CORE – Coordinated operation of integrated energy systems

WP1 - Presentation of the modelling test-bed

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1 Introduction

This document presents the variant energy systems and the test-bed setup for scenario development for WP1 of the CORE ("Coordinated Operation of Integrated Energy Systems") project. Three different variant energy systems are developed as a testbed for the Danish energy system. The variant energy systems all represent both medium- and long-term outlooks for 2035 and 2050, respectively. The 2050 variant energy systems correspond to the Danish political goal of being independent of fossil fuels by modelling an extensive utilisation of renewable energy sources (RES). However, the magnitude and type of RES harvested in the system varies between three variant energy systems. The selected variant energy systems are the following:

- Sustainable Transition (ST)
- Global Climate Action (GCA)
- IDA's Energy Vision 2050 (IDA)

The ST and GCA variant energy systems are based on "System Perspective 2035" a roadmap developed by the Danish transmission system operator (TSO), Energinet, in 2018 [1]. Energinet takes the European TYNDP2018 (Ten Year Network Development Plan) [2] as a starting point for developing different variant energy systems for the Danish energy system in 2035 and 2050, reflecting on the political goals in Denmark. The IDA variant energy system, "IDA's Energy Vision 2050", developed in 2015 [3], represents an energy system for Denmark based on 100% RES covering the all energy sectors. Besides the three variant energy systems scenarios, a short-term variant energy system for the Danish energy system in 2020 is also developed based on projection of the Danish Energy Agency's frozen policy projection from 2018. The 2020 scenario is not described in more detail in the main document, but the data used for this model is found in appendix E.

In the CORE project, these variant energy systems are modelled with the aid of the energy system simulation tool EnergyPLAN. EnergyPLAN can simulate hourly energy balances in all the sectors in an energy system, including the heating, power, gas, transportation, and water desalination sectors. The overview of technologies and sectors present in EnergyPLAN is shown in Figure 1.

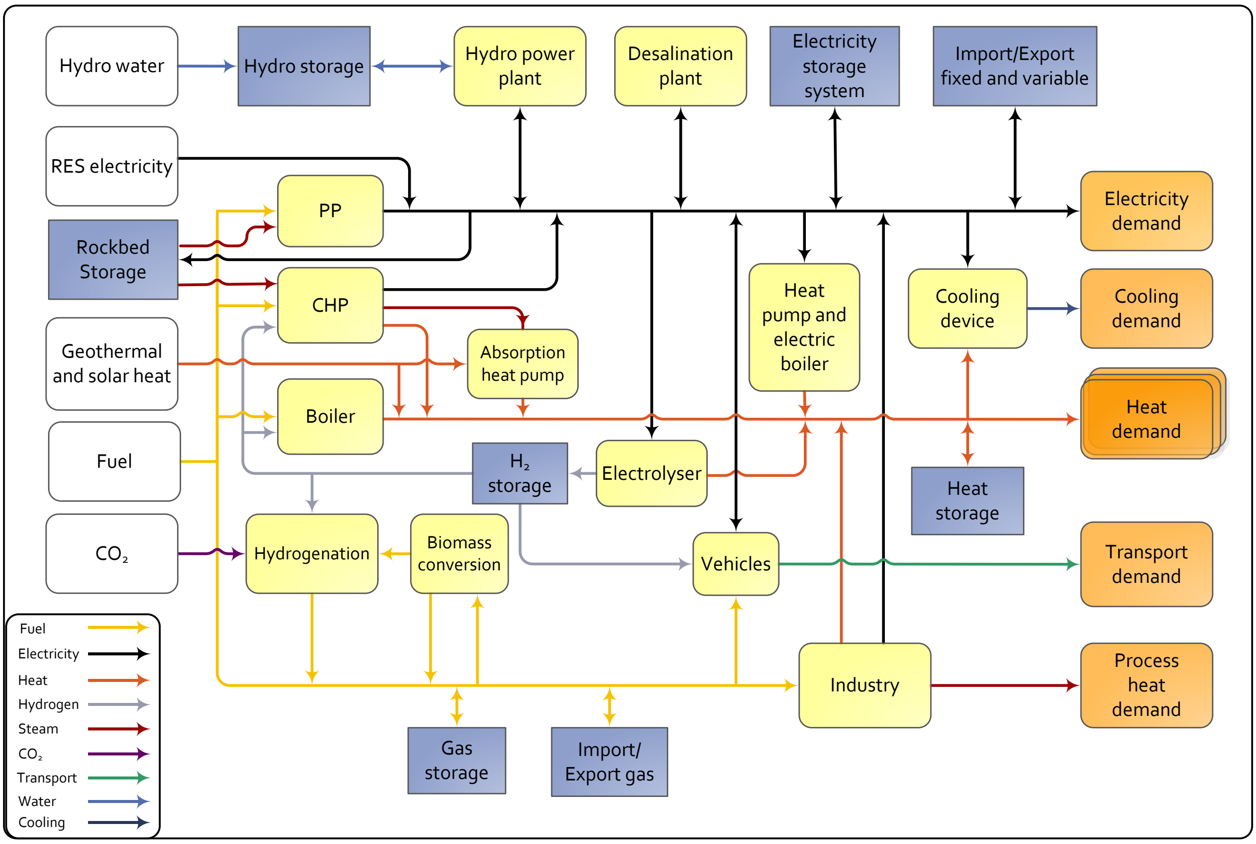

Figure 1 - Overview of EnergyPLAN technologies and cross-sector integration [4]

Among the selected variant energy systems for this study, only IDA has been originally developed by using EnergyPLAN, whereas ST and GCA were originally developed using the Sifre-Adapt-model developed by Energinet. In order to provide a level basis for comparison and evaluation of the variant energy systems, from input data and assumptions to the results and output, the ST and GCA variant energy systems are modelled in EnergyPLAN. The preliminary versions of the ST and GCA implementation into EnergyPLAN are done using the data described in appendix A, B, C, and D. Due to differences between the Sifre-Adapt-model and EnergyPLAN, some differences in the simulation results are expected. However, the efforts are made to build models and run simulations in EnergyPLAN consistent with the original variant energy systems developed using the Sifre-Adapt-model so that the output of the two models stand as close as possible.

2 Comparison of variant energy systems

In this section, the three variant energy systems are compared in terms of their structure, energy mix, and solutions offered by each. All numbers shown in this chapter are based on the values from the original simulation tool for each variant energy system, and not the adaption into EnergyPLAN. There may be numerous pathways to a sustainable or 100% renewable energy system. Hence, the goal of this section is not to favour one solution over the others, but to show the implications of each solution for the Danish energy system and discuss the origin of some of the discrepancy in the findings. One of the main driving factors in developing variant energy systems lies in the way that each variant energy system defines the system and projects the future. This narrative or overarching view behind each variant energy system plays a key role in synthesizing some of the assumptions and perhaps explains some of differences in the findings. To understand this better, the electricity generation mix across the three variant energy systems is compared in Figure 2.

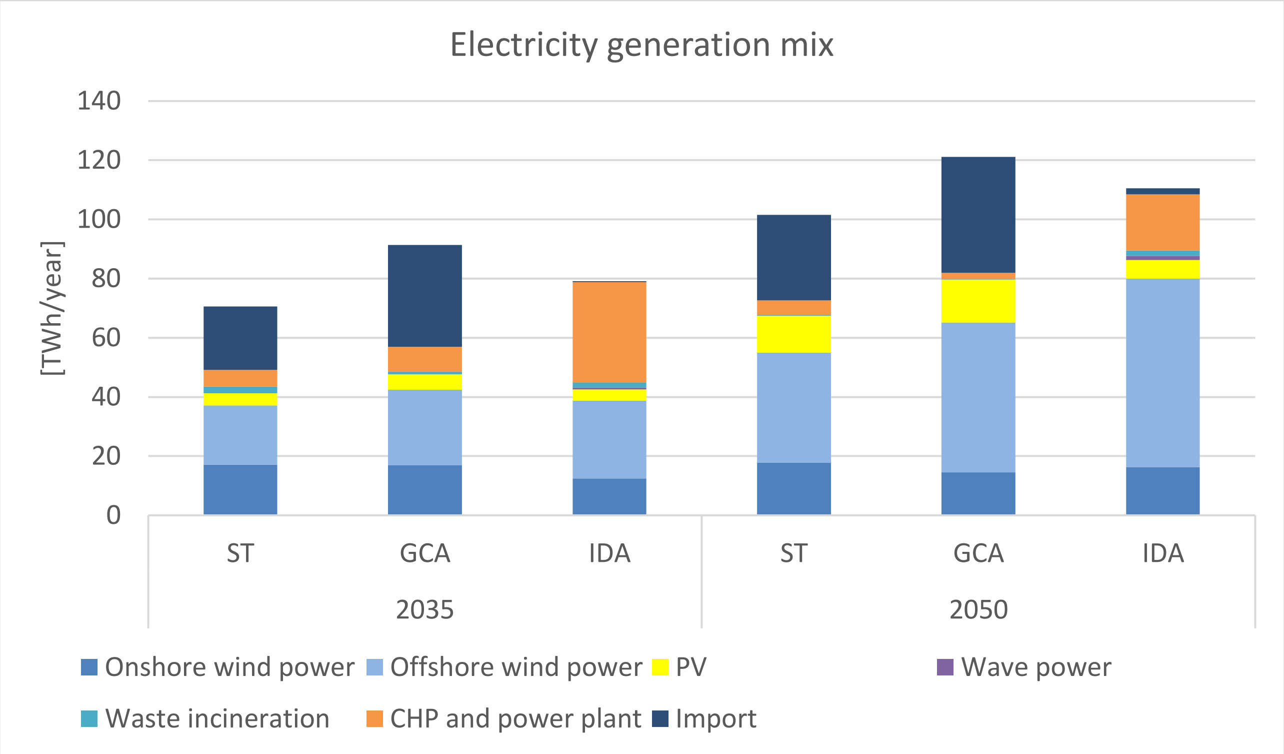

Figure 2 – Electricity production for the different variant energy systems divided into type of production unit

As demonstrated in Figure 2, the ST and GCA variant energy systems are highly dependent on import of electricity from neighbouring countries, whereas the IDA variant energy systems aim at meeting the national electricity demand only by relying on domestic electricity producing units. Accordingly, the share of thermal power and CHP plants in the IDA variant energy systems is significantly higher than the variant energy systems developed by the Energinet tool. Another key difference is in the share of solar photovoltaic (PV) in 2050; GCA and ST suggest more than double solar-based electricity production projected by IDA. While all three variant energy systems have a large share of offshore wind power in 2050, the share of this technology varies a lot across the variant energy systems, from approximately 59% of the electricity production in IDA to 38%

in ST. The electricity generation mix shows large differences across the three variant energy systems, while being consistent between 2035 and 2050 in each variant energy system.

