IDA's Energy Vision 2050

A Smart Energy System strategy for 100% renewable Denmark

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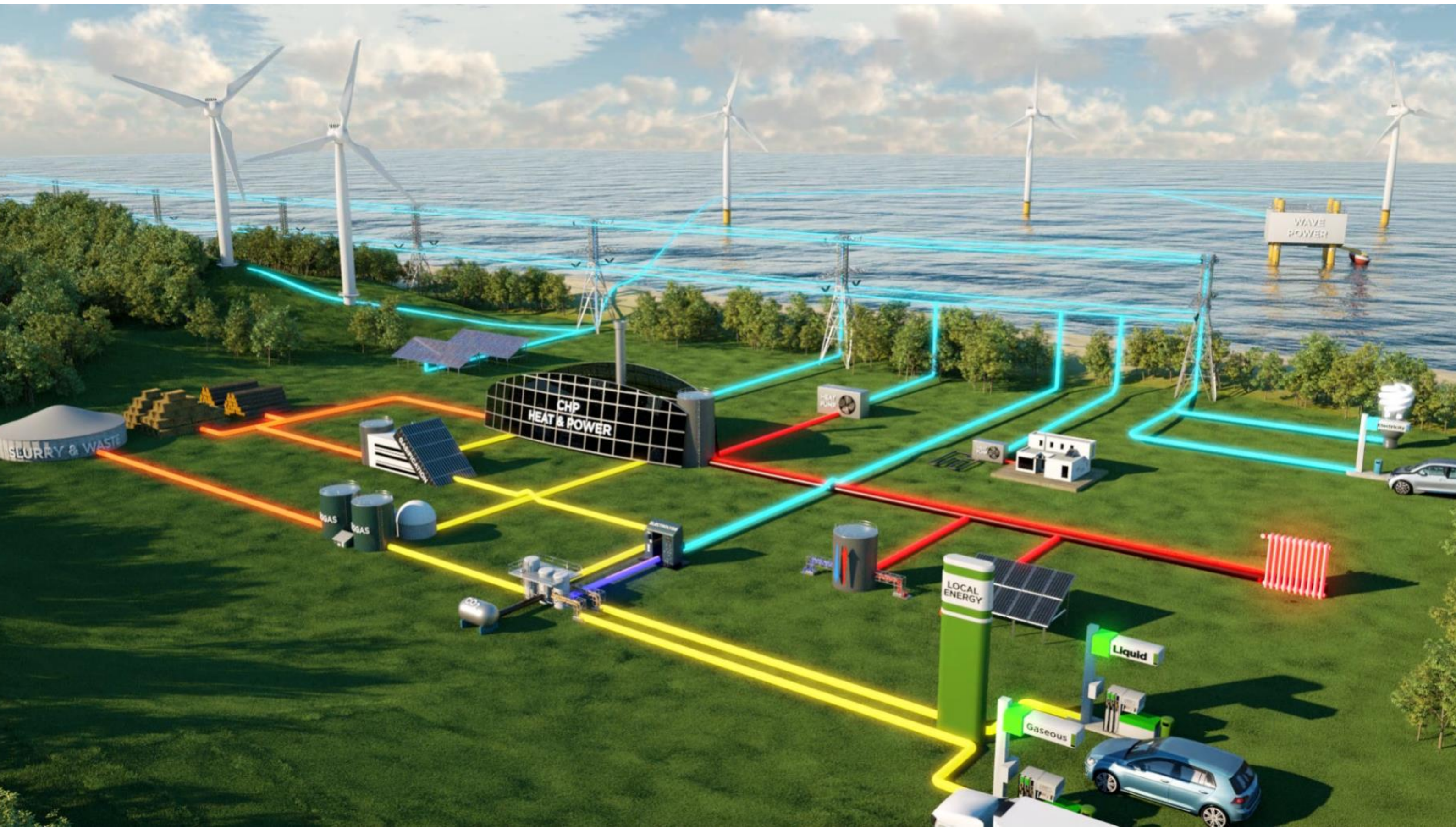

