86	-	-	7,30	-31,57	-0,41	3,68	16,20	59,89	6,35	-	4,59	58,36	1,32	11,82	154,11	-4,80	149,31	6,25	5,27

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Output specifications   Linear.txt   The EnergyPLAN model 13.0

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 MW	Gr.2 Balance MW
January	0	0	0	0	2205	77	354	427	893	0	340	109	17329	4
February	0	0	0	0	2249	163	357	489	839	0	329	66	16243	6
March	0	0	0	0	1957	184	335	354	841	0	128	126	12098	-11
April	0	0	0	0	1622	285	300	390	622	0	18	13	13728	-7
May	0	0	0	0	1332	304	256	278	465	0	1	2	16122	25
June	0	0	0	0	752	277	228	109	155	0	0	1	15930	-17
July	0	0	0	0	752	310	218	140	82	0	0	0	15988	2
August	0	0	0	0	752	296	222	106	133	0	0	0	16692	-6
September	0	0	0	0	1009	216	247	290	248	0	1	1	16136	6
October	0	0	0	0	1370	140	276	192	757	0	1	15	20117	-12
November	0	0	0	0	1712	87	312	356	782	0	69	96	16913	9
December	0	0	0	0	1991	52	340	194	939	0	274	192	18528	1
Average	0	0	0	0	1473	199	287	276	563	0	96	52	16326	0
Maximum	0	0	0	0	3653	1624	495	1125	1050	0	2182	300	35138	801
Minimum	0	0	0	0	692	0	174	0	7	0	0	0	0	-746
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	12,94	1,75	2,52	2,42	4,94	0,00	0,85	0,46		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	3800	26	1922	685	952	0	113	101	17083	0
February	3876	56	1929	818	859	0	142	72	25903	0
March	3372	63	1859	427	1001	0	15	46	18700	-39
April	2795	99	1743	388	573	0	1	0	33288	-8
May	2295	104	1597	194	405	0	0	0	34137	-6
June	1296	94	1505	0	13	0	0	0	34144	-317
July	1296	109	1472	0	13	0	0	0	34152	-298
August	1296	97	1486	0	13	0	0	0	34152	-300
September	1739	75	1569	70	100	0	0	0	34152	-75
October	2360	47	1665	135	522	0	0	0	34696	-9
November	2951	30	1783	287	848	0	1	2	33275	0
December	3432	18	1874	233	1146	0	33	110	32392	18
Average	2539	68	1700	268	537	0	25	28	30496	-86
Maximum	6296	841	2384	2625	1400	0	2494	600	56000	1865
Minimum	1193	0	1327	0	13	0	0	0	0	-1399
Total for the whole year TWh/year	22,30	0,60	14,93	2,35	4,72	0,00	0,22	0,24		-0,76

RES specification	RES1 Wind MW	RES2 Offshor MW	RES3 Photo \ MW	RES 4-7 ic MW	Total MW
January	1958	7664	149	156	9927
February	1435	6360	318	229	8342
March	2304	7841	844	181	11170
April	1984	6142	1112	121	9359
May	1527	5586	1183	116	8412
June	1755	6328	1177	108	9367
July	1160	4162	1267	93	6682
August	1587	5934	1081	125	8727
September	1375	5642	810	156	7983
October	2194	8719	407	197	11518
November	1956	7945	214	201	10316
December	2863	9424	100	166	12552
Average	1845	6818	723	154	9539
Maximum	4954	12999	4388	300	21419
Minimum	0	0	0	5	9
Total for the whole year TWh/year	16,20	59,89	6,35	1,35	83,79

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

ANNUAL COSTS (Million EUR)		
Total Fuel ex Ngas exchange =		2773
Uranium =	0	
Coal =	0	
FuelOil =	0	
Gasoil/Diesel=	1332	
Petrol/JP =	792	
Gas handling =	27	
Biomass =	622	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		-79
Marginal operation costs =		41
Total Electricity exchange =		2
Import =	2	
Export =	-143	
Bottleneck =	143	
Fixed imp/ex=	0	
Total CO2 emission costs =		263
Total variable costs =		3000
Fixed operation costs =		7650
Annual Investment costs =		19143
TOTAL ANNUAL COSTS =		29793

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	0	2852	135	0	0	957	3944	1721	499	2161	1778	-3173	1258	-301	0	301
February	0	3354	193	0	0	957	4504	1721	499	1578	1778	-3173	2402	-301	0	301
March	0	2004	46	0	0	957	3007	1721	499	2539	1778	-3173	-56	-301	0	301
April	0	1997	76	0	0	957	3031	1721	499	2125	1778	-3173	381	-301	0	301
May	0	1212	118	0	0	957	2287	1721	499	1719	1778	-3173	45	-301	0	301
June	0	279	266	0	0	957	1502	1721	499	2050	1778	-3173	-1072	-301	0	301
July	0	360	623	0	0	957	1941	1721	499	1321	1778	-3173	96	-301	0	301
August	0	272	453	0	0	957	1682	1721	499	1318	1778	-3173	-160	-301	0	301
September	0	924	496	0	0	957	2378	1721	499	1459	1778	-3173	395	-301	0	301
October	0	840	46	0	0	957	1843	1721	499	2777	1778	-3173	-1459	-301	0	301
November	0	1648	64	0	0	957	2669	1721	499	2271	1778	-3173	-126	-301	0	301
December	0	1095	25	0	0	957	2077	1721	499	3116	1778	-3173	-1563	-301	0	301
Average	0	1394	212	0	0	957	2563	1721	499	2039	1778	-3173	0	-301	0	301
Maximum	0	9615	5480	0	0	957	12199	1721	499	5127	1778	-3173	10533	-301	0	301
Minimum	0	0	0	0	0	957	957	1721	499	1141	1778	-3173	-4693	-301	0	301
Total for the whole year TWh/year	0,00	12,25	1,86	0,00	0,00	8,41	22,52	15,12	4,38	17,91	15,62	-27,87	0,00	-2,64	0,00	2,64

RES Share: 85,2 Percent of Primary Energy 98,4 Percent of Electricity 85,7 TWh electricity from RES   31-juli-2020 [23:13]

B.3 Scenario 1: Linear Growth - Biomass alternative

Input Linear Biomass.txt

The EnergyPLAN model 13.0

Electricity demand (TWh/year):		Flexible demand	3,44
Fixed demand	33,82	Fixed imp/exp.	0,00
Electric heating + HP	2,44	Transportation	2,80
Electric cooling	1,55	Total	44,06

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,00	12,94	22,30	35,24
Solar Thermal	0,00	1,75	0,60	2,35
Industrial CHP (CSHP)	0,00	0,00	0,00	0,00
Demand after solar and CSHP	0,00	11,19	21,70	32,89

Wind	5000	MW	16,20	TWh/year	0,00	Grid
Offshore Wind	11400	MW	51,92	TWh/year	0,00	stabili-
Photo Voltaic	5000	MW	6,35	TWh/year	0,00	sation
River Hydro	0	MW	1,35	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	1500	1125	0,52	0,39	
Heat Pump	300	1050			3,50
Boiler		4400		0,95	
Group 3:					
CHP	3500	2625	0,52	0,39	
Heat Pump	400	1400			3,50
Boiler		7600		0,95	
Condensing	4500		0,61		

Heatstorage: gr.2: 56 GWh gr.3: 56 GWh
Fixed Boiler: gr.2: 0,5 Per cent gr.3: 0,5 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	1,20	0,00
Gr.3:	0,00	1,89

Regulation Strategy:	Technical regulation no. 3	
CEEP regulation	234580000	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	0	MW

Di:Nord_pool_system_2013_EUR.TXT		
Addition factor	1,00	EUR/MWh
Multiplication factor	2,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	77	EUR/MWh
Gas Storage	6000	GWh
Syngas capacity	1709	MW
Biogas max to grid	1721	MW

Fuel Price level:

Capacities Storage Efficiencies	MW-e	GWh	elec.	Ther.
Hydro Pump:	0	0	0,80	
Hydro Turbine:	0		0,90	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	9009	552	0,73	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:	0,000			

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	0,00	0,00	0,00
Household	0,00	0,00	0,00	1,59
Industry	0,00	0,00	0,00	3,41
Various	0,00	0,00	8,41	0,00

Output WARNING!!: (1) Critical Excess; (3) PP/Import problem

	District Heating: Demand Distr. heating MW	DH Production: Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW	Electricity Consumption: Elec. demand MW	Flex.& Transp. MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Electricity Production: Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Balance: Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Exchange Payment Million EUR: Imp	Exp
January	6005	103	3079	0	889	1505	0	350	75	3	4578	721	954	4387	75	0	0	8907	0	0	352	1186	269	100	2	1	1	0	0	0
February	6126	218	3089	0	1112	1351	0	329	24	3	4462	691	901	3481	24	0	0	7496	0	0	352	1483	229	100	6	7	7	0	0	0
March	5328	247	2997	0	622	1248	0	139	102	-27	4296	716	780	5221	102	0	0	10127	0	0	352	829	77	100	0	270	270	0	0	13
April	4417	384	2846	0	566	660	0	47	17	-104	3920	718	492	4523	17	0	0	8542	0	0	352	755	125	100	0	104	104	0	0	5
May	3626	408	2655	0	394	413	0	1	1	-246	3651	694	332	3996	1	0	0	7669	0	0	352	525	164	100	0	36	36	0	0	1
June	2048	371	2536	0	115	163	0	0	1	-1138	3711	722	106	4495	1	0	0	8525	0	0	352	154	214	100	0	210	210	0	0	7
July	2048	419	2492	0	153	82	0	0	0	-1099	3615	705	79	2693	0	0	0	6128	0	0	352	204	467	100	0	59	59	0	0	2
August	2048	393	2511	0	119	136	0	0	0	-1112	3850	712	108	4013	0	0	0	7937	0	0	352	159	369	100	0	133	133	0	0	5
September	2747	291	2619	0	330	227	0	1	0	-720	3838	712	214	3572	0	0	0	7232	0	0	352	441	395	100	0	83	83	0	0	3
October	3730	187	2744	0	284	704	0	29	30	-248	3975	707	474	5844	30	0	0	10357	0	0	352	379	75	100	0	135	135	0	0	6
November	4663	117	2898	0	584	957	0	76	82	-51	4208	725	658	4732	82	0	0	9259	0	0	352	779	91	100	0	75	75	0	0	3
December	5423	70	3016	0	375	1509	0	290	166	-2	4232	708	896	6117	166	0	0	11298	0	0	352	499	42	100	0	72	72	0	0	3
Average	4012	267	2789	0	459	746	0	105	42	-396	4027	711	499	4429	42	0	0	8632	0	0	352	612	210	100	1	99	99	0	Average price	
Maximum	9949	2281	3682	0	3750	2450	0	2777	900	2181	6173	3620	1623	9382	900	0	0	19699	0	0	352	5000	3952	100	1136	3933	3933	0	(EUR/MWh)	
Minimum	1886	0	2304	0	0	20	0	0	0	-2043	2502	-67	6	83	0	0	0	9	0	0	352	0	0	100	0	0	0	0	106	56
TWh/year	35,24	2,35	24,50	0,00	4,03	6,55	0,00	0,92	0,37	-3,48	35,37	6,24	4,38	38,90	0,37	0,00	0,00	75,82	0,00	0,00	3,09	5,38	1,84		0,01	0,87	0,87	0,00	1	49