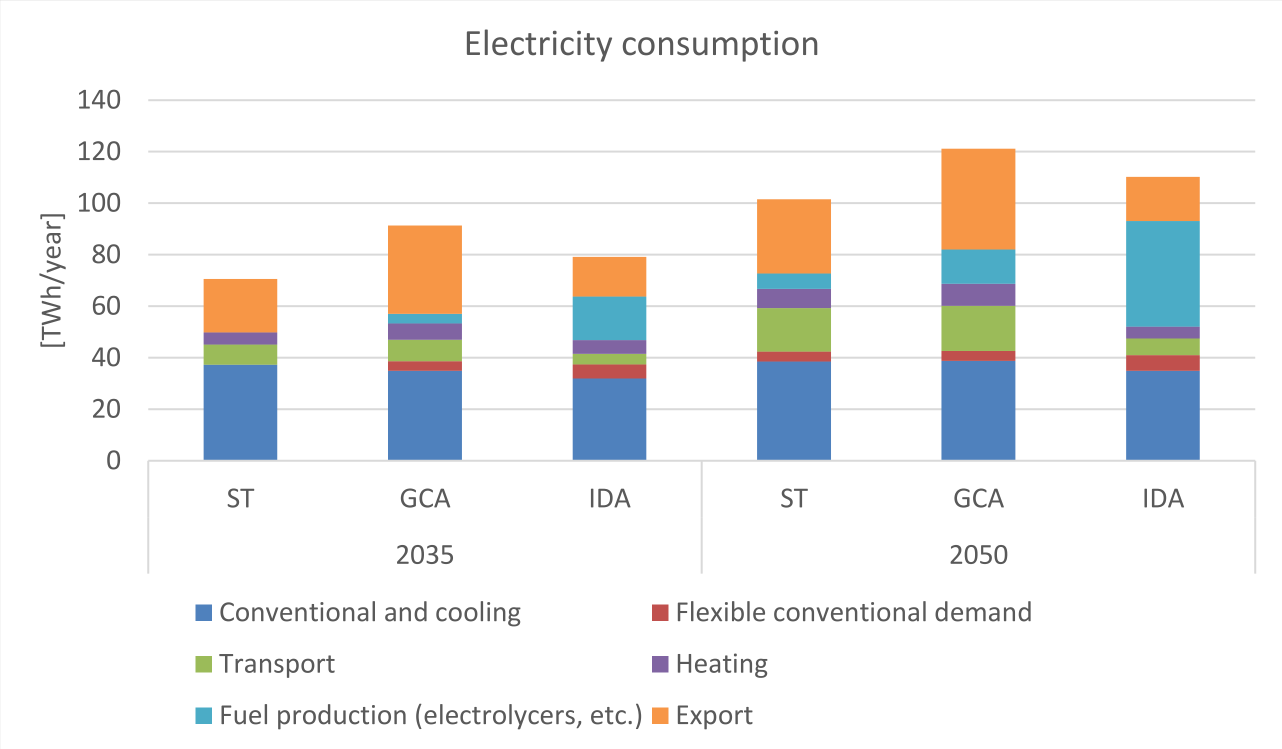

Figure 3 – Electricity consumption for the different variant energy systems based on the type of consumption

Figure 3 illustrates that the ST and GCA variant energy systems portray a larger export of electricity compared with the IDA variant energy systems; a pattern similar to electricity imports observed in Figure 2. However, ST and GCA variant energy systems propose a balanced electricity exchange: the net import of electricity is 0.61 and 0.01 TWh/year in ST2035 and ST2050, respectively, and 0.04 and 0.06 TWh/year in GCA2035 and GCA2050, respectively. The IDA variant energy systems project a future where Denmark is a net exporter, with 15.14 and 15.08 TWh/year exports to the neighbouring countries in 2035 and 2050, respectively. One of the main reasons for this difference between IDA and other two variant energy systems is especially due to the large share of CHP and power plants in IDA's variant energy systems, 6GW compared to 2.1 GW in ST and GCA in 2050. These thermal units are assumed to be highly efficient, able to export electricity in many hours of a year due to a low bidding price relative to the electricity market price.

The comparison reveals that electricity for synthetic fuel production through electrolysis is considerable in all variant energy systems, especially in IDA2050, where electricity used by electrolysers to produce hydrogen comprise the largest part of the electricity end use. On the other hand, the future projected by ST and GCA variant energy systems advocates more direct electrification of the transport sector compared to the IDA's vision, showing a shift between synthetic-fuel based versus electrified transport across the variant energy systems setups.

Finally, the projections for domestic electricity demand also varies between the IDA on one hand and the ST and GCA variant energy systems on the other. Total electricity generation in GCA is higher than any other variant energy system in 2050. However, the domestic electricity demand, i.e., generation minus exchange with the external market, in IDA's variant energy systems is higher than the others.

Figure 4 shows the individual heating production in all variant energy systems.

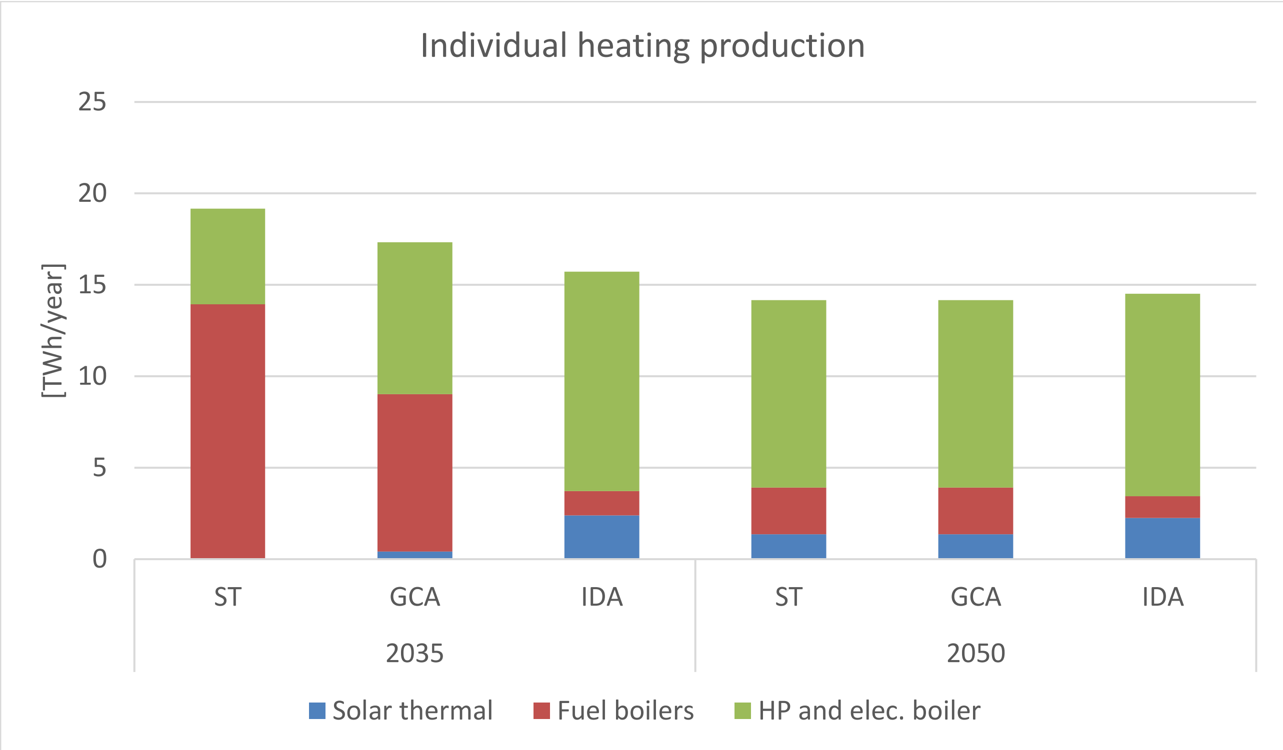

Figure 4 – Individual heating production for the different variant energy systems divided into type of production unit

As depicted in Figure 4, all the variant energy systems agree that individual heat pumps will be the main heating mode for individually heated households in 2050. IDA's results favour solar thermal over fuel-based boilers in 2050, however, which is opposite to the mix suggested by the ST and GCA variant energy systems. The heating solutions in 2035 show a larger structural difference between the variant energy systems. While the heating mix suggested by IDA, similar to 2050, is mainly based on heat pumps, ST followed to a lesser extent by GCA rely on fuel burning boilers for individual heating. Furthermore, IDA emphasizes on the role of solar thermal after heat pumps, but the other two variant energy systems see a little or no space for solar-based heating options in 2035.

Figure 5 shows district heating (DH) production in the different variant energy systems.

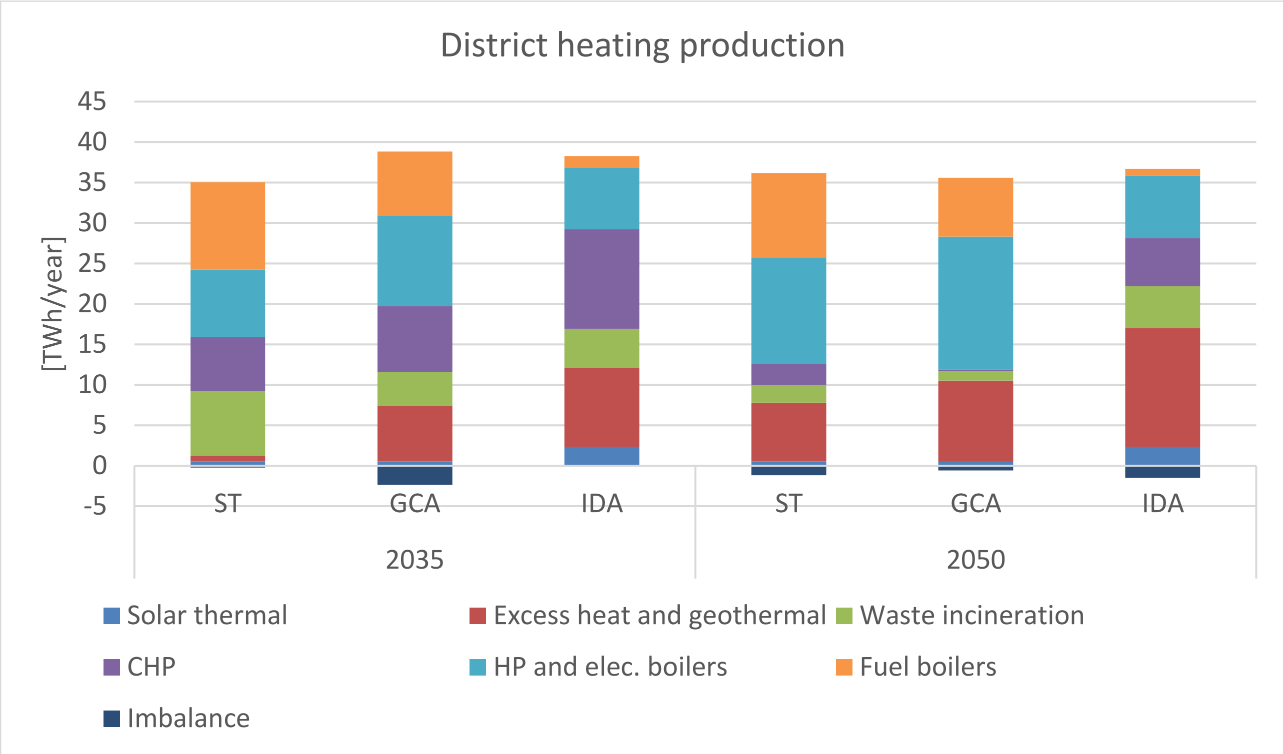

Figure 5 – District heating production for the different variant energy systems divided into types of production unit. Imbalance represent the surplus heat that is produced but cannot be utilised in the district heating system. HP is short heat pump

DH demand in three variant energy systems shows a more consistent projection for 2035 and 2050, compared to the electricity demand discussed earlier. However, the source of DH shows a structural difference in 2050, where IDA's solution ranks excess heat, geothermal first, while the other two variant energy systems prioritize heat pumps and electric boilers as the largest provider of DH. The other difference is the shift between fuel-based boilers and CHP, where IDA's CHP production units play a big role in DH. The differences in the choice of DH is partly due to the production of renewable fuels in the different variant energy systems.