AALBORG UNIVERSITY
DENMARK

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· **Table of Contents**

Appendix A Documentation of reference and DEA fossil and wind scenarios

The Danish Energy Agency has developed four different fossil free scenarios for a future Danish energy system; a wind scenario, a biomass scenario, a Bio+ scenario and a hydrogen scenario. The scenarios are constructed from a biomass perspective where the highest demands are in the bio+ scenario around 700 PJ/year, in the biomass scenario this level is 450 PJ/year while for the wind and hydrogen scenarios the biomass demand is around 200-250 PJ/year. The biomass and Bio+ scenarios will require import of biomass in the future and are therefore not feasible from a biomass and security of supply perspective. In the hydrogen scenario the annual energy system costs are higher than in all other scenarios except the Bio+ scenario. It is therefore decided to use the wind scenario from the DEA as a baseline scenario for developing the IDA scenarios.

The 2013 reference

The 2035 and 2050 fossil and wind scenarios from DEA

To compare the IDA Energy Vision scenarios with the Fossil and Wind scenarios from the Danish Energy Agency all four scenarios were recreated in EnergyPLAN. The 2035 Fossil, 2050 Fossil, 2035 Wind and 2050 Wind scenarios. These recreations are based on the report created by the Danish Energy Agency [27].

<u>Demands</u>

The Danish Energy Agency divides the electricity demand into seven subgroups: classical, transport, process, individual heating, electricity in district heating, and electricity demand in refineries. In EnergyPLAN these are interpreted so classical, process, and geothermal electricity demand are grouped as the fixed electricity demand in all scenarios. Some of the refinery demand is furthermore included here in the 2035 and 2050 Fossil scenarios. Else, the transport demand is added through transport, the individual heating demand is added through boilers and heat pumps, and district heating demands are added as central heat pumps. The refinery electricity demand in the Wind 2035 and Wind 2050 scenarios are replicated as a demand for electricity in the biogas upgrade and electrolyser's hydrogen production. See Table 1 and Table 2.

Table 1 - Fixed electricity for Fossil scenarios

<table>
<tr><th>[TWh]</th><th>Electricity demands 2035 (DEA)</th><th>Fixed electricity 2035 (EnergyPLAN)</th><th>Electricity demands 2050 (DEA)</th><th>Fixed electricity 2050 (EnergyPLAN)</th></tr>
<tr><td>Classical</td><td>30.57</td><td rowspan="4">30.66</td><td>29.11</td><td rowspan="4">29.23</td></tr>
<tr><td>Process</td><td>0</td><td>0</td></tr>
<tr><td>Refinery</td><td>0.07</td><td>0.07</td></tr>
<tr><td>District heating</td><td>0.02</td><td>0.05</td></tr>
<tr><td>TOTAL</td><td>30.66</td><td>30.66</td><td>29.23</td><td>29.23</td></tr>
</table>

Table 2 - Fixed electricity for Wind scenarios

[TWh]	Electricity demands 2035 (DEA)	Fixed electricity 2035 (EnergyPLAN)	Electricity demands 2050 (DEA)	Fixed electricity 2050 (EnergyPLAN)
Classical	30.57	31.36	29.11	31.54
Process	0.51		2.12	
Refinery	0		0.06	
District heating	0.28		0.25	
TOTAL	31.36	31.36	31.54	31.54

The heating demand is handled the exact same way in the DEA spreadsheet as in EnergyPLAN for all four scenarios. The heat demand for decentral district heating is inserted as group 2 in EnergyPLAN, for central district heating in group 3, and the individual heat demands as the corresponding boilers and heat pumps in EnergyPLAN. Individual solar heating are inserted equally for all individual heating units thus increasing demand for those. Losses in the district heating system are 20 %, which corresponds with the DEA spreadsheet. See Table 3 and Table 4. The process heat demand is included as a fuel demand in industry.

Table 3 - Heating demands in fossil scenario

[TWh]	Heating demands 2035 (DEA)	Heating demands 2035 (EnergyPLAN)	[TWh]	Heating demands 2050 (DEA)	Heating demands 2050 (EnergyPLAN)
Natural gas boiler (eff: 1)	0.7	0.72 (includes 0.02 solar)	Natural gas boiler (eff: 1)	0	0
Biomass boiler (eff: 0.91)	11.59	11.99 (includes 0.40 solar)	Biomass boiler (eff: 0.91)	7.89	8.64 (includes 0.75 solar)
Individual heat pumps (COP: 4.27)	8.8	9.08 (includes 0.28 solar)	Individual heat pumps (COP: 4.13)	8.4	9.06 (includes 0.65 solar)
Individual solar	0.7	0 (sum of the above: 0.7)	Individual solar	1.4	0 (sum of the above: 1.4)
Decentralized DH (eff: 0.8)	9.78	9.78	Decentralized DH (eff: 0.8)	8.54	8.54
Centralized DH (eff: 0.8)	14.67	14.67	Centralized DH (eff: 0.8)	12.8	12.8
TOTAL	46.24	46.24	**TOTAL**	39.03	39.03