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	Offsh.	PV	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Imp/Exp Corrected Net	CO2 emission (Mt): Total	CO2 emission (Mt): Net
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
N.Gas	-	7,43	2,91	-	-	3,00	-	-	-	-	-19,50	-2,23	-	-	-	-	-	-	-	8,41	0,02	-1,41	-1,39	0,00	-0,28
Biomass	-	-	-	0,96	0,01	-	-	-	7,30	-	68,36	-	-	-	-	-	-	-	1,32	3,41	81,36	0,00	81,36	0,00	0,00
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	16,20	51,92	6,35	-	4,59	-	-	-	80,41	0,00	80,41	0,00	0,00
H2 etc.	-	0,00	0,00	0,00	0,00	0,00	-	-	-	-27,63	-10,63	33,27	-	-	-	-	-	4,99	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-25,50	-27,87	-	-	-	-	-	53,37	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	-	7,43	2,91	0,96	0,01	3,00	-	-	7,30	-27,63	12,73	3,17	16,20	51,92	6,35	-	4,59	58,36	1,32	11,82	161,79	-1,41	160,39	0,00	-0,28

Output specifications   Linear Biomass.txt   The EnergyPLAN model 13.0

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 MW	Gr.2 Ba-lance MW
January	0	0	0	0	2205	77	354	499	856	0	347	68	18800	4
February	0	0	0	0	2249	163	357	583	801	0	319	24	18193	4
March	0	0	0	0	1957	184	335	415	791	0	137	102	14175	-8
April	0	0	0	0	1622	285	300	445	538	0	47	17	14653	-10
May	0	0	0	0	1332	304	256	362	378	0	1	1	14649	30
June	0	0	0	0	752	277	228	115	150	0	0	1	16925	-19
July	0	0	0	0	752	310	218	153	70	0	0	0	17365	1
August	0	0	0	0	752	296	222	119	123	0	0	0	18299	-9
September	0	0	0	0	1009	216	247	330	214	0	1	0	17645	0
October	0	0	0	0	1370	140	276	256	639	0	29	30	19556	-1
November	0	0	0	0	1712	87	312	457	692	0	76	81	17797	6
December	0	0	0	0	1991	52	340	241	903	0	289	165	20172	1
Average	0	0	0	0	1473	199	287	330	512	0	104	41	17354	0
Maximum	0	0	0	0	3653	1624	495	1125	1050	0	2187	300	31660	651
Minimum	0	0	0	0	692	0	174	0	7	0	0	0	0	-768
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	12,94	1,75	2,52	2,90	4,50	0,00	0,91	0,36		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	RES1 Wind MW	RES2 Offshor MW	RES3 Photo \ MW	RES 4-7 ic MW	Total MW
January	3800	26	2725	391	649	0	3	7	6134	-1	1958	6644	149	156	8907
February	3876	56	2732	529	550	0	10	0	15544	0	1435	5514	318	229	7496
March	3372	63	2662	207	457	0	2	0	7611	-19	2304	6798	844	181	10127
April	2795	99	2546	121	122	0	0	0	11573	-93	1984	5325	1112	121	8542
May	2295	104	2400	32	36	0	0	0	11573	-276	1527	4843	1183	116	7669
June	1296	94	2308	0	13	0	0	0	11573	-1119	1755	5486	1177	108	8525
July	1296	109	2275	0	13	0	0	0	11573	-1101	1160	3608	1267	93	6128
August	1296	97	2289	0	13	0	0	0	11573	-1103	1587	5144	1081	125	7937
September	1739	75	2371	0	13	0	0	0	11573	-721	1375	4891	810	156	7232
October	2360	47	2468	28	66	0	0	0	11580	-248	2194	7559	407	197	10357
November	2951	30	2586	127	265	0	0	0	11791	-57	1956	6888	214	201	9259
December	3432	18	2676	133	606	0	0	1	14944	-3	2863	8170	100	166	11298
Average	2539	68	2502	129	233	0	1	1	11395	-396	1845	5911	723	154	8632
Maximum	6296	841	3187	2625	1400	0	1203	600	38319	2128	4954	11269	4388	300	19699
Minimum	1193	0	2130	0	13	0	0	0	0	-1731	0	0	0	5	9
Total for the whole year TWh/year	22,30	0,60	21,98	1,14	2,05	0,00	0,01	0,01		-3,48	16,20	51,92	6,35	1,35	75,82

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

ANNUAL COSTS (Million EUR)		
Total Fuel ex Ngas exchange =		-9592
Uranium =	0	
Coal =	0	
FuelOil =	0	
Gasoil/Diesel=	246	
Petrol/JP =	439	
Gas handling =	30	
Biomass =	2443	
Food income =	-12750	
Waste =	0	
Total Ngas Exchange costs =		1
Marginal operation costs =		37
Total Electricity exchange =		1
Import =	1	
Export =	-49	
Bottleneck =	49	
Fixed imp/ex=	0	
Total CO2 emission costs =		0
Total variable costs =		-9554
Fixed operation costs =		5900
Annual Investment costs =		19156
TOTAL ANNUAL COSTS =		15501

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	0	2281	437	0	0	957	3675	1721	499	1622	1778	-3173	1226	2	2	0
February	0	2851	373	0	0	957	4181	1721	499	1288	1778	-3173	2066	2	2	0
March	0	1595	126	0	0	957	2678	1721	499	2022	1778	-3173	-170	2	2	0
April	0	1452	203	0	0	957	2612	1721	499	1664	1778	-3173	121	2	2	0
May	0	1010	267	0	0	957	2235	1721	499	1334	1778	-3173	73	2	2	0
June	0	296	348	0	0	957	1602	1721	499	1749	1778	-3173	-974	2	2	0
July	0	393	759	0	0	957	2110	1721	499	1142	1778	-3173	141	2	2	0
August	0	306	600	0	0	957	1863	1721	499	1142	1778	-3173	-106	2	2	0
September	0	847	642	0	0	957	2447	1721	499	1142	1778	-3173	478	2	2	0
October	0	729	122	0	0	957	1808	1721	499	2146	1778	-3173	-1165	2	2	0
November	0	1498	148	0	0	957	2603	1721	499	1834	1778	-3173	-58	2	2	0
December	0	960	68	0	0	957	1986	1721	499	2673	1778	-3173	-1514	2	2	0
Average	0	1178	341	0	0	957	2476	1721	499	1649	1778	-3173	0	2	2	0
Maximum	0	9615	6427	0	0	957	12199	1721	499	5127	1778	-3173	10230	2	2	0
Minimum	0	0	0	0	0	957	957	1721	499	1142	1778	-3173	-4996	2	2	0
Total for the whole year TWh/year	0,00	10,34	3,00	0,00	0,00	8,41	21,75	15,12	4,38	14,48	15,62	-27,87	0,00	0,02	0,02	0,00

RES Share: 100,0 Percent of Primary Energy 96,1 Percent of Electricity 77,7 TWh electricity from RES

31-juli-2020 [22:39]

B.4 Scenario 1: Linear Growth - Biomass and hydrogen alternative

Input Linear Biomass Alternative.txt

The EnergyPLAN model 13.0

Electricity demand (TWh/year):		Flexible demand	3,44
Fixed demand	33,39	Fixed imp/exp.	0,00
Electric heating + HP	2,44	Transportation	2,80
Electric cooling	1,55	Total	43,63

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,00	12,94	22,30	35,24
Solar Thermal	0,00	1,75	0,60	2,35
Industrial CHP (CSHP)	0,00	0,00	0,00	0,00
Demand after solar and CSHP	0,00	11,19	21,70	32,89

Wind	6250 MW	20,25	TWh/year	0,00	Grid
Offshore Wind	14000 MW	63,76	TWh/year	0,00	stabili-
Photo Voltaic	5000 MW	6,35	TWh/year	0,00	sation
River Hydro	0 MW	1,35	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	Efficiencies COP
Group 2:					
CHP	1500	1125	0,52	0,39	
Heat Pump	300	1050			3,50
Boiler		4400		0,95	
Group 3:					
CHP	3500	2625	0,52	0,39	
Heat Pump	400	1400			3,50
Boiler		7600		0,95	
Condensing	4500		0,61		

Heatstorage: gr.2: 56 GWh gr.3: 56 GWh
Fixed Boiler: gr.2: 0,5 Per cent gr.3: 0,5 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	1,20	0,00
Gr.3:	0,00	1,89

Regulation Strategy:	Technical regulation no. 3	
CEEP regulation	234580000	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	0	MW

Di:Nord_pool_system_2013_EUR.TXT		
Addition factor	1,00	EUR/MWh
Multiplication factor	2,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	77	EUR/MWh
Gas Storage	6000	GWh
Syngas capacity	1709	MW
Biogas max to grid	1721	MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Efficiencies Ther.
Hydro Pump:	0	0	0,80	
Hydro Turbine:	0		0,90	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	12500	800	0,73	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	0,00	0,00	0,00
Household	0,00	0,00	0,00	1,59
Industry	0,00	0,00	0,00	3,41
Various	0,00	0,00	8,41	0,00