3 Modelling testbed

As discussed in Section 2, reviewing the main findings of the three variant energy systems show some similarities and differences in the choice of available solutions as well as the share of each choice in the future Danish energy system across different variant energy systems. To better understand the implications of each variant energy system for the Danish energy sector, the three variant energy systems are modelled using the same tool, i.e., EnergyPLAN. The modelling platform built in EnergyPLAN will be the main starting point, a testbed, for analysing different technology and policy variants developed during the CORE project. By this approach, the project partners will be able to investigate the role of each selected technology or solution, with their specific assumptions and input parameters, under each testbed scenario. Energy policies have huge impacts on the society, investment requirements and planning, and R&D direction. Hence, analysing the role of each technology under different possible futures will help the experts and policy makers to explore different possibilities for the future Danish energy system quantitatively under different testbed setups.

The modelling testbed is made up by the 2020 reference model and the three variant energy systems. The overview of the modelling testbed used in WP1 of the CORE project can be seen in Figure 6.

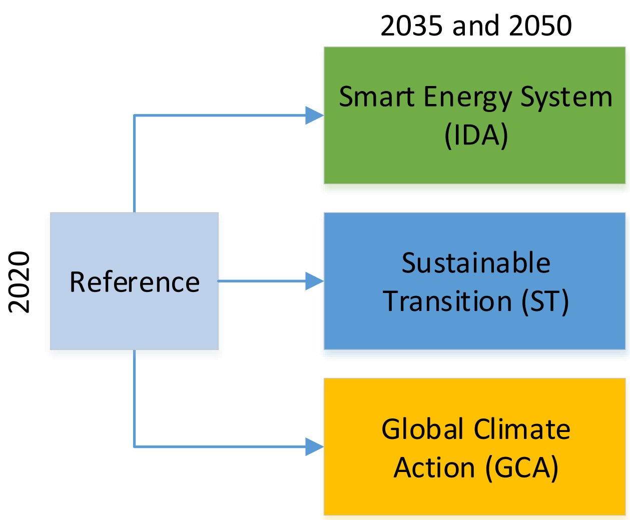

Figure 6 – The CORE modelling testbed for scenario development

Once the modelling platform is set up, the quantification of the scenarios takes place in two stages:

In stage one, the three variant energy system models are compared to each other in terms of costs, primary energy supply, emissions, amount of RES used, demands, etc. Emphasise will be put on biomass consumption, a core element in such energy systems setups.

In stage two, the three variant energy systems are tested with 'extreme' scenarios to determine the role of different technologies, including, but not limited to, thermal energy storage (TES) and power to gas (P2G) technologies. The extreme scenarios will be adaptations of the three variant energy system that emphasize some measures of an energy sector or a group of technologies. The extreme scenarios will be applied to those of the three variant energy systems, which are found most relevant for studying the role of a given technology.

For example, the IDA variant can prove as a suitable testbed for a scenario with increased electrification of both demand and supply side. Such a scenario will likely include high capacities of heat pumps and electric boilers in the district heating system, as well as an increased share of electric vehicles and electrolysers.

Another relevant scenario to test using the IDA variant is the simulation of increased shares of green gas (methane) in the energy system, as a replacement of natural gas. Such a scenario would imply less need for increased electricity production units such as wind and solar, but probably at the cost of reduced energy system flexibility, high shares of biomass consumption and high costs.

To join the public debate, some of the extreme scenarios will try to cover as many decarbonisation scenarios as possible, in the attempt to bring more light onto the most feasible solutions for achieving the Danish goals of being independent of fossil fuels by 2050.

The IDA variant may also be tested with:

- Assessing the role of P2G: This is to test the contribution of P2G in integrating wind and solar, as well as the balances with P2G via biomass gasification and P2L via CO_2 hydrogenation.
- Energy system flexibility of electrolysers: This should show how much electrolyser overcapacity is needed in the energy system to reduce the energy system costs and keep biomass consumption at a lowest level possible.
- Eliminating CHP: In this scenario all the CHP plants are removed, and technologies as heat pumps, power plants and boilers will supply the demands and ancillary services. This scenario should show how important CHP units are in the energy system
- Reducing costs in the transport sector: This can be achieved by adjusting the balances between electrification (via BEV) and electrofuels.
- Savings in buildings: A certain level of heat savings is accounted for 2035 and 2050, based on possible savings and mandates for energy efficiency in buildings. Such a scenario shall test how the energy system will perform if heat savings will not reach expected levels. Or the opposite, if the heat demands are reduced to less than expected. Here, the role of DH and individual heat pumps shall be analysed, as a new dimension.
- No commercial readiness and large-scale deployment of gasification technology: This scenario analyses how the energy system will perform without this element included, and how the transport and industrial demands will be fulfilled.
- Mass deployment of carbon capture and storage: This scenario shall analyse the costs of such a measure, that will likely entail the use of fossil fuels in a carbon neutral energy system.

All or some variant energy systems may be tested with:

- Different shares of renewable electricity resources: The ST and GCA variants have larger capacities of off-shore wind and PV, higher than the technical potentials. If these capacities are reduced to the technical potentials, or lower, similar to the IDA variant, these might prove to be considerably more expensive and/or more biomass intensive.
- Different shares of power plant and import/export levels: Denmark will play an important role in the future energy market, so the interaction with the neighbouring countries is a critical factor to account for. A market simulation should reveal how the technical setup of the energy system performs when it is subject to different levels of electricity prices on the Nord Pool Spot.

- Electrification of energy demand in industry: Industry still remains one of the most difficult sectors to decarbonise because of the variety of industries and different needs. Some industries require high temperature process heat, others require some type of high-quality liquid or gaseous fuel. In this scenario, it is considered that these demands can be replaced by electrification. This scenario would fit well with the general electrification scenario.
- Increased use of biomass: This scenario presents a high share of electricity and heat production via an increased use of biomass, that does not adhere to the biomass constraints listed earlier.

4 Accuracy of modelling ST and GCA in EnergyPLAN

To be done when final versions of the models are done

5 References

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6 Appendix A – ST2035

Input	Value	Reference	Note

6.1 Electricity production

Fixed electricity demand (TWh/year)	37.3	[5]	The fixed electricity demand includes the “classic demand” and the electricity demand for process heat pumps.
Flexible electricity demand (1 day) (TWh/year)	0	[5]	
Max-effect for flexible electricity demand (1 day) (MW)	-		

6.1.1 Wind (onshore)

Capacity (MW)	5,415	[5]	
Annual production (TWh)	17.16	[5]	

6.1.2 Offshore Wind

Capacity (MW)	4,546	[5]	Including offshore and near shore wind power capacity
Annual production (TWh)	19.98	[5]	Including offshore and near shore wind power production

6.1.3 Photo Voltaic

Capacity (MW)	3,450	[5]	
Annual production (TWh)	4.16	[5]	

6.1.4 Thermal power production

Large CHP units condensing power capacity (MW)	2,111	[5]	The difference between the condensing capacity and the central CHP capacity is unknown, and it is here assumed to be equal.
Large CHP units condensing power efficiency	0.328	[5]	The difference between the condensing efficiency and the CHP capacity is unknown, and it is here assumed to be equal. The efficiency is annual average.

6.2 District heating

6.2.1 Decentralised district heating

District heating production (TWh/year)	21.68	[5]	The amount of district heating produced by decentral plants. In EnergyPLAN 14.453 TWh has been allocated to district heating

			plants with heat-only technologies, in order to replicate the Energinet.dk scenario results.
Fuel boiler capacity (MW)	7,345		Assumed to be 120% of the simulated peak demand.
Fuel boiler efficiency	0.951	[5]	
Small-scale CHP - Electric capacity (MW)	2,029	[5]	Excl. waste incineration (waste incineration capacity is assumed to be 400 MW based on yearly production and assumed 8000 full load hours). Total incl. Waste from [5].
Small-scale CHP - Electric efficiency	0.324	[5]	The value represents the annual average efficiency.
Small-scale CHP - Thermal capacity (MW)	2,348	[5]	Based on average efficiencies and the electric capacity excl. waste incineration)
Small-scale CHP - Thermal efficiency	0.375	[5]	The value represents the annual average efficiency.
Fixed boiler share (%)	13		Used to replicate the yearly productions from Energinet.dks simulation
Grid loss	0.15	[5]	
Thermal storage capacity (GWh)	15	[5]	The total DH storage capacity is 30 GWh, and it is here assumed that it is split 50/50 between central and decentral plants.
Solar thermal input (TWh/year)	0.51	[5]	In EnergyPLAN 0.337 TWh has been allocated to district heating plants with heat-only technologies, in order to replicate the Energinet.dk scenario results.
Industrial CHP heat produced (TWh/year)	1.91	[5]	Includes all district heating produced from "Process – Kraftvarme" and "Process Fjernvarme", excl. heat coming from waste incineration the share of which is found based on assumed yearly efficiencies. In EnergyPLAN 1.271 TWh has been allocated to district heating plants with heat-only technologies, in order to replicate the Energinet.dk scenario results.
Industrial CHP electricity produced (TWh/year)	0.939	[5]	Includes all electricity produced from "Process – Kraftvarme", excl. electricity coming from waste incineration the share of which is found based on assumed yearly efficiencies
Industrial CHP heat demand (TWh/year)	1.04	[5]	Includes district heating demand for industries. In EnergyPLAN 0.691 TWh has been allocated to district heating plants with heat-only technologies, in order to replicate the Energinet.dk scenario results.
Compression heat pump electric capacity (MW)	27	[5]	
Compression heat pump COP	3.5	[5]	Yearly average COP

Compression heat pump maximum share of load	0.025		Used to replicate the DH production from the Energinet.dk simulations.
Electric boiler capacity (MW)	333	[5]	Divided between central and decentral based on total capacity and operation in each category.
Industrial excess heat (TWh/year)	0.72	[5]	The category "Overskudsvarme" from [5]. In EnergyPLAN 0.513 TWh has been allocated to district heating plants with heat-only technologies, in order to replicate the Energinet.dk scenario results.