Table 4 - Heating demands in Wind scenario

[TWh]	Heating demands 2035 (DEA)	Heating demands 2035 (EnergyPLAN)	[TWh]	Heating demands 2050 (DEA)	Heating demands 2050 (EnergyPLAN)
Biomass boiler (eff: 0.91)	6.99	7.22 (includes 0.23 solar)	Biomass boiler (eff: 0.91)	0	0
Individual heat pumps (COP: 4.36)	14.03	14.49 (includes 0.46 solar)	Individual heat pumps (COP: 4.13)	16.3	17.7 (includes 1.4 solar)
Individual solar	0.69	0 (sum of the above: 0.69)	Individual solar	1.4	0 (sum of the above: 1.4)
Decentralized DH (eff: 0.8)	9.78	9.78	Decentralized DH (eff: 0.8)	8.54	8.54
Centralized DH (eff: 0.8)	14.67	14.67	Centralized DH (eff: 0.8)	12.8	12.8
TOTAL	46.16	46.16	**TOTAL**	39.03	39.04

Industry demand is in EnergyPLAN handled as a fuel demand. Thus, to convert from the DEA inputs to EnergyPLAN all industry demands are inputted as their corresponding fuel demand. Only electricity demand for industry is not included here as it is part of the total electricity demand in the EnergyPLAN files for all scenarios. See Table 5 and Table 6.

Table 5 - Fuel demand for industry in Fossil scenarios

[TWh]	Industry fuel demands 2035 (DEA)	Industry fuel demands 2035 (EnergyPLAN)	Industry fuel demands 2050 (DEA)	Industry fuel demands 2050 (EnergyPLAN)
Coal	12.8	12.8	23.4	23.4
Oil	2	2	0	0
Natural gas	7.1	7.1	0	0
Biomass	0	0	0	0
TOTAL	21.9	21.9	23.4	23.4

Table 6 - Fuel demand for industry in Wind scenarios

[TWh]	Industry fuel demands 2035 (DEA)	Industry fuel demands 2035 (EnergyPLAN)	Industry fuel demands 2050 (DEA)	Industry fuel demands 2050 (EnergyPLAN)
Coal	0	0	0	0
Oil	4.5	4.5	0	0
Natural gas	11.8	11.8	3.9	3.9
Biomass	4.4	4.4	13.7	13.7
TOTAL	20.7	20.7	17.6	17.6

The DEA interprets transportation demand as either fuel driven or electrically driven. The electrically driven vehicles are primarily seen as electricity smart charge in EnergyPLAN whereas the fuel driven are put into their corresponding fuel types. For the Fossil scenario only some of the cars and trucks are converted to electricity and the remaining runs on fossil fuels which also include ships and planes. In the Wind scenarios, there is a slightly higher transportation demand for electric vehicles, and the fossil fuels are replaced with synthetic biodiesel, petrol and jet fuel. Gas busses and trucks are included in both fossil and wind scenarios, as an input from the gas grid. Depending on the scenario, it is either natural gas, or SNG created from biomass.

Table 7 - Fuel demand for transportation in Fossil scenarios

[TWh]	Transport demands 2035 (DEA)	Transport demands 2035 (EnergyPLAN)	Transport demands 2050 (DEA)	Transport demands 2050 (EnergyPLAN)
Electricity	2.79	0.61 (dump)	9.66	0.94 (dump)
		2.18 (smart)		8.82 (smart)
Diesel	12.55	12.55	14.02	14.02
Petrol	31.06	31.06	7.57	7.57
Jet petrol	10.31	10.31	10.47	10.47
Natural gas	1.89	1.89	7.54	7.54