Output WARNING!!: (1) Critical Excess; (3) PP/Import problem

District Heating

	Demand Distr. heating MW	Production Solar MW	Production Waste+ CSHP MW	Production DHP MW	Production CHP MW	Production HP MW	Production ELT MW	Production Boiler MW	Production EH MW	Balance MW
January	6005	103	2648	0	1091	1677	0	355	127	4
February	6126	218	2657	0	1272	1543	0	395	35	6
March	5328	247	2565	0	752	1559	0	151	109	-56
April	4417	384	2414	0	714	870	0	37	19	-21
May	3626	408	2224	0	489	524	0	1	1	-20
June	2048	371	2104	0	116	163	0	0	1	-707
July	2048	419	2061	0	157	81	0	0	0	-669
August	2048	393	2080	0	123	131	0	0	0	-679
September	2747	291	2187	0	343	233	0	1	0	-308
October	3730	187	2312	0	345	885	0	26	29	-54
November	4663	117	2466	0	674	1229	0	84	87	5
December	5423	70	2585	0	432	1819	0	288	185	46
Average	4012	267	2358	0	539	892	0	111	50	-205
Maximum	9949	2281	3250	0	3750	2450	0	3208	900	2241
Minimum	1886	0	1872	0	0	20	0	0	0	-1653
TWh/year	35,24	2,35	20,71	0,00	4,74	7,84	0,00	0,97	0,44	-1,80

Electricity

	Consumption Elec. demand MW	Consumption Flex.& Transp. MW	Consumption HP MW	Consumption Elec-trolyser MW	Consumption EH MW	Consumption Hydro Pump MW	Production Tur-bine MW	Production RES MW	Production Hy-dro MW	Production Geo-thermal MW	Production Waste+ CSHP MW	Production CHP MW	Production PP MW	Balance Stab-Load %	Balance Imp MW	Balance Exp MW	Balance CEEP MW	Balance EEP MW
January	4530	720	1004	6685	127	0	0	10912	0	0	352	1454	284	100	63	0	0	0
February	4413	694	957	5534	35	0	0	9112	0	0	352	1696	400	100	78	4	4	0
March	4248	714	868	7552	109	0	0	12253	0	0	352	1003	127	100	4	248	248	0
April	3871	718	549	6512	19	0	0	10252	0	0	352	952	189	100	1	77	77	0
May	3603	694	366	5660	1	0	0	9155	0	0	352	651	191	100	0	25	25	0
June	3662	722	105	6317	1	0	0	10215	0	0	352	155	241	100	0	156	156	0
July	3567	705	75	3943	0	0	0	7241	0	0	352	209	526	100	0	38	38	0
August	3801	712	106	5667	0	0	0	9507	0	0	352	164	376	100	0	113	113	0
September	3789	713	216	5151	0	0	0	8691	0	0	352	458	439	100	0	71	71	0
October	3926	707	525	8242	29	0	0	12630	0	0	352	460	96	100	0	109	109	0
November	4160	724	736	6917	87	0	0	11318	0	0	352	899	122	100	0	67	67	0
December	4183	709	985	8741	185	0	0	13877	0	0	352	576	60	100	0	63	63	0
Average	3978	711	540	6417	50	0	0	10441	0	0	352	719	253	100	12	81	81	0
Maximum	6124	3483	1623	13035	900	0	0	23463	0	0	352	5000	4136	100	2524	3833	3833	0
Minimum	2453	-47	6	637	0	0	0	9	0	0	352	0	0	100	0	0	0	0
TWh/year	34,94	6,25	4,75	56,36	0,44	0,00	0,00	91,71	0,00	0,00	3,09	6,31	2,23		0,10	0,71	0,71	0,00

Exchange

	Payment Imp	Payment Exp
	Million EUR	
January	6	0
February	6	0
March	0	11
April	0	4
May	0	1
June	0	5
July	0	1
August	0	4
September	0	3
October	0	5
November	0	3
December	0	2
Average price (EUR/MWh)		
Maximum	117	56
TWh/year	12	40

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	Offsh.	PV	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Imp/Exp Corrected Net	CO2 emission (Mt): Total	CO2 emission (Mt): Net
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
N.Gas	-	7,26	4,89	-	-	3,62	-	-	-	-	-19,50	-4,60	-	-	-	-	-	-	-	8,41	0,08	-0,99	-0,91	0,02	-0,19
Biomass	-	-	-	0,96	0,07	-	-	-	7,30	-	44,87	-	-	-	-	-	-	-	1,32	3,41	57,93	0,00	57,93	0,00	0,00
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	20,25	63,76	6,35	-	4,59	-	-	-	96,30	0,00	96,30	0,00	0,00
H2 etc.	-	0,00	0,00	0,00	0,00	0,00	-	-	-	-40,25	-10,63	36,00	-	-	-	-	-	14,89	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-10,00	-27,87	-	-	-	-	-	37,87	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	-	7,26	4,89	0,96	0,07	3,62	-	-	7,30	-40,25	4,74	3,52	20,25	63,76	6,35	-	4,59	52,76	1,32	11,82	154,31	-0,99	153,32	0,02	-0,19

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Output specifications   Linear Biomass Alternative.txt   The EnergyPLAN model 13.0

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 MW	Gr.2 Balance MW
January	0	0	0	0	2205	77	354	479	865	0	332	94	17989	4
February	0	0	0	0	2249	163	357	552	808	0	334	31	17376	6
March	0	0	0	0	1957	184	335	399	796	0	146	106	13202	-9
April	0	0	0	0	1622	285	300	442	547	0	37	19	12997	-9
May	0	0	0	0	1332	304	256	372	369	0	1	1	13804	28
June	0	0	0	0	752	277	228	116	150	0	0	1	16310	-20
July	0	0	0	0	752	310	218	157	68	0	0	0	16906	0
August	0	0	0	0	752	296	222	123	118	0	0	0	18231	-8
September	0	0	0	0	1009	216	247	339	209	0	1	0	18336	-3
October	0	0	0	0	1370	140	276	251	645	0	26	29	20154	2
November	0	0	0	0	1712	87	312	426	709	0	84	86	17553	8
December	0	0	0	0	1991	52	340	226	914	0	286	173	19708	1
Average	0	0	0	0	1473	199	287	322	516	0	103	45	16884	0
Maximum	0	0	0	0	3653	1624	495	1125	1050	0	2192	300	32836	915
Minimum	0	0	0	0	692	0	174	0	7	0	0	0	0	-757
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	12,94	1,75	2,52	2,83	4,54	0,00	0,91	0,40		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	RES1 Wind MW	RES2 Offshoı MW	RES3 Photo \ MW	RES 4-7 ic MW	Total MW
January	3800	26	2293	612	812	0	23	33	17135	0	2448	8159	149	156	10912
February	3876	56	2300	720	734	0	61	5	27747	0	1794	6771	318	229	9112
March	3372	63	2230	353	763	0	5	3	21975	-46	2879	8348	844	181	12253
April	2795	99	2114	271	324	0	0	0	34107	-13	2480	6539	1112	121	10252
May	2295	104	1968	117	155	0	0	0	34314	-49	1909	5947	1183	116	9155
June	1296	94	1876	0	13	0	0	0	34270	-687	2193	6737	1177	108	10215
July	1296	109	1843	0	13	0	0	0	34270	-669	1450	4431	1267	93	7241
August	1296	97	1858	0	13	0	0	0	34270	-672	1984	6317	1081	125	9507
September	1739	75	1940	4	24	0	0	0	34270	-305	1718	6007	810	156	8691
October	2360	47	2036	94	239	0	0	0	34403	-55	2743	9283	407	197	12630
November	2951	30	2154	249	520	0	0	1	34464	-2	2445	8458	214	201	11318
December	3432	18	2245	207	904	0	1	12	32324	45	3578	10033	100	166	13877
Average	2539	68	2071	217	376	0	7	5	31113	-205	2306	7259	723	154	10441
Maximum	6296	841	2755	2625	1400	0	1713	600	56000	2211	6193	13840	4388	300	23463
Minimum	1193	0	1698	0	13	0	0	0	0	-1313	0	0	0	5	9
Total for the whole year TWh/year	22,30	0,60	18,19	1,91	3,30	0,00	0,06	0,04		-1,80	20,25	63,76	6,35	1,35	91,71

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

ANNUAL COSTS (Million EUR)		
Total Fuel ex Ngas exchange =		-3209
Uranium =	0	
Coal =	0	
FuelOil =	0	
Gasoil/Diesel=	246	
Petrol/JP =	179	
Gas handling =	31	
Biomass =	1335	
Food income =	-5000	
Waste =	0	
Total Ngas Exchange costs =		2
Marginal operation costs =		41
Total Electricity exchange =		12
Import =	12	
Export =	-40	
Bottleneck =	40	
Fixed imp/ex=	0	
Total CO2 emission costs =		1
Total variable costs =		-3152
Fixed operation costs =		6001
Annual Investment costs =		20199
TOTAL ANNUAL COSTS =		23047