6.2.2 Central district heating

District heating production (TWh/year)	13.09	[5]	The amount of district heating produced by central plants.
Fuel boiler capacity (MW)	4,435		Assumed to be 120% of the simulated peak demand.
Fuel boiler efficiency	0.901	[5]	
Large CHP - Electric capacity (MW)	2,111	[5]	The difference between the condensing capacity and the central CHP capacity is unknown, and it is here assumed to be equal
Large CHP - Electric efficiency	0.328	[5]	The difference between the condensing efficiency and the central CHP capacity is unknown, and it is here assumed to be equal
Large CHP - Thermal capacity (MW)	3,224	[5]	
Large CHP - Thermal efficiency	0.501	[5]	
Fixed boiler share	13.5		Used to replicate the yearly productions from Energinet.dks simulation
Grid loss	0.15	[5]	
Thermal storage capacity (GWh)	15	[5]	The total DH storage capacity is 30 GWh, and it is here assumed that it is split 50/50 between central and decentral plants.
Industrial CHP heat produced (TWh/year)	0	[5]	
Industrial CHP electricity produced (TWh/year)	0	[5]	
Industrial CHP heat demand (TWh/year)	0	[5]	
Compression heat pump electric capacity (MW)	468	[5]	
Compression heat pump COP	3.5	[5]	Yearly average COP
Compression heat pump maximum share of load	1		Used to replicate the DH production from the Energinet.dk simulations.
Electric boiler capacity (MW)	304	[5]	Divided between central and decentral based on total capacity and operation in each category.

6.3 Fuel Distribution and Consumption

6.3.1 Fuel Distribution for Heat and Power Production

These relations indicate for each of the plant type the fuel mix for used for each plant type (Coal / Oil / Gas / Biomass).

Small-scale CHP units	0 / 0.01 / 2.45 / 2.91	[5]	Based on fuel consumption from [5]. Oil is fixed.
Large CHP units	0 / 0 / 1.35 / 7.77	[5]	Based on fuel consumption from [5].
Boilers in decentralised district heating	0 / 0.58 / 3.88 / 5.44	[5]	Based on fuel consumption from [5]. Oil is fixed.
Boilers in central district heating	0 / 0.02 / 0.31 / 0.08	[5]	Based on fuel consumption from [5]. Oil is fixed.
Condensing operation of large CHP units	0 / 0 / 1.35 / 7.77	[5]	Based on fuel consumption from [5].
Condensing power plants	-	[5]	Based on fuel consumption from [5].

6.3.2 Additional fuel consumption (TWh/year)

Coal in industry	0	[5]	
Oil in industry	0.86	[5]	Includes gas consumption of “Process – Kraftvarme”, “Process – Fjernvarme” and “Process – Varme”
Gas in industry	9.32	[5]	Includes gas consumption of “Process – Kraftvarme”, “Process – Fjernvarme” and “Process – Varme”
Biomass in industry	2.74	[5]	Includes gas consumption of “Process – Kraftvarme”, “Process – Fjernvarme” and “Process – Varme”
Coal, various	0	[5]	
Oil, various	0	[5]	
Natural gas, various	0	[5]	

6.4 Transport

6.4.1 Conventional fuels (TWh/year)

JP (Jet fuel) - fossil	11.1	[5]	
Diesel - fossil	9.73	[5]	
Petrol - fossil	9.22	[5]	
Grid gas	1.82	[5]	
JP (Jet fuel) - biofuel	0	[5]	
Diesel - biofuel	0	[5]	

Petrol - biofuel	0	[5]	
JP (Jet fuel) - electrofuel	1.23	[5]	
Diesel - electrofuel	0	[5]	
Petrol - electrofuel	3.35	[5]	

6.4.2 Electricity (TWh/year)

Electricity - dump charge	1.72	[5]	
Electricity – smart charge	6.14	[5]	All electric cars are assumed to be smart charge (not V2G), based on mail from Anders Bavnhøj
Max. share of cars during peak demand	0.2	[3]	IDA2050 number
Capacity of grid to battery connection (MW)	8,000	[1]	Based on page 39 in “Systemperspektiv 2035 – Baggrundsrapport”.
Share of parked cars grid connected	0.7	[3]	IDA2050 number
Efficiency (grid to battery)	0.9	[3]	IDA2050 number
Battery storage capacity (GWh)	10.7	[1]	Based on page 39 in “Systemperspektiv 2035 – Baggrundsrapport”.

6.5 Waste conversion

6.5.1 Waste incineration in decentralised district heating

Waste input (TWh/year)	10.25	[5]	Incl. waste used for DH CHP, DH boilers, and process heat. In EnergyPLAN 6.833 TWh has been allocated to district heating plants with heat-only technologies, in order to replicate the Energinet.dk scenario results.
Thermal efficiency	0.737	[5]	
Electric efficiency	0.219	[5]	

6.5.2 Waste incineration in central district heating

Waste input (TWh/year)	0.4	[5]	
Thermal efficiency	0.976	[5]	
Electric efficiency	0	[5]	

6.6 Individual heating

6.6.1 Coal boilers

Fuel consumption (TWh/year)	0	[5]	
Efficiency	-		

6.6.2 Oil boilers

Fuel consumption (TWh/year)	0	[5]	
Efficiency	-		

6.6.3 Gas boilers

Fuel consumption (TWh/year)	6.43	[5]	
Efficiency	1	[5]	Annual average value
Solar thermal input (TWh/year)	0	[5]	

6.6.4 Biomass boilers

Fuel consumption (TWh/year)	8.43	[5]	
Efficiency	0.89	[5]	Annual average value
Solar thermal input (TWh/year)	0	[5]	

6.6.5 Heat pumps

Heat demand (TWh/year)	4.69	[5]	
COP	3.28	[5]	Annual average value
Solar thermal input (TWh/year)	0	[5]	

6.6.6 Electric heating

Heat demand (TWh/year)	0.57	[5]	Based on electricity demand for individual electric heating

6.7 Biogas production

Biogas production (TWh/year)	0	[5]	
Biogas upgrade to grid efficiency	-		

6.8 Gasification plant

Biomas input (TWh/year)	0	[5]	
Electricity share	-		
Steam share	-		
Steam efficiency	-		
Coldgas efficiency	-		
DH central share	-		

6.9 Electrolysers

Electrolyser capacity (MW-e)	0	[5]	
Electrolyser efficiency (Biomass hydrogenation)	-		

Electrolyser efficiency (Biogas hydrogenation)	-		

6.10 Biomass hydrogenation

Liquid fuel output (TWh/year)	0	[5]	
Liquid fuel efficiency	-		
Hydrogen share	-		
DH central share	-		

6.11 Biogas hydrogenation

Gas fuel output (TWh/year)	0	[5]	
Gas fuel efficiency	-		
Hydrogen share	-		
DH decentral share	-		

6.12 Electricity exchange

Transmission line capacity (MW)	10,435	[5]	

6.13 Balancing

CEEP regulation strategy	2,3,4,5	[3]	IDA2050 strategy

6.14 Distributions

The distributions do not influence the total annual energy, but allocates the total onto each hour of the year.

Input for distribution	**Reference**	**Note**
Electricity demand	[3]	IDA2050 distribution
Individual heat demand	[3]	IDA2050 distribution
Individual solar thermal	[3]	IDA2050 distribution
District heating demand	[3]	IDA2050 distribution
District heating solar thermal	[3]	IDA2050 distribution
Offshore Wind	[3]	IDA2050 distribution
Onshore Wind	[3]	IDA2050 distribution
Photo Voltaic	[3]	IDA2050 distribution

7 Appendix B – ST2050

Input	Value	Reference	Note

7.1 Electricity production

Fixed electricity demand (TWh/year)	38.85	[5]	The fixed electricity demand includes the "classic demand", minus the 10% that are assumed flexible within 1 day, the electricity used for biofuelsynthesis and the electricity demand for process heat pumps.
Flexible electricity demand (1 day) (TWh/year)	3.82	[5]	10% of the classic electricity demand is flexible within 1 day.
Max-effect for flexible electricity demand (1 day) (MW)	691	[5]	Assumed to be equal to peak demand if distribution for "classic demand" was used.

7.1.1 Wind (onshore)

Capacity (MW)	6,164	[5]	
Annual production (TWh)	17.72	[5]	

7.1.2 Offshore Wind

Capacity (MW)	8,585	[5]	Including offshore and near shore wind power capacity
Annual production (TWh)	37.23	[5]	Including offshore and near shore wind power production

7.1.3 Photo Voltaic

Capacity (MW)	9,850	[5]	
Annual production (TWh)	12.49	[5]	

7.1.4 Thermal power production

Large CHP units condensing power capacity (MW)	-	[5]	A total of 491 MW is installed at the central energy plants. However, due to operational nature of these plants, their production has been added as Industrial CHP in the central DH areas.
Large CHP units condensing power efficiency	-		
Condensing power plant capacity (MW)	-		
Condensing power plant efficiency	-		

7.2 District heating

7.2.1 Decentralised district heating

District heating production (TWh/year)	17.346	[5]	The amount of district heating produced by decentral plants.
Fuel boiler capacity (MW)	5,877		Assumed to be 120% of the simulated peak demand.
Fuel boiler efficiency	0.955	[5]	
Small-scale CHP - Electric capacity (MW)	1,476		Excl. waste incineration (waste incineration capacity is assumed to be 160 MW based on yearly production and assumed 8000 full load hours). Total incl. Waste from [5].
Small-scale CHP - Electric efficiency	0.374	[5]	The value represents the annual average efficiency.
Small-scale CHP - Thermal capacity (MW)	2,044	[5]	Based on average efficiencies and the electric capacity excl. waste incineration
Small-scale CHP - Thermal efficiency	0.518	[5]	The value represents the annual average efficiency.
Fixed boiler share (%)	23		Used to replicate the yearly productions from Energinet.dks simulation
Grid loss	0.15	[5]	
Thermal storage capacity (GWh)	15	[5]	The total DH storage capacity is 30 GWh, and it is here assumed that it is split 50/50 between central and decentral plants.
Solar thermal input (TWh/year)	0.51	[5]	
Industrial CHP heat produced (TWh/year)	1.879	[5]	Includes all district heating produced from "Process – Kraftvarme" and "Process Fjernvarme", excl. heat coming from waste incineration the share of which is found based on assumed yearly efficiencies
Industrial CHP electricity produced (TWh/year)	0.919	[5]	Includes all electricity produced from "Process – Kraftvarme", excl. electricity coming from waste incineration the share of which is found based on assumed yearly efficiencies
Industrial CHP heat demand (TWh/year)	1.507	[5]	Includes district heating demand for electrolysis in decentral energy plants, and the district heating demand for industries.
Compression heat pump electric capacity (MW)	27	[5]	
Compression heat pump COP	3.5	[5]	Yearly average COP
Compression heat pump maximum share of load	0.02		Used to replicate the DH production from the Energinet.dk simulations.
Electric boiler capacity (MW)	333	[5]	Divided between central and decentral based on total capacity and operation in each category.
Industrial excess heat (TWh/year)	0.72	[5]	The category "Overskudsvarme" from [5].