Table 8 - Fuel demand for transportation in Fossil scenarios

[TWh]	Transport demands 2035 (DEA)	Transport demands 2035 (EnergyPLAN)	Transport demands 2050 (DEA)	Transport demands 2050 (EnergyPLAN)
Electricity	3.41	0.6 (dump) 2.81 (smart	12.02	0,9 (dump) 11.12 (smart)
Syn diesel	1.77	1.77	7.08	7.08
Diesel	24.39	24.39	0	0
Syn Petrol	1.8	1.8	7.33	7.33
Petrol	9.7	9.7	0	0
Syn Jet petrol	2.91	2.91	10.46	10.46
Jet petrol	7.41	7.41	0	0
Syn Natural gas	2	2	7.98	7.98

<u>Production Units</u>

The Danish Energy Agency ties the energy production units to four primary sectors, decentralized district heating areas, centralized district heating areas, electricity production, and refineries.

Table 9 - Capacities of heat producing units in decentralized district heating areas in the Fossil scenarios

[MW]	Capacities 2035 (DEA)	Capacities 2035 (EnergyPLAN)	Capacities 2050 (DEA)	Capacities 2050 (EnergyPLAN)
Coal Boiler	1000	3459	1800	3018
Natural gas Boiler	1000		0	
Biogas engine (electric)	285	1424	285	1424
Natural gas engine (electric)	1140		1140	
Biogas engine (thermal)	250	1250	250	1250
Natural gas engine (thermal)	1000		1000	
Geothermal [TWh]	0.2	0.2	0.2	0.2
Solar thermal [TWh]	0.7	0.7	1.4	1.4
Excess heat from industry [TWh]	0.6	0.6	0.4	0.4
Thermal storage [GWh]	331	331	62	62

In all scenarios, within the decentralized district heating areas all CHP capacities are inputted in EnergyPLAN as they appear in the DEA models. This also goes for heat pumps and geothermal heat pumps, solar thermal, and heat and electricity production from industry. In the Wind scenarios, the decentralized CHP plant is a synthetic natural gas engine and the boilers are biomass, whereas in the Fossil scenarios the boiler runs on coal and the CHP plant on natural gas. The fossil scenarios furthermore have decentral biogas plants where the gas motors are modelled as part of the other decentral combined heat and power plants.

Table 10 - Capacities of heat producing units in decentralized district heating areas in the Wind scenarios

[MW]	Capacities 2035 (DEA)	Capacities 2035 (EnergyPLAN)	Capacities 2050 (DEA)	Capacities 2050 (EnergyPLAN)
Biomass Boiler	2300	3500	1800	3500
Syn natural gas engine (electric)	1026	1026	684	684
Syn Natural gas engine (thermal)	900	900	600	600
Heat pump (electric)	133.33	133	248	250
Heat pump (thermal)	400	399	800	800
Geothermal [TWh]	0.8	0.84	0.8	0.84
Solar thermal [TWh]	0.7	0.69	1.4	1.4
Excess heat from industry [TWh]	0.4	0.42	0.4	0.42
Thermal storage [GWh]	75	75	138	138

For all scenarios, the DEA numbers are typed as they appear into EnergyPLAN for the centralized district heating areas when it comes to CHP, Waste CHP, heat pumps, geothermal heat pumps, solar thermal and heat production from industry. In all scenarios, the centralized heating areas have waste incineration plants that produce both heat and electricity. In the fossil scenarios, the centralized combined heat and power plants are coal extraction plants in both 2035 and 2050 that produces both heat and power. In the 2035 Wind scenario the central CHP plants are extraction mode biomass plants, whereas there are no central CHP plants in the 2050 wind scenario besides the waste incineration plants. The boilers are biomass boilers in the Wind scenarios and coal boilers in the Fossil scenarios.