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	0	2797	462	0	0	957	4217	1721	499	2076	1778	-3173	1307	9	9	0
February	0	3261	651	0	0	957	4870	1721	499	1386	1778	-3173	2650	9	9	0
March	0	1929	206	0	0	957	3092	1721	499	2709	1778	-3173	-450	9	9	0
April	0	1830	308	0	0	957	3095	1721	499	1937	1778	-3173	325	9	9	0
May	0	1253	310	0	0	957	2520	1721	499	1394	1778	-3173	293	9	9	0
June	0	298	392	0	0	957	1647	1721	499	1934	1778	-3173	-1120	9	9	0
July	0	401	855	0	0	957	2214	1721	499	1142	1778	-3173	239	9	9	0
August	0	315	611	0	0	957	1884	1721	499	1142	1778	-3173	-92	9	9	0
September	0	880	714	0	0	957	2551	1721	499	1142	1778	-3173	575	9	9	0
October	0	885	156	0	0	957	1998	1721	499	2560	1778	-3173	-1396	9	9	0
November	0	1728	198	0	0	957	2883	1721	499	2224	1778	-3173	-175	9	9	0
December	0	1108	98	0	0	957	2163	1721	499	3327	1778	-3173	-1998	9	9	0
Average	0	1383	412	0	0	957	2752	1721	499	1918	1778	-3173	0	9	9	0
Maximum	0	9615	6724	0	0	957	12199	1721	499	7343	1778	-3173	10223	9	9	0
Minimum	0	0	0	0	0	957	957	1721	499	1142	1778	-3173	-7219	9	9	0
Total for the whole year TWh/year	0,00	12,14	3,62	0,00	0,00	8,41	24,17	15,12	4,38	16,85	15,62	-27,87	0,00	0,08	0,08	0,00

RES Share: 100,0 Percent of Primary Energy 94,9 Percent of Electricity 93,6 TWh electricity from RES

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B.5 Scenario 2: 50% - Biomass alternative

Input Scenario 2 - Biomass alternative2.txt

The EnergyPLAN model 13.0

Electricity demand (TWh/year):		Flexible demand	3,44
Fixed demand	33,55	Fixed imp/exp.	0,00
Electric heating + HP	2,44	Transportation	6,38
Electric cooling	1,55	Total	47,37

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,00	12,94	22,30	35,24
Solar Thermal	0,00	1,75	0,60	2,35
Industrial CHP (CSHP)	0,00	0,00	0,00	0,00
Demand after solar and CSHP	0,00	11,19	21,70	32,89

					Grid stabilisation share
Wind	5000	MW	16,20	TWh/year	0,00
Offshore Wind	11850	MW	53,97	TWh/year	0,00
Photo Voltaic	5000	MW	6,35	TWh/year	0,00
River Hydro	0	MW	1,35	TWh/year	0,00
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	1500	1125	0,52	0,39	
Heat Pump	300	1050			3,50
Boiler		4400		0,95	
Group 3:					
CHP	3500	2625	0,52	0,39	
Heat Pump	400	1400			3,50
Boiler		7600		0,95	
Condensing	4500		0,61		

Heatstorage: gr.2: 56 GWh gr.3: 56 GWh
Fixed Boiler: gr.2: 0,5 Per cent gr.3: 0,5 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	1,20	0,00
Gr.3:	0,00	1,89

Regulation Strategy:	Technical regulation no. 3	
CEEP regulation	234580000	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	0	MW

Di:Nord_pool_system_2013_EUR.TXT		
Addition factor	1,00	EUR/MWh
Multiplication factor	2,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	77	EUR/MWh
Gas Storage	6000	GWh
Syngas capacity	2184	MW
Biogas max to grid	1721	MW

Fuel Price level: Basic

Capacities Storage Efficiencies	MW-e	GWh	elec.	Ther.
Hydro Pump:	0	0	0,80	
Hydro Turbine:	0		0,90	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	9009	593	0,73	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	0,00	0,00	0,00
Household	0,00	0,00	0,00	1,59
Industry	0,00	0,00	0,00	3,41
Various	0,00	0,00	8,41	0,00

Output WARNING!!: (1) Critical Excess; (3) PP/Import problem

	District Heating: Demand	District Heating Production									Electricity Consumption						Electricity Production							Balance					Exchange: 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	6005	103	2765	0	1002	1657	0	364	110	4	4548	1127	998	4546	110	0	0	9169	0	0	352	1336	457	100	18	4	4	0	2	0
February	6126	218	2774	0	1213	1505	0	389	22	5	4431	1085	947	3733	22	0	0	7713	0	0	352	1617	520	100	20	4	4	0	1	0
March	5328	247	2682	0	696	1494	0	148	101	-40	4265	1126	849	5299	101	0	0	10395	0	0	352	927	190	100	0	225	225	0	0	10
April	4417	384	2531	0	647	840	0	34	15	-35	3889	1124	541	4618	15	0	0	8752	0	0	352	863	301	100	0	81	81	0	0	4
May	3626	408	2341	0	408	522	0	1	1	-54	3620	1116	365	4049	1	0	0	7860	0	0	352	544	417	100	0	21	21	0	0	1
June	2048	371	2221	0	114	164	0	0	1	-823	3680	1121	107	4538	1	0	0	8742	0	0	352	152	378	100	0	176	176	0	0	6
July	2048	419	2178	0	148	87	0	0	0	-785	3585	1113	81	2793	0	0	0	6271	0	0	352	198	784	100	0	32	32	0	0	1
August	2048	393	2197	0	116	139	0	0	0	-797	3819	1134	110	4150	0	0	0	8140	0	0	352	154	662	100	0	95	95	0	0	4
September	2747	291	2304	0	315	240	0	1	0	-404	3807	1109	218	3663	0	0	0	7425	0	0	352	420	652	100	0	52	52	0	0	2
October	3730	187	2429	0	308	871	0	10	21	-97	3944	1126	521	5866	21	0	0	10656	0	0	352	410	199	100	0	138	138	0	0	6
November	4663	117	2583	0	629	1177	0	85	72	-1	4178	1134	721	4780	72	0	0	9531	0	0	352	838	227	100	0	63	63	0	0	3
December	5423	70	2702	0	410	1764	0	292	167	19	4201	1118	969	6093	167	0	0	11621	0	0	352	546	104	100	0	74	74	0	0	3
Average	4012	267	2475	0	497	871	0	110	43	-251	3996	1120	535	4516	43	0	0	8865	0	0	352	663	407	100	3	81	81	0	Average price	
Maximum	9949	2281	3367	0	3750	2450	0	3098	900	2097	6142	8284	1623	9382	900	0	0	20142	0	0	352	5000	4247	100	1608	3576	3576	0	(EUR/MWh)	
Minimum	1886	0	1989	0	0	20	0	0	0	-1722	2471	-396	6	83	0	0	0	9	0	0	352	0	0	100	0	0	0	0	111	56
TWh/year	35,24	2,35	21,74	0,00	4,37	7,65	0,00	0,96	0,38	-2,21	35,10	9,83	4,70	39,67	0,38	0,00	0,00	77,87	0,00	0,00	3,09	5,82	3,58		0,03	0,71	0,71	0,00	3	40

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	Offsh.	PV	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Imp/Exp Corrected Net	CO2 emission (Mt): Total	CO2 emission (Mt): Net
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
N.Gas	-	7,06	4,15	-	-	5,82	-	-	-	-	-23,66	-2,70	-	-	-	-	-	-	-	8,41	-0,94	-1,11	-2,05	-0,19	-0,42
Biomass	-	-	-	0,96	0,06	-	-	-	7,30	-	55,48	-	-	-	-	-	-	-	1,32	3,41	68,53	0,00	68,53	0,00	0,00
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	16,20	53,97	6,35	-	4,59	-	-	-	82,46	0,00	82,46	0,00	0,00
H2 etc.	-	0,00	0,00	0,00	0,00	0,00	-	-	-	-28,16	-10,63	33,81	-	-	-	-	-	4,99	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-13,70	-27,87	-	-	-	-	-	41,57	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	-	7,06	4,15	0,96	0,06	5,82	-	-	7,30	-28,16	7,48	3,24	16,20	53,97	6,35	-	4,59	46,56	1,32	11,82	150,05	-1,11	148,94	-0,19	-0,42

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Output specifications   Scenario 2 - Biomass alternative2.txt   The EnergyPLAN model 13.0

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 MW	Gr.2 Ba-lance MW
January	0	0	0	0	2205	77	354	481	866	0	341	82	16830	4
February	0	0	0	0	2249	163	357	552	811	0	341	22	15887	4
March	0	0	0	0	1957	184	335	396	806	0	144	100	12051	-9
April	0	0	0	0	1622	285	300	427	570	0	34	15	12273	-10
May	0	0	0	0	1332	304	256	335	406	0	1	1	13729	30
June	0	0	0	0	752	277	228	114	151	0	0	1	15202	-19
July	0	0	0	0	752	310	218	148	75	0	0	0	15433	1
August	0	0	0	0	752	296	222	116	127	0	0	0	16576	-9
September	0	0	0	0	1009	216	247	313	224	0	1	0	15546	8
October	0	0	0	0	1370	140	276	239	693	0	10	21	20933	-10
November	0	0	0	0	1712	87	312	427	720	0	85	72	16443	8
December	0	0	0	0	1991	52	340	227	915	0	292	165	18589	1
Average	0	0	0	0	1473	199	287	313	530	0	104	40	15801	0
Maximum	0	0	0	0	3653	1624	495	1125	1050	0	2187	300	32837	651
Minimum	0	0	0	0	692	0	174	0	7	0	0	0	0	-773
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	12,94	1,75	2,52	2,75	4,65	0,00	0,91	0,35		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	RES1 Wind MW	RES2 Offshor MW	RES3 Photo \ MW	RES 4-7 ic MW	Total MW
January	3800	26	2410	522	790	0	24	28	9158	0	1958	6906	149	156	9169
February	3876	56	2418	661	694	0	48	0	24944	0	1435	5731	318	229	7713
March	3372	63	2347	299	689	0	4	2	15010	-32	2304	7066	844	181	10395
April	2795	99	2231	220	270	0	0	0	23599	-25	1984	5535	1112	121	8752
May	2295	104	2085	73	116	0	0	0	23676	-83	1527	5034	1183	116	7860
June	1296	94	1993	0	13	0	0	0	23656	-804	1755	5702	1177	108	8742
July	1296	109	1960	0	13	0	0	0	23656	-786	1160	3751	1267	93	6271
August	1296	97	1975	0	13	0	0	0	23656	-789	1587	5347	1081	125	8140
September	1739	75	2057	1	16	0	0	0	23656	-411	1375	5084	810	156	7425
October	2360	47	2153	69	178	0	0	0	23665	-86	2194	7857	407	197	10656
November	2951	30	2271	201	457	0	0	0	23858	-9	1956	7159	214	201	9531
December	3432	18	2362	183	849	0	1	2	27359	18	2863	8492	100	166	11621
Average	2539	68	2188	184	341	0	6	3	22126	-251	1845	6144	723	154	8865
Maximum	6296	841	2872	2625	1400	0	1596	600	56000	2094	4954	11714	4388	300	20142
Minimum	1193	0	1815	0	13	0	0	0	0	-1416	0	0	0	5	9
Total for the whole year TWh/year	22,30	0,60	19,22	1,62	3,00	0,00	0,05	0,02		-2,21	16,20	53,97	6,35	1,35	77,87