7.2.2 Central district heating

District heating production (TWh/year)	17.65	[5]	The amount of district heating produced by central plants.
Fuel boiler capacity (MW)	5,980		Assumed to be 120% of the simulated peak demand.
Fuel boiler efficiency	0.95	[5]	
Large CHP - Electric capacity (MW)	-	[5]	A total of 491 MW is installed at the central energy plants. However, due to operational nature of these plants, their production has been added as Industrial CHP in the central DH areas.
Large CHP - Electric efficiency	-	[5]	
Large CHP - Thermal capacity (MW)	-	[5]	
Large CHP - Thermal efficiency	-	[5]	
Fixed boiler share	0		
Grid loss	0.15	[5]	
Thermal storage capacity (GWh)	15	[5]	The total DH storage capacity is 30 GWh, and it is here assumed that it is split 50/50 between central and decentral plants.
Industrial CHP heat produced (TWh/year)	0	[5]	The yearly net heat demand for the CHP units at the central energy plants are negative, as excess heat from other processes are used in the steam turbines to produce electricity. Due to the availability of data this has been simulated by including the thermal productions from the individual processes and adding a thermal demand for the industrial CHP.
Industrial CHP electricity produced (TWh/year)	1.218	[5]	Electricity produced from CHP units at the central energy plants
Industrial CHP heat demand (TWh/year)	1.8	[5]	The net heat consumption of the CHP unit at the central energy plants.
Compression heat pump electric capacity (MW)	703	[5]	
Compression heat pump COP	3.5	[5]	Yearly average COP
Compression heat pump maximum share of load	0.7		Used to replicate the DH production from the Energinet.dk simulations.
Electric boiler capacity (MW)	304	[5]	Divided between central and decentral based on total capacity and operation in each category.

7.3 Fuel Distribution and Consumption

7.3.1 Fuel Distribution for Heat and Power Production

These relations indicate for each of the plant type the fuel mix for used for each plant type (Coal / Oil / Gas / Biomass).

Small-scale CHP units	0 / 0 / 6.58 / 0.91	[5]	Based on fuel consumption from [5].
Large CHP units	-	[5]	Based on fuel consumption from [5].
Boilers in decentralised district heating	0 / 0.19 / 3.46 / 5.55	[5]	Based on fuel consumption from [5]. The oil demand is satisfied with electrofuels
Boilers in central district heating	0 / 0 / 0.55 / 0.02	[5]	Based on fuel consumption from [5].
Condensing operation of large CHP units	-	[5]	Based on fuel consumption from [5].
Condensing power plants	-	[5]	Based on fuel consumption from [5].

7.3.2 Additional fuel consumption (TWh/year)

Coal in industry	0	[5]	
Oil in industry	0	[5]	
Gas in industry	5.75	[5]	Includes gas consumption of "Process – Kraftvarme", "Process – Fjernvarme" and "Process – Varme"
Biomass in industry	0	[5]	
Coal, various	0	[5]	
Oil, various	0	[5]	
Natural gas, various	0	[5]	

7.4 Transport

7.4.1 Conventional fuels (TWh/year)

JP (Jet fuel) - fossil	0	[5]	
Diesel - fossil	0	[5]	
Petrol - fossil	0	[5]	
Grid gas	7.29	[5]	
JP (Jet fuel) - biofuel	0	[5]	
Diesel - biofuel	0	[5]	
Petrol - biofuel	0	[5]	
JP (Jet fuel) - electrofuel	11.17	[5]	
Diesel - electrofuel	0	[5]	
Petrol - electrofuel	4.87	[5]	

7.4.2 Electricity (TWh/year)

Electricity - dump charge	5.37	[5]	
Electricity – smart charge	11.51	[5]	All electric cars are assumed to be smart charge (not V2G), based on mail from Anders Bavnhøj

Max. share of cars during peak demand	0.2	[3]	IDA2050 number
Capacity of grid to battery connection (MW)	15,000	[1]	Based on page 39 in "Systemperspektiv 2035 – Baggrundsrapport".
Share of parked cars grid connected	0.7	[3]	IDA2050 number
Efficiency (grid to battery)	0.9	[3]	IDA2050 number
Battery storage capacity (GWh)	20	[1]	Based on page 39 in "Systemperspektiv 2035 – Baggrundsrapport".

7.5 Waste conversion

7.5.1 Waste incineration in decentralised district heating

Waste input (TWh/year)	2.26	[5]	Incl. waste used for DH CHP, DH boilers, and process heat
Thermal efficiency	0.84	[5]	
Electric efficiency	0.13	[5]	

7.5.2 Waste incineration in central district heating

Waste input (TWh/year)	0.34	[5]	
Thermal efficiency	0.976	[5]	
Electric efficiency	0	[5]	

7.6 Individual heating

7.6.1 Coal boilers

Fuel consumption (TWh/year)	0	[5]	
Efficiency	-		

7.6.2 Oil boilers

Fuel consumption (TWh/year)	0	[5]	
Efficiency	-		

7.6.3 Gas boilers

Fuel consumption (TWh/year)	0.2	[5]	
Efficiency	1	[5]	Annual average value
Solar thermal input (TWh/year)	0	[5]	

7.6.4 Biomass boilers

Fuel consumption (TWh/year)	2.64	[5]	
Efficiency	0.89	[5]	Annual average value
Solar thermal input (TWh/year)	0		

7.6.5 Heat pumps

Heat demand (TWh/year)	11.365	[5]	
COP	3.136	[5]	Annual average value
Solar thermal input (TWh/year)	1.367	[5]	

7.6.6 Electric heating

Heat demand (TWh/year)	0.26	[5]	Based on electricity demand for individual electric heating

7.7 Biogas production

Biogas production (TWh/year)	18.86	[5]	
Biogas upgrade to grid efficiency	0.733	[5]	Based on the produced amount minus the biogas to methanation, and the amount sent to the grid

7.8 Gasification plant

Biomas input (TWh/year)	13.42	[5]	
Electricity share	0.017	[5]	
Steam share	0.13	[5]	Total efficiency from [5]
Steam efficiency	1.25	[5]	Total efficiency from [5]
Coldgas efficiency	0.839	[5]	Total efficiency from [5]
DH central share	0.239	[5]	

7.9 Electrolysers

Electrolyser capacity (MW-e)	823	[5]	
Electrolyser efficiency (Biomass hydrogenation)	0.905	[5]	
Electrolyser efficiency (Biogas hydrogenation)	0.83	[5]	

7.10 Biomass hydrogenation

Liquid fuel output (TWh/year)	11.12	[5]	
Liquid fuel efficiency	0.7746	[5]	
Hydrogen share	0.3	[5]	
DH central share	0.213	[5]	

7.11 Biogas hydrogenation

Gas fuel output (TWh/year)	1.18	[5]	

Gas fuel efficiency	0.85	[5]	
Hydrogen share	0.267	[5]	
DH decentral share	0.2	[5]	

7.12 Electricity exchange

Transmission line capacity (MW)	10,435	[5]	

7.13 Balancing

CEEP regulation strategy	2,3,4,5	[3]	IDA2050 strategy

7.14 Distributions

The distributions do not influence the total annual energy, but allocates the total onto each hour of the year.

Input for distribution	Reference	Note
Electricity demand	[3]	IDA2050 distribution
Individual heat demand	[3]	IDA2050 distribution
Individual solar thermal	[3]	IDA2050 distribution
District heating demand	[3]	IDA2050 distribution
District heating solar thermal	[3]	IDA2050 distribution
Offshore Wind	[3]	IDA2050 distribution
Onshore Wind	[3]	IDA2050 distribution
Photo Voltaic	[3]	IDA2050 distribution

8 Appendix C – GCA2035

Input	Value	Reference	Note

8.1 Electricity production

Fixed electricity demand (TWh/year)	35.28	[5]	The fixed electricity demand includes the “classic demand”, minus the 10% that are assumed flexible within 1 day, the electricity used for biofuelsynthesis and the electricity demand for process heat pumps.
Flexible electricity demand (1 day) (TWh/year)	3.72	[5]	10% of the classic electricity demand is flexible within 1 day.
Max-effect for flexible electricity demand (1 day) (MW)	638	[5]	Assumed to be equal to peak demand if distribution for “classic demand” was used.

8.1.1 Wind (onshore)

Capacity (MW)	5,414	[5]	Resulting capacity factor is 0.36
Annual production (TWh)	16.95	[5]	

8.1.2 Offshore Wind

Capacity (MW)	5,796	[5]	Resulting capacity factor is 0.51
Annual production (TWh)	25.50	[5]	

8.1.3 Photo Voltaic

Capacity (MW)	4250	[5]	Resulting capacity factor is 0.16
Annual production (TWh)	5.19	[5]	

8.1.4 Thermal power production

Large CHP units condensing power capacity (MW)	2,491	[5]	The difference between the condensing capacity and the central CHP capacity is unknown, and it is here assumed to be equal.
Large CHP units condensing power efficiency	0.432	[5]	The difference between the condensing efficiency and the CHP capacity is unknown, and it is here assumed to be equal. The efficiency is annual average.

8.2 District heating

8.2.1 Decentralised district heating

District heating production (TWh/year)	18.16	[5]	The amount of district heating produced by decentral plants. In EnergyPLAN 5.45

			TWh has been allocated to district heating plants with heat-only technologies, in order to replicate the Energinet.dk scenario results.
Fuel boiler capacity (MW)	6150		Assumed to be 120% of the simulated peak demand.
Fuel boiler efficiency	0.917	[5]	
Small-scale CHP - Electric capacity (MW)	1,664	[5]	Excl. waste incineration (waste incineration capacity is assumed to be 220 MW based on yearly production and assumed 8000 full load hours). Total incl. Waste from [5].
Small-scale CHP - Electric efficiency	0.331	[5]	The value represents the annual average efficiency.
Small-scale CHP - Thermal capacity (MW)	2,859	[5]	Based on average efficiencies and the electric capacity excl. waste incineration)
Small-scale CHP - Thermal efficiency	0.515	[5]	The value represents the annual average efficiency.
Fixed boiler share (%)	15		Used to replicate the yearly productions from Energinet.dks simulation
Grid loss	0.15	[5]	
Thermal storage capacity (GWh)	15	[5]	The total DH storage capacity is 30 GWh, and it is here assumed that it is split 50/50 between central and decentral plants.
Solar thermal input (TWh/year)	0.51	[5]	In EnergyPLAN 015 TWh has been allocated to district heating plants with heat-only technologies, in order to replicate the Energinet.dk scenario results.
Industrial CHP heat produced (TWh/year)	1.6	[5]	Includes all district heating produced from “Process – Kraftvarme” and “Process Fjernvarme”, excl. heat coming from waste incineration the share of which is found based on assumed yearly efficiencies. In EnergyPLAN 0.48 TWh has been allocated to district heating plants with heat-only technologies, in order to replicate the Energinet.dk scenario results.
Industrial CHP electricity produced (TWh/year)	0.791	[5]	Includes all electricity produced from “Process – Kraftvarme”, excl. electricity coming from waste incineration the share of which is found based on assumed yearly efficiencies
Industrial CHP heat demand (TWh/year)	2.21	[5]	Includes district heating demand for industries. In EnergyPLAN 0.66 TWh has been allocated to district heating plants with heat-only technologies, in order to replicate the Energinet.dk scenario results.
Compression heat pump electric capacity (MW)	306	[5]	
Compression heat pump COP	3.5	[5]	Yearly average COP

Compression heat pump maximum share of load	0.08		Used to replicate the DH production from the Energinet.dk simulations.
Electric boiler capacity (MW)	21	[5]	Divided between central and decentral based on total capacity and operation in each category.
Industrial excess heat (TWh/year)	0.8	[5]	The category "Overskudsvarme" from [5]. In EnergyPLAN 0.26 TWh has been allocated to district heating plants with heat-only technologies, in order to replicate the Energinet.dk scenario results.