Table 11 - Capacities of heat producing units in centralized district heating areas in the Fossil scenarios

[MW]	Capacities 2035 (DEA)	Capacities 2035 (EnergyPLAN)	Capacities 2050 (DEA)	Capacities 2 (EnergyPLAN)
Coal boiler	500	5188	1200	4259
Coal CHP Plant (electric)	2154	2154	1568	1568
Coal CHP Plant (thermal)	2872	2872	1500	1500
Waste CHP (electric) [TWh]	2.78	2.78	3.17	3.17
Waste CHP (thermal) [TWh]	7.60	7.60	8.66	8.66
Geothermal [TWh]	0.01	0.01	0.06	0.06
Solar thermal [TWh]	0.3	0.3	0.6	0.6
Excess heat from industry [TWh]	0.9	0.9	0.9	0.9
Thermal storage [GWh]	94.5	94.5	82.5	82.5

Table 12 - Capacities of heat producing units in centralized district heating areas in the Wind scenarios

[MW]	Capacities 2035 (DEA)	Capacities 2035 (EnergyPLAN)	Capacities 2050 (DEA)	Capacities 2 (EnergyPLAN)
Biomass Boiler	2300	5200	2300	5200
Biomass CHP (electric)	926.37	926.37	0	0
Biomass CHP (thermal)	1269	1268	0	0
Heat pump (electric)	83.33	83	78.13	78.13
Heat pump (thermal)	250	249	250	250
Waste CHP (electric) [TWh]	2.8	2.78	3.0	3.0
Waste CHP (thermal) [TWh]	7.6	7.6	8.2	8.2
Geothermal [TWh]	0.48	0.48	0.39	0.39
Solar thermal [TWh]	0.3	0.28	0.6	0.6

Excess heat from industry [TWh]	0.9	0.89	0.9	0.89
Thermal storage [GWh]	241.5	241.5	186	186

The electricity production units have all been treated by typing in the exact number from the DEA into the EnergyPLAN representations. Furthermore, the fluctuating renewable sources such as wind, offshore wind and PV have all been correct to have the same production as in the spreadsheet. Besides fluctuating RES, power plants are included in this category. For the 2035 Fossil scenario, this is only the central coal CHP plants running condensing mode, whereas in the 2050 Fossil scenario it is both the central coal CHP units and a natural gas turbine. For the 2035 Wind scenario, electricity is also produced at the central biomass CHP plants and synthetic natural gas turbines. For the 2050 Wind scenario, only synthetic natural gas turbines are present as power plants.

Table 13 - Capacities of electricity producing units in Fossil scenarios

[MW]	Capacities 2035 (DEA)	Capacities 2035 (EnergyPLAN)	Capacities 2050 (DEA)	Capacities 2050 (EnergyPLAN)
Onshore wind	3500	3500	3500	3500
Offshore wind	2150	2150	5000	5000
PV	800	800	800	800
PP1	2776	2776	1575	1575
PP2	0	0	1400	1400
Industrial CHP [TWh]	2.3	2.3	3.4	3.4

Table 14 - Capacities of electricity producing units in Wind scenarios

[MW]	Capacities 2035 (DEA)	Capacities 2035 (EnergyPLAN)	Capacities 2050 (DEA)	Capacities 2050 (EnergyPLAN)
Onshore wind	3500	3500	3500	3500
Offshore wind	5000	5000	14000	14000
PV	1000	1000	2000	2000
PP1	1421	1421	0	0
PP2	900	900	4600	4600
Industrial CHP [TWh]	2.4	2.4	2.3	2.3

In all scenarios 4140 MW interconnector capacity is used, which equals the number from the Danish Energy Agency's models.

The Fossil 2035 and 2050 scenarios only include refineries as the biogas plants used to produce biogas for gas engines. The output of gas and input of manure is typed into EnergyPLAN as well as the electricity demand. The heating and electricity demands are included in the fixed electricity demand and the decentral district heating demand with the numbers from the DEA model.

In the Wind 2035 and 2050 scenarios, refineries include the production of synthetic fuels for the transportation sector and synthetic natural gas for transportation, and the gas turbines and engines. For the production of synthetic natural gas, the DEA uses a biogas plant to produce biogas that is then upgraded with hydrogen in methanation process. However, the DEA only includes an electricity demand for this meaning that the hydrogen production for this is not visible. The same step is replicated in energy plan by adding an electricity demand to the biogas plant equal to deliver the grid gas. For the hydrogen used in the production of synthetic fuels, the DEA models have a hydrogen plant that produces hydrogen from water electrolysis. This hydrogen is used in the advanced BTL process to produce synthetic jet fuel, diesel and petrol. Due to these things being modelled differently in EnergyPLAN and that the DEA does not include the necessary hydrogen for SNG and the BTL process, the refinery processes are created slightly different.