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

ANNUAL COSTS (Million EUR)		
Total Fuel ex Ngas exchange =		-4603
Uranium =	0	
Coal =	0	
FuelOil =	0	
Gasoil/Diesel=	246	
Petrol/JP =	241	
Gas handling =	31	
Biomass =	1729	
Food income =	-6850	
Waste =	0	
Total Ngas Exchange costs =		-28
Marginal operation costs =		43
Total Electricity exchange =		3
Import =	3	
Export =	-40	
Bottleneck =	40	
Fixed imp/ex=	0	
Total CO2 emission costs =		-8
Total variable costs =		-4592
Fixed operation costs =		6946
Annual Investment costs =		19596
TOTAL ANNUAL COSTS =		21950

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	0	2570	744	0	0	957	4271	1721	973	1719	1778	-3173	1359	-106	0	106
February	0	3110	845	0	0	957	4913	1721	973	1285	1778	-3173	2435	-106	0	106
March	0	1783	310	0	0	957	3051	1721	973	2186	1778	-3173	-329	-106	0	106
April	0	1660	489	0	0	957	3107	1721	973	1746	1778	-3173	168	-106	0	106
May	0	1045	678	0	0	957	2680	1721	973	1372	1778	-3173	116	-106	0	106
June	0	292	615	0	0	957	1865	1721	973	1773	1778	-3173	-1101	-106	0	106
July	0	380	1275	0	0	957	2612	1721	973	1176	1778	-3173	244	-106	0	106
August	0	296	1077	0	0	957	2330	1721	973	1142	1778	-3173	-4	-106	0	106
September	0	808	1061	0	0	957	2826	1721	973	1167	1778	-3173	466	-106	0	106
October	0	789	324	0	0	957	2070	1721	973	2301	1778	-3173	-1423	-106	0	106
November	0	1612	369	0	0	957	2939	1721	973	1863	1778	-3173	-117	-106	0	106
December	0	1051	169	0	0	957	2177	1721	973	2658	1778	-3173	-1674	-106	0	106
Average	0	1275	662	0	0	957	2895	1721	973	1702	1778	-3173	0	-106	0	106
Maximum	0	9615	6906	0	0	957	12199	1721	973	5127	1778	-3173	9864	-106	0	106
Minimum	0	0	0	0	0	957	957	1721	973	1141	1778	-3173	-5362	-106	0	106
Total for the whole year TWh/year	0,00	11,20	5,82	0,00	0,00	8,41	25,43	15,12	8,55	14,95	15,62	-27,87	0,00	-0,94	0,00	0,94

RES Share: 100,6 Percent of Primary Energy 93,0 Percent of Electricity 79,8 TWh electricity from RES

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B.6 Scenario 2: 50% - Biomass and hydrogen alternative

Input Scenario 2 - Biomass Hydrogen.txt

The EnergyPLAN model 13.0

Electricity demand (TWh/year):		Flexible demand	3,44
Fixed demand	33,36	Fixed imp/exp.	0,00
Electric heating + HP	2,44	Transportation	6,38
Electric cooling	1,55	Total	47,18

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,00	12,94	22,30	35,24
Solar Thermal	0,00	1,75	0,60	2,35
Industrial CHP (CSHP)	0,00	0,00	0,00	0,00
Demand after solar and CSHP	0,00	11,19	21,70	32,89

Wind	5000 MW	16,20	TWh/year	0,00	Grid
Offshore Wind	13100 MW	59,66	TWh/year	0,00	stabili-
Photo Voltaic	5000 MW	6,35	TWh/year	0,00	sation
River Hydro	0 MW	1,35	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	1500	1125	0,52	0,39	
Heat Pump	300	1050			3,50
Boiler		4400		0,95	
Group 3:					
CHP	3500	2625	0,52	0,39	
Heat Pump	400	1400			3,50
Boiler		7600		0,95	
Condensing	4500		0,61		

Heatstorage: gr.2: 56 GWh gr.3: 56 GWh
Fixed Boiler: gr.2: 0,5 Per cent gr.3: 0,5 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	1,20	0,00
Gr.3:	0,00	1,89

Regulation Strategy:	Technical regulation no. 3	
CEEP regulation	234580000	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	0	MW

Di:Nord_pool_system_2013_EUR.TXT		
Addition factor	1,00	EUR/MWh
Multiplication factor	2,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	77	EUR/MWh
Gas Storage	6000	GWh
Syngas capacity	2184	MW
Biogas max to grid	1721	MW

Fuel Price level: Basic

	Capacities	Storage	Efficiencies	
	MW-e	GWh	elec.	Ther.
Hydro Pump:	0	0	0,80	
Hydro Turbine:	0		0,90	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	10810	662	0,73	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	0,00	0,00	0,00
Household	0,00	0,00	0,00	1,59
Industry	0,00	0,00	0,00	3,41
Various	0,00	0,00	8,41	0,00

Output WARNING!!: (1) Critical Excess; (3) PP/Import problem

	District Heating										Electricity																			Exchange	
	Demand	Production									Consumption						Production							Balance							
	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	Payment Imp Million EUR	Exp
January	6005	103	2576	0	1103	1698	0	383	137	4	4526	1127	1010	5405	137	0	0	9898	0	0	352	1471	429	100	54	0	0	0	5	0
February	6126	218	2586	0	1285	1578	0	429	25	5	4410	1085	968	4555	25	0	0	8318	0	0	352	1713	597	100	64	1	1	0	5	0
March	5328	247	2494	0	765	1621	0	160	100	-59	4244	1126	885	6262	100	0	0	11141	0	0	352	1020	210	100	3	109	109	0	0	5
April	4417	384	2343	0	729	925	0	36	17	-16	3868	1124	565	5411	17	0	0	9336	0	0	352	972	349	100	0	24	24	0	0	1
May	3626	408	2152	0	482	589	0	1	1	-6	3599	1115	385	4708	1	0	0	8391	0	0	352	642	434	100	0	11	11	0	0	1
June	2048	371	2033	0	115	163	0	0	1	-635	3658	1121	105	5299	1	0	0	9343	0	0	352	154	407	100	0	71	71	0	0	2
July	2048	419	1989	0	154	83	0	0	0	-598	3563	1110	79	3237	0	0	0	6666	0	0	352	205	779	100	0	13	13	0	0	0
August	2048	393	2008	0	121	133	0	0	0	-608	3798	1133	107	4795	0	0	0	8704	0	0	352	162	654	100	0	39	39	0	0	2
September	2747	291	2116	0	346	244	0	1	0	-250	3786	1107	219	4327	0	0	0	7962	0	0	352	462	682	100	0	18	18	0	0	1
October	3730	187	2241	0	348	946	0	20	27	-39	3923	1126	543	6901	27	0	0	11485	0	0	352	464	256	100	0	37	37	0	0	2
November	4663	117	2395	0	684	1291	0	93	76	7	4156	1136	754	5640	76	0	0	10286	0	0	352	911	234	100	0	21	21	0	0	1
December	5423	70	2513	0	444	1859	0	295	191	51	4180	1119	996	7063	191	0	0	12516	0	0	352	592	110	100	0	22	22	0	0	1
Average	4012	267	2286	0	545	927	0	118	48	-179	3975	1119	551	5306	48	0	0	9513	0	0	352	727	428	100	10	31	31	0	Average price	
Maximum	9949	2281	3179	0	3750	2450	0	3683	900	2307	6121	10137	1623	11267	900	0	0	21370	0	0	352	5000	4133	100	2517	2855	2855	0	(EUR/MWh)	
Minimum	1886	0	1801	0	0	20	0	0	0	-1742	2449	-396	6	83	0	0	0	9	0	0	352	0	0	100	0	0	0	0	117	59
TWh/year	35,24	2,35	20,08	0,00	4,79	8,14	0,00	1,03	0,42	-1,57	34,91	9,83	4,84	46,61	0,42	0,00	0,00	83,56	0,00	0,00	3,09	6,38	3,76		0,09	0,27	0,27	0,00	10	16

FUEL BALANCE (TWh/year):	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon- version	Electro- Fuel	Wind	Offsh.	PV	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
N.Gas	-	7,15	5,12	-	-	6,11	-	-	-	-	-23,66	-3,17	-	-	-	-	-	-	-	8,41	-0,04	-0,29	-0,34	-0,01	-0,07
Biomass	-	-	-	0,98	0,11	-	-	-	7,30	-	45,18	-	-	-	-	-	-	-	1,32	3,41	58,29	0,00	58,29	0,00	0,00
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	16,20	59,66	6,35	-	4,59	-	-	-	88,15	0,00	88,15	0,00	0,00
H2 etc.	-	0,00	0,00	0,00	0,00	0,00	-	-	-	-33,20	-10,63	34,35	-	-	-	-	-	9,49	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-6,90	-27,87	-	-	-	-	-	34,77	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	-	7,15	5,12	0,98	0,11	6,11	-	-	7,30	-33,20	3,98	3,31	16,20	59,66	6,35	-	4,59	44,26	1,32	11,82	146,41	-0,29	146,11	-0,01	-0,07

Output specifications — Scenario 2 - Biomass Hydrogen.txt — The EnergyPLAN model 13.0