8.2.2 Central district heating

District heating production (TWh/year)	18.3	[5]	The amount of district heating produced by central plants.
Fuel boiler capacity (MW)	6,200		Assumed to be 120% of the simulated peak demand.
Fuel boiler efficiency	0.901	[5]	
Large CHP - Electric capacity (MW)	2,491	[5]	The difference between the condensing capacity and the central CHP capacity is unknown, and it is here assumed to be equal
Large CHP - Electric efficiency	0.331	[5]	The difference between the condensing efficiency and the central CHP capacity is unknown, and it is here assumed to be equal
Large CHP - Thermal capacity (MW)	1972	[5]	
Large CHP - Thermal efficiency	0.342	[5]	
Fixed boiler share	0		Used to replicate the yearly productions from Energinet.dks simulation
Grid loss	0.15	[5]	
Thermal storage capacity (GWh)	15	[5]	The total DH storage capacity is 30 GWh, and it is here assumed that it is split 50/50 between central and decentral plants.
Industrial CHP heat produced (TWh/year)	0	[5]	
Industrial CHP electricity produced (TWh/year)	0	[5]	
Industrial CHP heat demand (TWh/year)	0.261	[5]	
Compression heat pump electric capacity (MW)	555	[5]	
Compression heat pump COP	3.5	[5]	Yearly average COP
Compression heat pump maximum share of load	0.5		Used to replicate the DH production from the Energinet.dk simulations.
Electric boiler capacity (MW)	465	[5]	Divided between central and decentral based on total capacity and operation in each category.

8.3 Fuel Distribution and Consumption

8.3.1 Fuel Distribution for Heat and Power Production

These relations indicate for each of the plant type the fuel mix for used for each plant type (Coal / Oil / Gas / Biomass).

Small-scale CHP units	0 / 0.01 / 3.47 / 3.04	[5]	Based on fuel consumption from [5]. Oil is fixed.
Large CHP units	0 / 0 / 1.46 / 11.11	[5]	Based on fuel consumption from [5].
Boilers in decentralised district heating	0 / 0.091 / 1.21 / 5.94	[5]	Based on fuel consumption from [5]. Oil is fixed.
Boilers in central district heating	0 / 0.02 / 0.28 / 0.03	[5]	Based on fuel consumption from [5]. Oil is fixed.
Condensing operation of large CHP units	0 / 0 / 1.46 / 11.11	[5]	Based on fuel consumption from [5].
Condensing power plants	-	[5]	Based on fuel consumption from [5].

8.3.2 Additional fuel consumption (TWh/year)

Coal in industry	0	[5]	
Oil in industry	0.43	[5]	Includes gas consumption of “Process – Kraftvarme”, “Process – Fjernvarme” and “Process – Varme”
Gas in industry	6.74	[5]	Includes gas consumption of “Process – Kraftvarme”, “Process – Fjernvarme” and “Process – Varme”
Biomass in industry	1.59	[5]	Includes gas consumption of “Process – Kraftvarme”, “Process – Fjernvarme” and “Process – Varme”
Coal, various	0	[5]	
Oil, various	0	[5]	
Natural gas, various	0	[5]	

8.4 Transport

8.4.1 Conventional fuels (TWh/year)

JP (Jet fuel) - fossil	11.1	[5]	
Diesel - fossil	7.82	[5]	
Petrol - fossil	9.22	[5]	
Grid gas	2.85	[5]	
JP (Jet fuel) - biofuel	0	[5]	
Diesel - biofuel	0	[5]	

Petrol - biofuel	0	[5]	
JP (Jet fuel) - electrofuel	1.23	[5]	
Diesel - electrofuel	0	[5]	
Petrol - electrofuel	3.36	[5]	

8.4.2 Electricity (TWh/year)

Electricity - dump charge	2.18	[5]	
Electricity – smart charge	6.14	[5]	All electric cars are assumed to be smart charge (not V2G), based on mail from Anders Bavnhøj
Max. share of cars during peak demand	0.2	[3]	IDA2050 number
Capacity of grid to battery connection (MW)	8,000	[1]	Based on page 39 in "Systemperspektiv 2035 – Baggrundsrapport".
Share of parked cars grid connected	0.7	[3]	IDA2050 number
Efficiency (grid to battery)	0.9	[3]	IDA2050 number
Battery storage capacity (GWh)	10.7	[1]	Based on page 39 in "Systemperspektiv 2035 – Baggrundsrapport".

8.5 Waste conversion

8.5.1 Waste incineration in decentralised district heating

Waste input (TWh/year)	5.18	[5]	Incl. waste used for DH CHP, DH boilers, and process heat. In EnergyPLAN 1.554 TWh has been allocated to district heating plants with heat-only technologies, in order to replicate the Energinet.dk scenario results.
Thermal efficiency	0.76	[5]	
Electric efficiency	0.178	[5]	

8.5.2 Waste incineration in central district heating

Waste input (TWh/year)	0.251	[5]	
Thermal efficiency	0.976	[5]	
Electric efficiency	0	[5]	

8.6 Individual heating

8.6.1 Coal boilers

Fuel consumption (TWh/year)	0	[5]	
Efficiency	-		

8.6.2 Oil boilers

Fuel consumption (TWh/year)	0	[5]	
Efficiency	-		

8.6.3 Gas boilers

Fuel consumption (TWh/year)	2.84	[5]	
Efficiency	1	[5]	Annual average value
Solar thermal input (TWh/year)	0	[5]	

8.6.4 Biomass boilers

Fuel consumption (TWh/year)	6.48	[5]	
Efficiency	0.89	[5]	Annual average value
Solar thermal input (TWh/year)	0	[5]	

8.6.5 Heat pumps

Heat demand (TWh/year)	8.44	[5]	
COP	3.12	[5]	Annual average value
Solar thermal input (TWh/year)	0.41	[5]	

8.6.6 Electric heating

Heat demand (TWh/year)	0.29	[5]	Based on electricity demand for individual electric heating

8.7 Biogas production

Biomass input (TWh/year)	26.24	[5]	
Biogas production (TWh/year)	18.89	[5]	
Biogas upgrade to grid efficiency	0.862	[5]	
Input to gas grid (TWh/year)	16	[5]	Amount purified and sent to the grid

8.8 Gasification plant

Biomas input (TWh/year)	13.51	[5]	
Electricity share	0.0175	[5]	
Steam share	0.13	[5]	Total efficiency from [5]
Steam efficiency	1.25	[5]	Total efficiency from [5]
Coldgas efficiency	0.843	[5]	Total efficiency from [5]
DH central share	0.24	[5]	

8.9 Electrolysers

Electrolyser capacity (MW-e)	685	[5]	

Electrolyser efficiency (Biomass hydrogenation)	0.89	[5]	
Electrolyser efficiency (Biogas hydrogenation)	0.82	[5]	

8.10 Biomass hydrogenation

Liquid fuel output (TWh/year)	9.73	[5]	
Liquid fuel efficiency	0.764	[5]	
Hydrogen share	0.205	[5]	
DH central share	0.215	[5]	

8.11 Biogas hydrogenation

Gas fuel output (TWh/year)	0.41	[5]	
Gas fuel efficiency	0.8	[5]	
Hydrogen share	0.365	[5]	
DH decentral share	-	[5]	

8.12 Electricity exchange

Transmission line capacity (MW)	12,735	[5]	

8.13 Balancing

CEEP regulation strategy	2,3,4,5	[3]	IDA2050 strategy

8.14 Distributions

The distributions do not influence the total annual energy, but allocates the total onto each hour of the year.

Input for distribution	**Reference**	**Note**
Electricity demand	[3]	IDA2050 distribution
Individual heat demand	[3]	IDA2050 distribution
Individual solar thermal	[3]	IDA2050 distribution
District heating demand	[3]	IDA2050 distribution
District heating solar thermal	[3]	IDA2050 distribution
Offshore Wind	[3]	IDA2050 distribution
Onshore Wind	[3]	IDA2050 distribution
Photo Voltaic	[3]	IDA2050 distribution

9 Appendix D – GCA2050

Input	Value	Reference	Note

9.1 Electricity production

Input	Value	Reference	Note
Fixed electricity demand (TWh/year)	39.12	[5]	The fixed electricity demand includes the “classic demand”, minus the 10% that are assumed flexible within 1 day, the electricity used for biofuelsynthesis and the electricity demand for process heat pumps.
Flexible electricity demand (1 day) (TWh/year)	3.91	[5]	10% of the classic electricity demand is flexible within 1 day.
Max-effect for flexible electricity demand (1 day) (MW)	705	[5]	Assumed to be equal to peak demand if distribution for “classic demand” was used.