Table 15 - Inputs in the Danish Energy Agency's Model

	Inputs Fossil2035	Inputs Fossil2050	Inputs Wind2035	Inputs Wind2050
Hydrogen for biofuels [TWh]	0	0	2.9	10.7
Biomass for biofuels [TWh]	0	0	7.9	31.7
Surplus heat for centralized DH [TWh]	0	0	2.0	7.9
Electrolysers [MW]	0	0	1032	4128
Biomass for biogas plant [TWh]	4.7	4.7	7.5	11.7
Biogas upgrade [TWh]	0	0	4.5	18
Electricity for biogas upgrade [TWh]	0	0	2.7	10.7

In EnergyPLAN the electrolysis is modelled to create the necessary hydrogen for some of the synthetic natural gas and the synthetic fuels. The biogas plant produces biogas that together with an electricity demand for electrolysers create SNG. Furthermore, the biomass needed for BTL fuels is gasified in a gasifier that generates additional heat that is used for district heating in the centralized district heating grid. A more complete process would be to include the electricity demand as electrolysers instead of as tied to the biogas process, however the way it is done here resembles the DEA method the most.

Table 16 - Inputs in EnergyPLAN model

	Inputs Fossil2035	Inputs Fossil2050	Inputs Wind2035	Inputs Wind2050
Biomass for biogas plant [TWh]	4.7	4.7	7.5	11.7
Electricity for biogas upgrade [TWh]	0	0	2.9	10.7
Upgraded biogas [TWh]	4.7	4.7	9.10	18.0
Biomass for gasification [TWh]	0	0	7.9	31.7
DH output from gasification [TWh]	0	0	1.98	7.92
Syngas output [TWh]	0	0	6.37	25.56
Syngas for methanation [TWh]	0	0	5.33	20.78
Electrolysers [MW]	0	0	1634	6561
Hydrogen storage [GWh]	0	0	87.7	323
Biomass hydrogenation output [TWh]	0	0	6.48	24.87

The investment costs for production units used in the EnergyPLAN model are from the Danish Energy Agency's technology catalogue which is also used in the DEA's model. The fuel costs are inputted based on the DEA model and IEA assumptions with a specific focus on biomass costs. The investment costs for heat savings are based on the background note regarding development of savings and the report "Heat Saving Strategies in Sustainable Smart Energy Systems"[28].

The distribution files used for this study are for the cases of electricity demand, renewable energy production, district heating demands, individual heating demands and process heat all from the DEA model, imported into EnergyPLAN. The DEA uses normal years, where EnergyPLAN models for leap years. To correct for this and add the missing day, the last day is included twice in all distributions from the DEA model.

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Appendix B Documentation of the Reference 2015 model

The Reference 2015 model is based on the newest national energy statistics for Denmark from 2013. To make the model represent 2015, some key inputs have been updated using newer data sources. In the documentation of the specific inputs, in the tables below, the values updated with 2015 data are put in brackets after the 2013 value and the same for the reference.

The most of the inputs are from the National Energy Statistics 2013 from the Danish Energy Agency [16]. This consists of a main report and a spreadsheet as an appendix and both documents have been used. For some of the more plant or plant type specific inputs, the Register of energy producers 2012, (Energiproducenttællingen) also by the Danish Energy Agency, has been used. This is only used for distribution of production between plant types and fuel mix and not for total fuel consumption or energy production. To supplement these two, a number of other references have been used for 2015 values or more specific issues, that the National Energy Statistics do not cover, such as thermal storage capacity, district heating grid losses and cooling demand and production.

The 2013 model has been calibrated to match the energy balance reported in [16]. The calibration has been done by firstly, adjusting the calculated efficiencies of the CHP plants in central district heating areas to match the total fuel consumption of the system, and secondly, adjusting the calculated fuel distribution of the CHP plants in central district heating areas to make the model match the fuel mix in the statistics. In the documentation of the inputs in the tables below, it has been noted which inputs that have been used for calibration. After the calibration, the selected 2013 values are replaced with the 2015 values, as mentioned above.

In the modelling, the district heating areas have been divided into central and decentralised areas. The central areas are those areas where large extraction CHP plants are located. The decentralised areas are the rest of the areas. The decentralised district heating areas consist of both areas with CHP and without CHP. In all district heating areas there are heat-only boilers, that serves as peak load or back-up supply units.