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 MW	Gr.2 Balance MW
January	0	0	0	0	2205	77	354	478	867	0	336	88	16161	4
February	0	0	0	0	2249	163	357	548	813	0	340	24	15549	5
March	0	0	0	0	1957	184	335	395	802	0	154	95	11569	-9
April	0	0	0	0	1622	285	300	433	559	0	36	17	11600	-9
May	0	0	0	0	1332	304	256	350	391	0	1	1	12632	28
June	0	0	0	0	752	277	228	115	151	0	0	1	14905	-20
July	0	0	0	0	752	310	218	154	71	0	0	0	15399	0
August	0	0	0	0	752	296	222	121	120	0	0	0	16699	-8
September	0	0	0	0	1009	216	247	338	211	0	1	0	16649	-4
October	0	0	0	0	1370	140	276	244	660	0	20	27	19638	2
November	0	0	0	0	1712	87	312	421	715	0	93	75	15928	8
December	0	0	0	0	1991	52	340	226	916	0	292	166	18219	1
Average	0	0	0	0	1473	199	287	317	523	0	106	41	15419	0
Maximum	0	0	0	0	3653	1624	495	1125	1050	0	2190	300	31941	651
Minimum	0	0	0	0	692	0	174	0	7	0	0	0	0	-876
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	12,94	1,75	2,52	2,79	4,59	0,00	0,93	0,36		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	RES1 Wind MW	RES2 Offshoı MW	RES3 Photo \ MW	RES 4-7 ic MW	Total MW
January	3800	26	2222	626	831	0	46	49	15001	0	1958	7635	149	156	9898
February	3876	56	2229	737	765	0	89	1	28069	0	1435	6336	318	229	8318
March	3372	63	2159	370	819	0	7	5	23509	-50	2304	7812	844	181	11141
April	2795	99	2043	296	365	0	0	0	37116	-7	1984	6119	1112	121	9336
May	2295	104	1897	131	198	0	0	0	37316	-35	1527	5565	1183	116	8391
June	1296	94	1805	0	13	0	0	0	37299	-616	1755	6304	1177	108	9343
July	1296	109	1771	0	13	0	0	0	37299	-597	1160	4146	1267	93	6666
August	1296	97	1786	0	13	0	0	0	37299	-600	1587	5911	1081	125	8704
September	1739	75	1868	9	33	0	0	0	37299	-246	1375	5620	810	156	7962
October	2360	47	1964	103	286	0	0	0	37390	-41	2194	8686	407	197	11485
November	2951	30	2082	263	576	0	0	1	37465	-1	1956	7915	214	201	10286
December	3432	18	2173	218	944	0	4	25	33424	50	2863	9388	100	166	12516
Average	2539	68	1999	228	404	0	12	7	33191	-179	1845	6792	723	154	9513
Maximum	6296	841	2684	2625	1400	0	1784	600	56000	2282	4954	12950	4388	300	21370
Minimum	1193	0	1627	0	13	0	0	0	0	-1337	0	0	0	5	9
Total for the whole year TWh/year	22,30	0,60	17,56	2,00	3,55	0,00	0,10	0,06		-1,57	16,20	59,66	6,35	1,35	83,56

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

ANNUAL COSTS (Million EUR)		
Total Fuel ex Ngas exchange =		-1800
Uranium =	0	
Coal =	0	
FuelOil =	0	
Gasoil/Diesel=	246	
Petrol/JP =	127	
Gas handling =	33	
Biomass =	1244	
Food income =	-3450	
Waste =	0	
Total Ngas Exchange costs =		-1
Marginal operation costs =		47
Total Electricity exchange =		10
Import =	10	
Export =	-16	
Bottleneck =	16	
Fixed imp/ex=	0	
Total CO2 emission costs =		0
Total variable costs =		-1745
Fixed operation costs =		6982
Annual Investment costs =		20013
TOTAL ANNUAL COSTS =		25250

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	0	2829	697	0	0	957	4484	1721	973	1812	1778	-3173	1377	-5	0	5
February	0	3294	971	0	0	957	5223	1721	973	1302	1778	-3173	2626	-5	0	5
March	0	1962	342	0	0	957	3261	1721	973	2408	1778	-3173	-442	-5	0	5
April	0	1869	567	0	0	957	3394	1721	973	1798	1778	-3173	301	-5	0	5
May	0	1235	706	0	0	957	2899	1721	973	1339	1778	-3173	265	-5	0	5
June	0	296	661	0	0	957	1914	1721	973	1820	1778	-3173	-1200	-5	0	5
July	0	394	1267	0	0	957	2619	1721	973	1142	1778	-3173	182	-5	0	5
August	0	311	1064	0	0	957	2333	1721	973	1142	1778	-3173	-104	-5	0	5
September	0	888	1108	0	0	957	2954	1721	973	1142	1778	-3173	518	-5	0	5
October	0	892	416	0	0	957	2265	1721	973	2338	1778	-3173	-1368	-5	0	5
November	0	1753	380	0	0	957	3091	1721	973	1960	1778	-3173	-164	-5	0	5
December	0	1139	179	0	0	957	2276	1721	973	2821	1778	-3173	-1840	-5	0	5
Average	0	1397	695	0	0	957	3050	1721	973	1755	1778	-3173	0	-5	0	5
Maximum	0	9615	6720	0	0	957	12199	1721	973	6270	1778	-3173	9763	-5	0	5
Minimum	0	0	0	0	0	957	957	1721	973	1142	1778	-3173	-6607	-5	0	5
Total for the whole year TWh/year	0,00	12,27	6,11	0,00	0,00	8,41	26,79	15,12	8,55	15,42	15,62	-27,87	0,00	-0,04	0,00	0,04

RES Share: 100,0 Percent of Primary Energy 92,3 Percent of Electricity 85,5 TWh electricity from RES

06-maj-2020 [17:01]

B.7 Scenario 3: 90% - Biomass alternative

Input Scenario 3 - Biomass alternative.txt

The EnergyPLAN model 13.0

Electricity demand (TWh/year):			
Fixed demand	33,30	Flexible demand	3,44
Electric heating + HP	2,44	Fixed imp/exp.	0,00
Electric cooling	1,55	Transportation	9,80
		Total	50,54

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,00	12,94	22,30	35,24
Solar Thermal	0,00	1,75	0,60	2,35
Industrial CHP (CSHP)	0,00	0,00	0,00	0,00
Demand after solar and CSHP	0,00	11,19	21,70	32,89

Wind	5000 MW	16,20	TWh/year	0,00	Grid
Offshore Wind	12300 MW	56,02	TWh/year	0,00	stabili-
Photo Voltaic	5000 MW	6,35	TWh/year	0,00	sation
River Hydro	0 MW	1,35	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	1500	1125	0,52	0,39	
Heat Pump	300	1050			3,50
Boiler		4400		0,95	
Group 3:					
CHP	3500	2625	0,52	0,39	
Heat Pump	400	1400			3,50
Boiler		7600		0,95	
Condensing	4500		0,61		

Heatstorage: gr.2: 56 GWh gr.3: 56 GWh
Fixed Boiler: gr.2: 0,5 Per cent gr.3: 0,5 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0,00	0,00
Gr.2:	1,20	0,00
Gr.3:	0,00	1,89

Regulation Strategy:	Technical regulation no. 3	
CEEP regulation	234580000	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	0	MW

Di:Nord_pool_system_2013_EUR.TXT		
Addition factor	1,00	EUR/MWh
Multiplication factor	2,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	77	EUR/MWh
Gas Storage	6000	GWh
Syngas capacity	2184	MW
Biogas max to grid	1721	MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Ther.
Hydro Pump:	0	0	0,80	
Hydro Turbine:	0		0,90	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	10810	662	0,79	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:		0,000		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	0,00	0,00	0,00
Household	0,00	0,00	0,00	1,59
Industry	0,00	0,00	0,00	3,41
Various	0,00	0,00	8,41	0,00

Output WARNING!!: (1) Critical Excess; (3) PP/Import problem

	District Heating Demand: Distr. heating MW	DH Production: Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW	Electricity Consumption: Elec. demand MW	Flex.& Transp. MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Electricity Production: Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Balance: Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Exchange Payment Imp (Million EUR)	Exp (Million EUR)
January	6005	103	2406	0	1080	1809	0	428	175	4	4519	1516	1041	4544	175	0	0	9432	0	0	352	1439	525	100	47	0	0	0	4	0
February	6126	218	2416	0	1271	1665	0	484	65	6	4403	1468	995	3722	65	0	0	7931	0	0	352	1695	632	100	43	0	0	0	3	0
March	5328	247	2324	0	749	1791	0	156	120	-59	4237	1514	932	5497	120	0	0	10663	0	0	352	999	304	100	1	20	20	0	0	1
April	4417	384	2173	0	732	1103	0	23	13	-11	3861	1512	618	4748	13	0	0	8962	0	0	352	976	461	100	0	0	0	0	0	0
May	3626	408	1982	0	440	779	0	1	1	14	3592	1513	441	3931	1	0	0	8051	0	0	352	587	491	100	0	2	2	0	0	0
June	2048	371	1863	0	109	169	0	0	1	-465	3651	1504	111	4760	1	0	0	8958	0	0	352	146	592	100	0	21	21	0	0	1
July	2048	419	1819	0	143	94	0	0	0	-427	3556	1501	84	2868	0	0	0	6413	0	0	352	190	1053	100	0	0	0	0	0	0
August	2048	393	1838	0	111	139	0	0	0	-434	3791	1511	110	4354	0	0	0	8343	0	0	352	148	923	100	0	0	0	0	0	0
September	2747	291	1946	0	329	311	0	1	1	-130	3779	1516	238	3776	1	0	0	7618	0	0	352	439	899	100	1	0	0	0	0	0
October	3730	187	2071	0	318	1163	0	5	18	-32	3915	1522	605	5942	18	0	0	10954	0	0	352	424	278	100	0	5	5	0	0	0
November	4663	117	2225	0	643	1496	0	93	78	11	4149	1524	812	4801	78	0	0	9802	0	0	352	858	353	100	0	1	1	0	0	0
December	5423	70	2343	0	421	2002	0	306	241	40	4173	1506	1037	6045	241	0	0	11943	0	0	352	561	146	100	0	0	0	0	0	0
Average	4012	267	2116	0	526	1043	0	124	60	-124	3968	1509	585	4588	60	0	0	9098	0	0	352	701	554	100	8	4	4	0	Average price	
Maximum	9949	2281	3009	0	3750	2450	0	4388	900	2414	6114	11724	1623	11279	900	0	0	20584	0	0	352	5000	4500	100	2478	1510	1510	0	(EUR/MWh)	
Minimum	1886	0	1631	0	0	20	0	0	0	-1572	2442	-530	6	83	0	0	0	9	0	0	352	0	0	100	0	0	0	0	115	64
TWh/year	35,24	2,35	18,59	0,00	4,62	9,16	0,00	1,09	0,52	-1,09	34,85	13,26	5,14	40,30	0,52	0,00	0,00	79,92	0,00	0,00	3,09	6,16	4,87		0,07	0,04	0,04	0,00	8	2