9.1.1 Wind (onshore)

Input	Value	Reference	Note
Capacity (MW)	6,164	[5]	Resulting capacity factor is 0.27
Annual production (TWh)	14.55	[5]	

9.1.2 Offshore Wind

Input	Value	Reference	Note
Capacity (MW)	12,785	[5]	Including offshore and near shore wind power capacity. Capacity factor is 0.46
Annual production (TWh)	50.59	[5]	

9.1.3 Photo Voltaic

Input	Value	Reference	Note
Capacity (MW)	11,450	[5]	Resulting capacity factor is 0.16
Annual production (TWh)	14.57	[5]	

9.1.4 Thermal power production

Input	Value	Reference	Note
Large CHP units condensing power capacity (MW)	-	[5]	A total of 491 MW is installed at the central energy plants. However, due to operational nature of these plants, their production has been added as Industrial CHP in the central DH areas.
Large CHP units condensing power efficiency	-		
Condensing power plant capacity (MW)	-		
Condensing power plant efficiency	-		

9.2 District heating

9.2.1 Decentralised district heating

District heating production (TWh/year)	17.5	[5]	The amount of district heating produced by decentral plants. In EnergyPLAN 8.75 TWh has been allocated to district heating plants with heat-only technologies, in order to replicate the Energinet.dk scenario results.
Fuel boiler capacity (MW)	5,928		Assumed to be 120% of the simulated peak demand.
Fuel boiler efficiency	0.92	[5]	Defined using the heat production divided by the amount of fuel used.
Small-scale CHP - Electric capacity (MW)	1,586		Excl. waste incineration (waste incineration capacity is assumed to be 160 MW based on yearly production and assumed 8000 full load hours). Total incl. Waste from [5].
Small-scale CHP - Electric efficiency	0.352	[5]	The value represents the annual average efficiency.
Small-scale CHP - Thermal capacity (MW)	2,370	[5]	Based on average efficiencies and the electric capacity excl. waste incineration)
Small-scale CHP - Thermal efficiency	0.526	[5]	The value represents the annual average efficiency.
Fixed boiler share (%)	30		Used to replicate the yearly productions from Energinet.dks simulation. It represents the share of hours when boilers should not operate.
Grid loss	0.15	[5]	
Thermal storage capacity (GWh)	15	[5]	The total DH storage capacity is 30 GWh, and it is here assumed that it is split 50/50 between central and decentral plants.
Solar thermal input (TWh/year)	0.51	[5]	Split equally between group 1 and 2 to achieve results similar to the energinet data
Industrial CHP heat produced (TWh/year)	1.18	[5]	Includes all district heating produced from "Process – Kraftvarme" and "Process Fjernvarme", excl. heat coming from waste incineration the share of which is found based on assumed yearly efficien-cies. In EnergyPLAN 0.59 TWh has been allocated to district heating plants with heat-only technologies, in order to repli-cate the Energinet.dk scenario results.
Industrial CHP electricity produced (TWh/year)	0.254	[5]	Includes all electricity produced from "Process – Kraftvarme", excl. electricity coming from waste incineration the share of which is found based on assumed yearly efficiencies
Industrial CHP heat demand (TWh/year)	1.26	[5]	Includes district heating demand for in-dustries. In EnergyPLAN 0.63 TWh has

			been allocated to district heating plants with heat-only technologies, in order to replicate the Energinet.dk scenario re-sults.
Compression heat pump electric capacity (MW)	306	[5]	
Compression heat pump COP	3.5	[5]	Yearly average COP
Compression heat pump maximum share of load	0.57		Used to replicate the DH production from the Energinet.dk simulations.
Electric boiler capacity (MW)	21	[5]	Divided between central and decentral based on total capacity and operation in each category.
Industrial excess heat (TWh/year)	2.69	[5]	The category "Overskudsvarme" from [5]. This heat is split in its turn in 2 group, to better simulate the energi net scenarios. Group 1 has 2.3 TWh and group 2 has 0.39 TWh

9.2.2 Central district heating

District heating production (TWh/year)	17.497	[5]	The amount of district heating produced by central plants.
Fuel boiler capacity (MW)	5,928		Assumed to be 120% of the simulated peak demand.
Fuel boiler efficiency	0.891	[5]	Defined using the heat production divided by the amount of fuel used.
Large CHP - Electric capacity (MW)	-	[5]	A total of 491 MW is installed at the central energy plants. However, due to operational nature of these plants, their production has been added as Industrial CHP in the central DH areas.
Large CHP - Electric efficiency	-		
Large CHP - Thermal capacity (MW)	-		
Large CHP - Thermal efficiency	-		
Fixed boiler share	0		Used to replicate the yearly productions from Energinet.dks simulation. It represents the share of hours when boilers should not operate.
Grid loss	0.15	[5]	
Thermal storage capacity (GWh)	15	[5]	The total DH storage capacity is 30 GWh, and it is here assumed that it is split 50/50 between central and decentral plants.
Industrial CHP heat produced (TWh/year)	0	[5]	The yearly net heat demand for the CHP units at the central energy plants are negative, as excess heat from other processes are used in the steam turbines to produce electricity. Due to the availability of data this has been simulated

			by including the thermal productions from the individual processes and adding a thermal demand for the industrial CHP.
Industrial CHP electricity produced (TWh/year)	0.921	[5]	Electricity produced from CHP units at the central energy plants.
Industrial CHP heat demand (TWh/year)	1.494	[5]	The net heat consumption of the CHP unit at the central energy plants.
Compression heat pump electric capacity (MW)	714	[5]	
Compression heat pump COP	3.5	[5]	Yearly average COP
Compression heat pump maximum share of load	0.81		Used to replicate the DH production from the Energinet.dk simulations.
Electric boiler capacity (MW)	465	[5]	Divided between central and decentral based on total capacity and operation in each category.

9.3 Fuel Distribution and Consumption

9.3.1 Fuel Distribution for Heat and Power Production

These relations indicate for each of the plant type the fuel mix for used for each plant type (Coal / Oil / Gas / Biomass).

Small-scale CHP units	0 / 0 / 2 / 0.73	[5]	Based on fuel consumption from [5].
Large CHP units	-	[5]	Based on fuel consumption from [5].
Boilers in decentralised district heating	0 / 0.06 / 1.19 / 5.61	[5]	Based on fuel consumption from [5]. The oil demand is satisfied with electrofuels
Boilers in central district heating	0 / 0 / 0.15 / 0.02	[5]	Based on fuel consumption from [5].
Condensing operation of large CHP units	-	[5]	Based on fuel consumption from [5].
Condensing power plants	-	[5]	Based on fuel consumption from [5].

9.3.2 Additional fuel consumption (TWh/year)

Coal in industry	0	[5]	
Oil in industry	0	[5]	
Gas in industry	4.58	[5]	Includes gas consumption of “Process – Kraftvarme”, “Process – Fjernvarme” and “Process – Varme”
Biomass in industry	0	[5]	
Coal, various	0	[5]	
Oil, various	0	[5]	
Natural gas, various	0	[5]	

9.4 Transport

9.4.1 Conventional fuels (TWh/year)

JP (Jet fuel) - fossil	0	[5]	
Diesel - fossil	0	[5]	
Petrol - fossil	0	[5]	
Grid gas	8.16	[5]	
JP (Jet fuel) - biofuel	0	[5]	
Diesel - biofuel	0	[5]	
Petrol - biofuel	0	[5]	
JP (Jet fuel) - electrofuel	11.17	[5]	
Diesel - electrofuel	0	[5]	
Petrol - electrofuel	2.78	[5]	

9.4.2 Electricity (TWh/year)

Electricity - dump charge	5.94	[5]	
Electricity – smart charge	11.51	[5]	All electric cars are assumed to be smart charge (not V2G), based on mail from Anders Bavnhøj
Max. share of cars during peak demand	0.2	[3]	IDA2050 number
Capacity of grid to battery connection (MW)	15,000	[1]	Based on page 39 in "Systemperspektiv 2035 – Baggrundsrapport".
Share of parked cars grid connected	0.7	[3]	IDA2050 number
Efficiency (grid to battery)	0.9	[3]	IDA2050 number
Battery storage capacity (GWh)	20	[1]	Based on page 39 in "Systemperspektiv 2035 – Baggrundsrapport".

9.5 Waste conversion

9.5.1 Waste incineration in decentralised district heating

Waste input (TWh/year)	1.12	[5]	Incl. waste used for DH CHP, DH boilers, and process heat
Thermal efficiency	0.894	[5]	
Electric efficiency	0.076	[5]	

9.5.2 Waste incineration in central district heating

Waste input (TWh/year)	0.169	[5]	
Thermal efficiency	0.976	[5]	
Electric efficiency	0.09	[5]	

9.6 Individual heating

9.6.1 Coal boilers

Fuel consumption (TWh/year)	0	[5]	
Efficiency	-		

9.6.2 Oil boilers

Fuel consumption (TWh/year)	0	[5]	
Efficiency	-		

9.6.3 Gas boilers

Fuel consumption (TWh/year)	0.2	[5]	
Efficiency	1	[5]	Annual average value
Solar thermal input (TWh/year)	0	[5]	

9.6.4 Biomass boilers

Fuel consumption (TWh/year)	2.64	[5]	
Efficiency	0.89	[5]	Annual average value
Solar thermal input (TWh/year)	0	[5]	

9.6.5 Heat pumps

Heat demand (TWh/year)	11.36	[5]	
COP	3.14	[5]	Annual average value
Solar thermal input (TWh/year)	1.367	[5]	

9.6.6 Electric heating

Heat demand (TWh/year)	0.26	[5]	Based on electricity demand for individual electric heating

9.7 Biogas production

Biomass input (TWh/year)	26.24	[5]	
Biogas production (TWh/year)	18.78	[5]	
Biogas upgrade to grid efficiency	0.785	[5]	Based on the produced amount minus the biogas to methanation, and the amount sent to the grid
Input to gas grid (TWh/year)	5.19	[5]	Amount purified and sent to the grid

9.8 Gasification plant

Biomas input (TWh/year)	13.14	[5]	
Electricity share	0.0175	[5]	
Steam share	0.13	[5]	Total efficiency from [5]

Steam efficiency	1.25	[5]	Total efficiency from [5]
Coldgas efficiency	0.846	[5]	Total efficiency from [5]
DH central share	0.24	[5]	

9.9 Electrolysers

Electrolyser capacity (MW-e)	1938	[5]	
Electrolyser efficiency (Biomass hydrogenation)	0.891	[5]	
Electrolyser efficiency (Biogas hydrogenation)	0.868	[5]	

9.10 Biomass hydrogenation

Liquid fuel output (TWh/year)	10.72	[5]	
Liquid fuel efficiency	0.764	[5]	
Hydrogen share	0.298	[5]	
DH central share	0.215	[5]	

9.11 Biogas hydrogenation

Gas fuel output (TWh/year)	15.33	[5]	
Gas fuel efficiency	0.8	[5]	
Hydrogen share	0.365	[5]	
DH decentral share	0.1	[5]	

9.12 Electricity exchange

Transmission line capacity (MW)	12,735	[5]	

9.13 Balancing

CEEP regulation strategy	2,3,4,5	[3]	IDA2050 strategy

9.14 Distributions

The distributions do not influence the total annual energy, but allocates the total onto each hour of the year.

Input for distribution	**Reference**	**Note**
Electricity demand	[3]	IDA2050 distribution
Individual heat demand	[3]	IDA2050 distribution
Individual solar thermal	[3]	IDA2050 distribution
District heating demand	[3]	IDA2050 distribution
District heating solar thermal	[3]	IDA2050 distribution

Offshore Wind	[3]	IDA2050 distribution
Onshore Wind	[3]	IDA2050 distribution
Photo Voltaic	[3]	IDA2050 distribution

10 Appendix E – 2020 reference system

Input	Value	Reference	Note

10.1 Electricity production

Input	Value	Reference	Note
Electricity demand (TWh/year)	33.25	[6]	Electricity demand including grid losses, excluding demands for heating, cooling, and transport.