Input	Value	Reference	Note

B.1 Electricity production

Electricity demand (TWh/year)	30.68	[16]	Electricity demand including grid losses, excluding demands for heating, cooling and transport.

B.1.1 Wind (onshore)

Capacity (MW)	3539 (3,759)	[16] ([17])	
Annual production (TWh)	6.77 (7.19)	[16] ([17])	The 2015 production is based on the production distribution from 2013 but scaled up with the increased capacity.

B.1.2 Offshore Wind

Capacity (MW)	1271	[16]	
Annual production (TWh)	4.35	[16]	

B.1.3 Photo Voltaic

Capacity (MW)	571 (629)	[16] ([18])	
Annual production (TWh)	0.52 (0.57)	[16] ([18])	The 2015 production is based on the production distribution from 2013 but scaled up with the increased capacity.

B.1.4 River Hydro

Capacity (MW)	9	[16]	
Annual production (TWh)	0.01	[16]	

B.1.5 Thermal power production

CHP condensing power capacity (MW)	6,244	[16]	
CHP condensing power efficiency	0.331	[19]	The values represent the annual average efficiency. This input has been used for calibration of the fuel consumption.
Condensing power plant capacity (MW)	841	[16]	

Condensing power plant efficiency	0.269	[19]	

B.2 District heating

B.2.1 Decentralised district heating

Demand (TWh/year)	10.48	[16] [19]	The distribution of heat demand between decentralised and central district heating areas is from [19]. The total is from [16].
Boiler capacity (MW)	4176	[19]	
Boiler efficiency	0.983	[19]	
CHP Electric capacity (MW)	1,889	[16]	
CHP Electric efficiency	0.36	[19]	
CHP Thermal capacity (MW)	2333	[16]	
CHP Thermal efficiency	0.4	[19]	The values represent the annual average efficiency. This input has been used for calibration of the fuel consumption.
Fixed boiler share	24.3	[19]	This value accounts for the share of district heating demand that cannot be supplied be CHP.
Grid loss	0.2	[20]	
Thermal storage capacity (GWh)	33.2	[21]	
Solar thermal input (TWh/year)	0.139 (0.278)	[16] ([22])	On the basis of [22], it is interpreted that a production of 1 TJ will be reached in 2015.
Industrial heat supply (TWh/year)	0.345	[16] [19]	The distribution of industrial heat supply between decentralised and central district heating areas is from [19]. The total is from [16].
Industrial electricity supply (TWh/year)	0.86	[16] [19]	The distribution of industrial electricity supply between decentralised and central district heating areas is from [19]. The total is from [16].

B.2.2 Central district heating

Demand (TWh/year)	17.01	[16] [19]	The distribution of heat demand between decentralised and central district heating areas is from [19]. The total is from [16].
Boiler capacity (MW)	5922	[19]	
Boiler efficiency	0.871	[19]	
CHP Electric capacity (MW)	4852	[16]	
CHP Electric efficiency	0.3	[19]	

CHP Thermal capacity (MW)	6301	[16]	
CHP Thermal efficiency	0.481	[19]	The values represent the annual average efficiency. This input has been used for calibration of the fuel consumption.
Fixed boiler share	1		To account for limits in the transmission grids and maintenance periods of CHP units.
Grid loss	0.15	[20]	
Thermal storage capacity (GWh)	15.7	[21]	
Industrial heat supply (TWh/year)	0.955	[16] [19]	The distribution of industrial heat supply between decentralised and central district heating areas is from [19]. The total is from [16].
Industrial electricity supply (TWh/year)	0.34	[16] [19]	The distribution of industrial electricity supply between decentralised and central district heating areas is from [19]. The total is from [16].

B.3 Cooling

Electricity for cooling (TWh/year)	1.67	[23]	
Electricity for cooling efficiency	4.55	[23]	

B.4 Fuel Distribution and Consumption

B.4.1 Fuel Distribution for Heat and Power Production

These relations indicated for each of the plant type indicate the relations between fuel types in the fuel mix for each plant type (Coal / Oil / Gas / Biomass).