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	Offsh.	PV	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (Mt): Total	Net
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
N.Gas	-	6,40	5,44	-	-	7,91	-	-	-	-	-23,66	-4,62	-	-	-	-	-	-	-	8,41	-0,12	0,05	-0,07	-0,02	-0,01
Biomass	-	-	-	0,96	0,19	-	-	-	7,30	-	27,97	-	-	-	-	-	-	-	1,32	3,41	41,15	0,00	41,15	0,00	0,00
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	16,20	56,02	6,35	-	4,59	-	-	-	84,51	0,00	84,51	0,00	0,00
H2 etc.	-	0,00	0,00	0,00	0,00	0,00	-	-	-	-30,37	-10,63	36,02	-	-	-	-	-	4,99	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-2,72	-27,87	-	-	-	-	-	30,59	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	-	6,40	5,44	0,96	0,19	7,91	-	-	7,30	-30,37	-9,04	3,53	16,20	56,02	6,35	-	4,59	35,58	1,32	11,82	125,54	0,05	125,59	-0,02	-0,01

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Output specifications　Scenario 3 - Biomass alternative.txt　The EnergyPLAN model 13.0

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 MW	Gr.2 Balance MW
January	0	0	0	0	2205	77	354	442	886	0	341	101	17131	4
February	0	0	0	0	2249	163	357	501	833	0	352	38	15990	6
March	0	0	0	0	1957	184	335	363	833	0	146	106	11918	-11
April	0	0	0	0	1622	285	300	397	611	0	23	13	13666	-7
May	0	0	0	0	1332	304	256	286	457	0	1	1	15243	27
June	0	0	0	0	752	277	228	109	156	0	0	1	15889	-18
July	0	0	0	0	752	310	218	143	81	0	0	0	16093	0
August	0	0	0	0	752	296	222	111	127	0	0	0	17351	-4
September	0	0	0	0	1009	216	247	294	245	0	1	1	15497	5
October	0	0	0	0	1370	140	276	201	743	0	5	18	20136	-13
November	0	0	0	0	1712	87	312	375	758	0	93	77	16729	10
December	0	0	0	0	1991	52	340	202	934	0	291	172	18997	1
Average	0	0	0	0	1473	199	287	284	555	0	104	44	16230	0
Maximum	0	0	0	0	3653	1624	495	1125	1050	0	2181	300	35371	697
Minimum	0	0	0	0	692	0	174	0	7	0	0	0	0	-746
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	12,94	1,75	2,52	2,49	4,88	0,00	0,91	0,39		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	RES1 Wind MW	RES2 Offshor MW	RES3 Photo \ MW	RES 4-7 ic MW	Total MW
January	3800	26	2052	638	923	0	87	74	16071	0	1958	7168	149	156	9432
February	3876	56	2059	770	833	0	132	27	29121	0	1435	5949	318	229	7931
March	3372	63	1989	386	957	0	10	14	21558	-48	2304	7335	844	181	10663
April	2795	99	1873	335	492	0	0	0	35654	-3	1984	5745	1112	121	8962
May	2295	104	1727	154	323	0	0	0	35762	-13	1527	5225	1183	116	8051
June	1296	94	1635	0	13	0	0	0	35786	-446	1755	5919	1177	108	8958
July	1296	109	1602	0	13	0	0	0	35792	-428	1160	3893	1267	93	6413
August	1296	97	1616	0	13	0	0	0	35792	-430	1587	5550	1081	125	8343
September	1739	75	1698	35	66	0	0	0	35792	-136	1375	5277	810	156	7618
October	2360	47	1794	117	421	0	0	0	36096	-19	2194	8155	407	197	10954
November	2951	30	1913	269	738	0	1	1	35785	0	1956	7431	214	201	9802
December	3432	18	2003	219	1068	0	15	69	32711	40	2863	8814	100	166	11943
Average	2539	68	1829	242	488	0	20	15	32137	-124	1845	6377	723	154	9098
Maximum	6296	841	2514	2625	1400	0	2208	600	56000	1899	4954	12159	4388	300	20584
Minimum	1193	0	1457	0	13	0	0	0	0	-1428	0	0	0	5	9
Total for the whole year TWh/year	22,30	0,60	16,07	2,12	4,29	0,00	0,18	0,14		-1,09	16,20	56,02	6,35	1,35	79,92

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

ANNUAL COSTS (Million EUR)		
Total Fuel ex Ngas exchange =		673
Uranium =	0	
Coal =	0	
FuelOil =	0	
Gasoil/Diesel=	246	
Petrol/JP =	56	
Gas handling =	32	
Biomass =	918	
Food income =	-579	
Waste =	0	
Total Ngas Exchange costs =		-4
Marginal operation costs =		50
Total Electricity exchange =		8
Import =	8	
Export =	-2	
Bottleneck =	2	
Fixed imp/ex=	0	
Total CO2 emission costs =		-1
Total variable costs =	726	
Fixed operation costs =	8014	
Annual Investment costs =	20191	
TOTAL ANNUAL COSTS =	28932	

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	0	2768	853	0	0	957	4579	1721	973	1892	1778	-3173	1401	-14	0	14
February	0	3260	1028	0	0	957	5245	1721	973	1387	1778	-3173	2572	-14	0	14
March	0	1921	494	0	0	957	3373	1721	973	2511	1778	-3173	-424	-14	0	14
April	0	1878	749	0	0	957	3584	1721	973	2022	1778	-3173	277	-14	0	14
May	0	1129	798	0	0	957	2884	1721	973	1484	1778	-3173	115	-14	0	14
June	0	280	962	0	0	957	2200	1721	973	2076	1778	-3173	-1162	-14	0	14
July	0	366	1713	0	0	957	3036	1721	973	1306	1778	-3173	444	-14	0	14
August	0	284	1501	0	0	957	2742	1721	973	1328	1778	-3173	129	-14	0	14
September	0	844	1462	0	0	957	3263	1721	973	1479	1778	-3173	498	-14	0	14
October	0	815	452	0	0	957	2224	1721	973	2652	1778	-3173	-1714	-14	0	14
November	0	1650	574	0	0	957	3181	1721	973	2053	1778	-3173	-158	-14	0	14
December	0	1079	238	0	0	957	2274	1721	973	2820	1778	-3173	-1831	-14	0	14
Average	0	1348	901	0	0	957	3206	1721	973	1920	1778	-3173	0	-14	0	14
Maximum	0	9615	7317	0	0	957	12199	1721	973	6444	1778	-3173	9772	-14	0	14
Minimum	0	0	0	0	0	957	957	1721	973	1141	1778	-3173	-6773	-14	0	14
Total for the whole year TWh/year	0,00	11,84	7,91	0,00	0,00	8,41	28,16	15,12	8,55	16,87	15,62	-27,87	0,00	-0,12	0,00	0,12

RES Share: 100,1 Percent of Primary Energy 91,0 Percent of Electricity 81,8 TWh electricity from RES

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B.8 Scenario 3: 90% - Hydrogen alternative

Input Scenario 3 - hydrogen alternative.txt

The EnergyPLAN model 13.0

Electricity demand (TWh/year):		Flexible demand	3,44
Fixed demand	33,17	Fixed imp/exp.	0,00
Electric heating + HP	2,44	Transportation	9,80
Electric cooling	1,55	Total	50,41

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0,00	12,94	22,30	35,24
Solar Thermal	0,00	1,75	0,60	2,35
Industrial CHP (CSHP)	0,00	0,00	0,00	0,00
Demand after solar and CSHP	0,00	11,19	21,70	32,89

				Grid stabilisation share
Wind	5000 MW	16,20	TWh/year	0,00
Offshore Wind	12800 MW	58,29	TWh/year	0,00
Photo Voltaic	5000 MW	6,35	TWh/year	0,00
River Hydro	0 MW	1,35	TWh/year	0,00
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	1500	1125	0,52	0,39	
Heat Pump	300	1050			3,50
Boiler		4400		0,95	
Group 3:					
CHP	3500	2625	0,52	0,39	
Heat Pump	400	1400			3,50
Boiler		7600		0,95	
Condensing	4500		0,61		

Heatstorage: gr.2: 56 GWh gr.3: 56 GWh
Fixed Boiler: gr.2: 0,5 Per cent gr.3: 0,5 Per cent

Electricity prod. from (TWh/year)	CSHP	Waste
Gr.1:	0,00	0,00
Gr.2:	1,20	0,00
Gr.3:	0,00	1,89

Regulation Strategy: Technical regulation no. 3

CEEP regulation	234580000	
Minimum Stabilisation share	0,00	
Stabilisation share of CHP	0,00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0,50	
Maximum import/export	0	MW

Di:Nord_pool_system_2013_EUR.TXT

Addition factor	1,00	EUR/MWh
Multiplication factor	2,00	
Dependency factor	0,00	EUR/MWh pr. MW
Average Market Price	77	EUR/MWh
Gas Storage	6000	GWh
Syngas capacity	2184	MW
Biogas max to grid	1721	MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Efficiencies Ther.
Hydro Pump:	0	0	0,80	
Hydro Turbine:	0		0,90	
Electrol. Gr.2:	0	0	0,80	0,10
Electrol. Gr.3:	0	0	0,80	0,10
Electrol. trans.:	10810	662	0,79	
Ely. MicroCHP:	0	0	0,80	
CAES fuel ratio:	0,000			

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0,00	0,00	0,00	0,00
Household	0,00	0,00	0,00	1,59
Industry	0,00	0,00	0,00	3,41
Various	0,00	0,00	8,41	0,00