10.1.1 Wind (onshore)

Input	Value	Reference	Note
Capacity (MW)	4,232	[7]	
Annual production (TWh)	10.43	[6]	

10.1.2 Offshore Wind

Input	Value	Reference	Note
Capacity (MW)	2051	[7]	
Annual production (TWh)	8.62	[6]	

10.1.3 Photo Voltaic

Input	Value	Reference	Note
Capacity (MW)	952	[7]	
Annual production (TWh)	1.01	[6]	

10.1.4 River Hydro

Input	Value	Reference	Note
Capacity (MW)	6.88	[8]	
Annual production (TWh)	0.02	[6]	

10.1.5 Thermal power production

Input	Value	Reference	Note
Large CHP units condensing power capacity (MW)	3,112	[7]	
Large CHP units condensing power efficiency	0.363	[6]	The value represents the expected annual average efficiency based on fuel consumption and production of these units as found in [6].
Reserve power plant capacity (MW)	557	[7]	
Condensing power plant efficiency	0.239	[9]	The value represents the annual average efficiency.

10.2 District heating

10.2.1 Decentralised district heating

Input	Value	Reference	Note
District heating production (TWh/year)	16.22	[6], [9]	The distribution of heat demand between decentralised and central district heating areas is from [9]. The total is from [6].

Fuel boiler capacity (MW)	6,354	[9]	Excl. units using biogas.
Fuel boiler efficiency	0.983	[9]	
Small-scale CHP - Electric capacity (MW)	876	[7], [9]	Excl. waste incineration units. The waste incineration capacity based on [9].
Small-scale CHP - Electric efficiency	0.34	[6]	The value represents the expected annual average efficiency based on fuel consumption and production of these units as found in [6].
Small-scale CHP - Thermal capacity (MW)	1,215		Based on found efficiencies.
Small-scale CHP - Thermal efficiency	0.47	[6]	The value represents the expected annual average efficiency based on fuel consumption and production of these units as found in [6].
Fixed boiler share	20	[6]	The value are found based on fuel consumption and production of these units as found in [6].
Grid loss	0.2	[8]	
Thermal storage capacity (GWh)	33.2	[10]	
Solar thermal input (TWh/year)	1	[6]	
Industrial heat supply (TWh/year)	0.784	[6], [9]	The distribution between decentralised and central district heating areas is from [9]. The total is from [6]. Incl. units using biogas.
Industrial electricity supply (TWh/year)	0.363	[6], [9]	The distribution between decentralised and central district heating areas is from [9]. The total is from [6]. Incl. units using biogas.
Compression heat pump electric capacity (MW)	64	[7]	
Compression heat pump COP	3		Assumed.
Electric boiler capacity (MW)	489	[7]	

10.2.2 Central district heating

District heating production (TWh/year)	21.18	[6], [9]	The distribution of heat demand between decentralised and central district heating areas is from [9]. The total is from [6].
Fuel boiler capacity (MW)	6,109	[9]	
Fuel boiler efficiency	0.922	[9]	
Large CHP - Electric capacity (MW)	1760	[7], [9]	Found based on thermal capacity and found efficiencies.
Large CHP - Electric efficiency	0.283	[6]	The value represents the expected annual average efficiency based on fuel consumption and production of these units as found in [6].
Large CHP - Thermal capacity (MW)	4,521	[7], [9]	Calculated using the thermal capacity from [9], with changes to central plants in operation listed in [7].

Large CHP - Thermal efficiency	0.727	[6]	The value represents the expected annual average efficiency based on fuel consumption and production of these units as found in [6].
Fixed boiler share	0		
Grid loss	0.2	[8]	
Thermal storage capacity (GWh)	15.7	[10]	
Industrial heat supply (TWh/year)	0.928	[6], [9]	The distribution between decentralised and central district heating areas is from [9]. The total is from [6]. Incl. units using biogas.
Industrial electricity supply (TWh/year)	0.103	[6], [9]	The distribution between decentralised and central district heating areas is from [9]. The total is from [6]. Incl. units using biogas.
Electric boiler capacity (MW)	271	[7]	

10.3 Cooling

Electricity for cooling (TWh/year)	1.67	[11]	
Electricity for cooling efficiency	4.55	[11]	

10.4 Fuel Distribution and Consumption

10.4.1 Fuel Distribution for Heat and Power Production

These relations indicate for each of the plant type the fuel mix for used for each plant type (Coal / Oil / Gas / Biomass). Oil is fixed through the year.

Small-scale CHP units	0 / 0.02 / 4.1 / 3.1	[6]	The gas usage is excl. biogas, as this fuel consumption is included in “Natural gas, various”
Large CHP units	3.15 / 0 / 1 / 18.9	[6]	The value are found based on fuel consumption and production of these units as found in [6].
Boilers in decentralised district heating	0 / 0 / 1.02 / 6.54	[6]	The value are found based on fuel consumption and production of these units as found in [6].
Boilers in central district heating	0 / 0 / 1.02 / 6.54	[6]	The value are found based on fuel consumption and production of these units as found in [6].
Condensing operation of large CHP units	10.06 / 0.4 / 0 / 0.5	[6]	The value are found based on fuel consumption and production of these units as found in [6].
Condensing power plants	0 / 1 / 0 / 0	[6]	

10.4.2 Additional fuel consumption (TWh/year)

Coal in industry	1.33	[6]	
Oil in industry	10.68	[6]	
Natural gas in industry	10.74	[6]	
Biomass in industry	2.98	[6]	
Coal, various	0	[6]	The fuel consumption in "Various" includes own consumption in the energy sector for producing and refining fuels. It also includes non-energy use of fuels.
Oil, various	6.65	[6]	
Natural gas, various	5.31	[6]	Is incl. biogas consumption at CHP and boiler units.
Biomass, various	0.47	[6]	

10.5 Transport

10.5.1 Conventional fuels (TWh/year)

JP (Jet fuel) - fossil	11.82	[6]	
Diesel - fossil	30.77	[6]	
Petrol - fossil	14.83	[6]	
Grid gas	0.06	[6]	
JP (Jet fuel) - biofuel	0	[6]	
Diesel - biofuel	1.98	[6]	
Petrol - biofuel	0.51	[6]	

10.5.2 Electricity (TWh/year)

Electricity dump charge	0.53	[6]	

10.6 Waste conversion

10.6.1 Waste incineration in decentralised district heating

Waste input (TWh/year)	3.54	[6], [9]	The distribution of waste input between decentralised and central district heating areas is from [9]. The total is from [6].
Thermal efficiency	0.759	[6]	
Electric efficiency	0.148	[6]	Average electric efficiency for all waste incineration plants.

10.6.2 Waste incineration in central district heating

Waste input (TWh/year)	7.1	[6], [9]	The distribution of waste input between decentralised and central district heating areas is from [9]. The total is from [6].
Thermal efficiency	0.759	[6]	
Electric efficiency	0.148	[6]	Average electric efficiency for all waste incineration plants.

10.7 Individual heating

10.7.1 Coal boilers

Fuel consumption (TWh/year)	0	[6]	
Efficiency	0.7		Assumed annual average value

10.7.2 Oil boilers

Fuel consumption (TWh/year)	2.13	[6]	
Efficiency	0.85		Assumed annual average value
Solar thermal input (TWh/year)	0.013	[6]	The total solar thermal input from [6] is distributed on the fuel boiler types according to the fuel consumption.

10.7.3 Natural gas boilers

Fuel consumption (TWh/year)	7.00	[6]	
Efficiency	0.95		Assumed annual average value
Solar thermal input (TWh/year)	0.043	[6]	The total solar thermal input from [6] is distributed on the fuel boiler types according to the fuel consumption.

10.7.4 Biomass boilers

Fuel consumption (TWh/year)	11.43	[6]	
Efficiency	0.8		Assumed annual average value
Solar thermal input (TWh/year)	0.07	[6]	The total solar thermal input from [6] is distributed on the fuel boiler types according to the fuel consumption.

10.7.5 Heat pumps

Heat demand (TWh/year)	2	[7]	
COP	3		Assumed annual average value

10.7.6 Electric heating

Heat demand (TWh/year)	0.75	[8]	

10.8 Biogas production

Biogas production (TWh/year)	5.42	[6]	

10.9 Electricity exchange

Transmission line capacity (MW)	7,105	[7]	

10.10 Balancing

Minimum CHP in group 3 (MW)	10	[12]	Based on minimum load in 2015
Minimum PP (MW)	10	[12]	Based on minimum load in 2015
CEEP regulation strategy	2,3,4,5		

10.11 Distributions

The distributions do not influence the total annual energy, but allocates the total onto each hour of the year.

Input for distribution	**Reference**	**Note**
Electricity demand	[12]	Total electricity demand for East and West Denmark in 2015
Individual heat demand	[13]	Heat demand outside district heating areas in Denmark 2015. Generated using heating degree days with a reference temperature of 17°C and a temperature dependent of 75%. Hourly outdoor temperature from CFSR data [13].
Individual solar thermal	[14]	Solar thermal production in Denmark
District heating demand	[13]	Demand for district heating (incl. grid loss) in Denmark 2015. Generated using heating degree days with a reference temperature of 17°C and a temperature dependent of 75%. Hourly outdoor temperature from CFSR data [13].
District heating solar thermal	[14]	
Offshore Wind	[12]	Offshore wind power production in Denmark 2015
Onshore Wind	[12]	Onshore wind power production in Denmark 2015
Photo Voltaic	[12]	Photovoltaic power production in Denmark 2015

10.12 Price assumptions

The fuel prices and handling costs are shown in Table 3. Fuel oil, Diesel fuel/Gas Oil, Biomass and Dry biomass costs are only given incl. handling cost for plants. Petrol/ JP1 cost is only given at airport and consumer level, hence the Fuel price is set for airport level.

[2015-EUR/GJ]	**Coal**	**Natural gas**	**Fuel oil**	**Diesel fuel/ Gas Oil**	**Petrol/ JP1**	**Biomass**	**Dry biomass**
Fuel price	2.71	4.75	7.49	15.92	11.88	6.6	8.9
Handling costs							
Power plants	0.17	0.34	0	-	-	0	0
Small plants and industry	0.17	1.25	0	-	-	0	-
Households	-	4.49	-	0	-	3.8	-

Road transport	-	-	-	0	4.24	-	-
Aviation	-	-	-	-	0	-	-

Table 3 – Fuel prices and handling costs in 2020 [6]

The CO_2 quota price is set at 6.45 EUR/t [6].

The variable operation and maintenance (O&M) cost is for the fuel boilers sat at 0.15 EUR/MWh_{th}, for CHP units it is 2.7 EUR/MWh_e, for heat pumps it is 0.27 EUR/MWh_e, for electric heating it is 1.35 EUR/MWh_e and for condensing power plants it is 2.654 EUR/MWh_e. [3]