Output WARNING!!: (1) Critical Excess; (3) PP/Import problem

	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	6005	103	2344	0	1111	1818	0	441	184	4	4504	1516	1044	4881	184	0	0	9723	0	0	352	1482	510	100	63	0	0	0	6	0
February	6126	218	2353	0	1300	1674	0	497	78	6	4388	1470	997	4027	78	0	0	8173	0	0	352	1733	640	100	62	0	0	0	5	0
March	5328	247	2261	0	770	1814	0	162	132	-58	4222	1512	938	5797	132	0	0	10962	0	0	352	1027	303	100	3	44	44	0	0	2
April	4417	384	2110	0	767	1136	0	24	13	-16	3846	1512	627	5018	13	0	0	9196	0	0	352	1022	452	100	0	6	6	0	0	0
May	3626	408	1920	0	465	813	0	1	1	18	3577	1513	451	4178	1	0	0	8263	0	0	352	620	490	100	0	5	5	0	0	0
June	2048	371	1800	0	110	167	0	0	1	-401	3637	1504	111	4981	1	0	0	9199	0	0	352	146	576	100	0	40	40	0	0	1
July	2048	419	1757	0	144	93	0	0	0	-365	3541	1501	83	3027	0	0	0	6571	0	0	352	192	1038	100	0	0	0	0	0	0
August	2048	393	1776	0	111	139	0	0	0	-371	3776	1524	110	4555	0	0	0	8569	0	0	352	148	896	100	0	0	0	0	0	0
September	2747	291	1883	0	346	325	0	1	1	-99	3764	1503	242	4033	1	0	0	7833	0	0	352	462	894	100	1	0	0	0	0	0
October	3730	187	2008	0	329	1210	0	4	17	-26	3901	1522	618	6284	17	0	0	11286	0	0	352	439	280	100	0	14	14	0	0	1
November	4663	117	2162	0	658	1541	0	95	79	11	4134	1524	825	5115	79	0	0	10104	0	0	352	877	350	100	0	7	7	0	0	0
December	5423	70	2280	0	431	2031	0	316	259	36	4158	1507	1045	6398	259	0	0	12301	0	0	352	575	146	100	0	6	6	0	0	0
Average	4012	267	2054	0	542	1063	0	128	64	-106	3953	1509	590	4863	64	0	0	9358	0	0	352	723	547	100	11	10	10	0	Average price	
Maximum	9949	2281	2946	0	3750	2450	0	4519	900	2472	6099	11084	1623	11280	900	0	0	21075	0	0	352	5000	4500	100	2798	1970	1970	0	(EUR/MWh)	
Minimum	1886	0	1568	0	0	20	0	0	0	-1509	2428	-530	6	83	0	0	0	9	0	0	352	0	0	100	0	0	0	0	118	61
TWh/year	35,24	2,35	18,04	0,00	4,76	9,34	0,00	1,12	0,56	-0,93	34,72	13,26	5,19	42,72	0,56	0,00	0,00	82,20	0,00	0,00	3,09	6,35	4,81		0,09	0,09	0,09	0,00	11	5

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	Offsh.	PV	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Imp/Exp Corrected Net	CO2 emission (Mt): Total	CO2 emission (Mt): Net
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
N.Gas	-	6,39	5,82	-	-	7,81	-	-	-	-	-23,66	-4,74	-	-	-	-	-	-	-	8,41	0,03	0,01	0,04	0,01	0,01
Biomass	-	-	-	0,96	0,22	-	-	-	7,30	-	23,02	-	-	-	-	-	-	-	1,32	3,41	36,23	0,00	36,23	0,00	0,00
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	16,20	58,29	6,35	-	4,59	-	-	-	86,79	0,00	86,79	0,00	0,00
H2 etc.	-	0,00	0,00	0,00	0,00	0,00	-	-	-	-32,31	-10,63	36,15	-	-	-	-	-	6,79	-	-	0,00	0,00	0,00	0,00	0,00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-27,87	-	-	-	-	-	27,87	-	-	0,00	0,00	0,00	0,00	0,00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,00	0,00	0,00	0,00	0,00
Total	-	6,39	5,82	0,96	0,22	7,81	-	-	7,30	-32,31	-11,28	3,55	16,20	58,29	6,35	-	4,59	34,66	1,32	11,82	123,05	0,01	123,05	0,01	0,01

Output specifications   Scenario 3 - hydrogen alternative.txt   The EnergyPLAN model 13.0

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 MW	Gr.2 Balance MW
January	0	0	0	0	2205	77	354	439	887	0	343	101	16991	4
February	0	0	0	0	2249	163	357	499	833	0	349	42	15825	6
March	0	0	0	0	1957	184	335	362	833	0	148	105	11769	-11
April	0	0	0	0	1622	285	300	398	609	0	24	13	13464	-8
May	0	0	0	0	1332	304	256	288	455	0	1	1	15429	26
June	0	0	0	0	752	277	228	110	154	0	0	1	15735	-18
July	0	0	0	0	752	310	218	144	80	0	0	0	15957	0
August	0	0	0	0	752	296	222	111	126	0	0	0	17199	-4
September	0	0	0	0	1009	216	247	295	244	0	1	1	15602	5
October	0	0	0	0	1370	140	276	201	743	0	4	17	20232	-13
November	0	0	0	0	1712	87	312	372	759	0	94	78	16566	10
December	0	0	0	0	1991	52	340	201	935	0	291	172	18821	1
Average	0	0	0	0	1473	199	287	284	555	0	104	45	16143	0
Maximum	0	0	0	0	3653	1624	495	1125	1050	0	2184	300	35245	707
Minimum	0	0	0	0	692	0	174	0	7	0	0	0	0	-746
Total for the whole year TWh/year	0,00	0,00	0,00	0,00	12,94	1,75	2,52	2,49	4,87	0,00	0,92	0,39		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	RES1 Wind MW	RES2 Offshoı MW	RES3 Photo \ MW	RES 4-7 ic MW	Total MW
January	3800	26	1989	672	931	0	98	83	17187	0	1958	7460	149	156	9723
February	3876	56	1996	801	840	0	147	35	26941	0	1435	6191	318	229	8173
March	3372	63	1926	408	981	0	14	27	21568	-47	2304	7633	844	181	10962
April	2795	99	1810	368	527	0	0	0	38872	-9	1984	5979	1112	121	9196
May	2295	104	1664	177	358	0	0	0	39549	-8	1527	5437	1183	116	8263
June	1296	94	1572	0	13	0	0	0	39584	-384	1755	6159	1177	108	9199
July	1296	109	1539	0	13	0	0	0	39593	-365	1160	4051	1267	93	6571
August	1296	97	1554	0	13	0	0	0	39593	-368	1587	5776	1081	125	8569
September	1739	75	1636	51	81	0	0	0	39593	-104	1375	5492	810	156	7833
October	2360	47	1732	128	467	0	0	0	40045	-13	2194	8487	407	197	11286
November	2951	30	1850	286	782	0	1	1	39269	1	1956	7733	214	201	10104
December	3432	18	1941	230	1096	0	25	87	35646	35	2863	9173	100	166	12301
Average	2539	68	1767	258	508	0	23	20	34780	-106	1845	6636	723	154	9358
Maximum	6296	841	2451	2625	1400	0	2335	600	56000	1962	4954	12653	4388	300	21075
Minimum	1193	0	1394	0	13	0	0	0	0	-1377	0	0	0	5	9
Total for the whole year TWh/year	22,30	0,60	15,52	2,27	4,47	0,00	0,20	0,17		-0,93	16,20	58,29	6,35	1,35	82,20

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

ANNUAL COSTS (Million EUR)		
Total Fuel ex Ngas exchange =		1041
Uranium =	0	
Coal =	0	
FuelOil =	0	
Gasoil/Diesel=	246	
Petrol/JP =	11	
Gas handling =	32	
Biomass =	753	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		1
Marginal operation costs =		51
Total Electricity exchange =		11
Import =	11	
Export =	-5	
Bottleneck =	5	
Fixed imp/ex=	0	
Total CO2 emission costs =		0
Total variable costs =		1105
Fixed operation costs =		8004
Annual Investment costs =		20311
TOTAL ANNUAL COSTS =		29420

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	0	2849	829	0	0	957	4635	1721	973	1943	1778	-3173	1390	3	3	0
February	0	3333	1040	0	0	957	5331	1721	973	1417	1778	-3173	2612	3	3	0
March	0	1975	493	0	0	957	3425	1721	973	2545	1778	-3173	-422	3	3	0
April	0	1965	734	0	0	957	3657	1721	973	2033	1778	-3173	322	3	3	0
May	0	1193	796	0	0	957	2947	1721	973	1474	1778	-3173	170	3	3	0
June	0	281	937	0	0	957	2176	1721	973	2061	1778	-3173	-1187	3	3	0
July	0	369	1688	0	0	957	3014	1721	973	1286	1778	-3173	425	3	3	0
August	0	285	1457	0	0	957	2700	1721	973	1284	1778	-3173	113	3	3	0
September	0	888	1454	0	0	957	3300	1721	973	1452	1778	-3173	544	3	3	0
October	0	845	455	0	0	957	2257	1721	973	2700	1778	-3173	-1745	3	3	0
November	0	1687	569	0	0	957	3214	1721	973	2091	1778	-3173	-180	3	3	0
December	0	1105	237	0	0	957	2299	1721	973	2885	1778	-3173	-1889	3	3	0
Average	0	1390	890	0	0	957	3237	1721	973	1934	1778	-3173	0	3	3	0
Maximum	0	9615	7317	0	0	957	12199	1721	973	6450	1778	-3173	9755	3	3	0
Minimum	0	0	0	0	0	957	957	1721	973	1141	1778	-3173	-6795	3	3	0
Total for the whole year TWh/year	0,00	12,21	7,81	0,00	0,00	8,41	28,43	15,12	8,55	16,99	15,62	-27,87	0,00	0,03	0,03	0,00

RES Share: 100,0 Percent of Primary Energy 91,1 Percent of Electricity 84,1 TWh electricity from RES 08-juli-2020 [13:05]