Decentralised CHP	1 / 0 / 19 / 7	[19]	
Central CHP	104 / 2 / 11 / 36	[16] [19]	These relations have been used for calibration of total fuel mix.
Boilers in decentralised district heating	0 / 0 / 12 / 6	[19]	
Boilers in central district heating	0 / 2 / 2 / 1	[19]	
Condensing operation of central CHP	104 / 2 / 11 / 36	[16] [19]	These relations have been used for calibration of total fuel mix.
Condensing power plants	0 / 1 / 0 / 0	[19]	

B.4.2 Additional fuel consumption (TWh/year)

Coal in industry	1.49	[16]	Industry include the following categories in the DEA energy statistics:
Oil in industry	11.19	[16]	-
Natural gas in industry	10.77	[16]	-
Biomass in industry	3.31	[16]	-
Coal, various	2.2	[16]	The fuel consumption in “Various” counts own consumption in the energy sector for producing and refining fuels. It also counts non-energy use of fuels.
Oil, various	5.3	[16]	
Natural gas, various	6.7	[16]	

B.5 Transport

B.5.1 Conventional fuels (TWh/year)

JP (Jet fuel)	10.35	[16]	
Diesel	28.66	[16]	Includes the share of biodiesel added to the fuel.
Petrol	16.57	[16]	Includes the share of bioethanol added to the fuel.

B.5.2 Electricity (TWh/year)

Electricity dump charge	0.3863	[16]	

B.6 Waste conversion

B.6.1 Waste incineration in decentralised district heating

Waste input (TWh/year)	3.91	[16] [19]	The distribution of waste input between decentralised and central district heating areas is from [19]. The total is from [16].
Thermal efficiency	0.643	[19]	
Electric efficiency	0.146	[19]	

B.6.2 Waste incineration in central district heating

Waste input (TWh/year)	6.51	[16] [19]	The distribution of waste input between decentralised and central district heating areas is from [19]. The total is from [16].
Thermal efficiency	0.441	[19]	
Electric efficiency	0.279	[19]	

B.7 Individual heating

B.7.1 Coal boilers

Fuel consumption (TWh/year)	0.01	[16]	
Efficiency	0.7		Assumed annual average value

B.7.2 Oil boilers

Fuel consumption (TWh/year)	3.46	[16]	
Efficiency	0.85		Assumed annual average value
Solar thermal input (TWh/year)	0.02	[16]	The total solar thermal input is distributed on the fuel boiler types according to the fuel consumption.

B.7.3 Natural gas boilers

Fuel consumption (TWh/year)	7.58	[16]	
Efficiency	0.95		Assumed annual average value
Solar thermal input (TWh/year)	0.05	[16]	The total solar thermal input is distributed on the fuel boiler types according to the fuel consumption.

B.7.4 Biomass boilers

Fuel consumption (TWh/year)	9.44	[16]	
Efficiency	0.8		Assumed annual average value
Solar thermal input (TWh/year)	0.06	[16]	The total solar thermal input is distributed on the fuel boiler types according to the fuel consumption.

B.7.5 Heat pumps

Heat demand (TWh/year)	1.17	[16]	
COP	3		Assumed annual average value

B.7.6 Electric heating

Heat demand (TWh/year)	1.089	[16]	

B.8 Biogas production

Biogas production (TWh/year)	1.06	[16]	

B.9 Electricity exchange

Transmission line capacity (MW)	5,750 (6,150)	[24] ([24])	

B.10 Distributions

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

Input for distribution	**Reference**	**Note**
Electricity demand	[25]	Total electricity demand for East and West Denmark
Individual heat demand	[26]	Heat demand outside district heating in Denmark 2006
Individual solar thermal	[26]	Solar thermal production in Denmark
District heating demand	[26]	District heating demand in Denmark 2006
DH Solar thermal	[26]	Solar thermal production in Denmark
Offshore Wind	[25]	Off shore wind power production in Denmark 2013
Onshore Wind	[25]	On shore wind power production in Denmark 2013
Photo Voltaic	[25]	Photovoltaic power production in Denmark 2013
Electricity price	[25]	Nordpool hourly system prices from 2013

Appendix C Fuel price assumptions in Energy Vision 2050

C.1 Historic price development and price forecasts

Historically the fuel prices have gone up and down and have been affected by economic, geopolitical or natural events. The historic development of the crude oil price in 2015-USD/barrel in Denmark is shown in Figure C1.

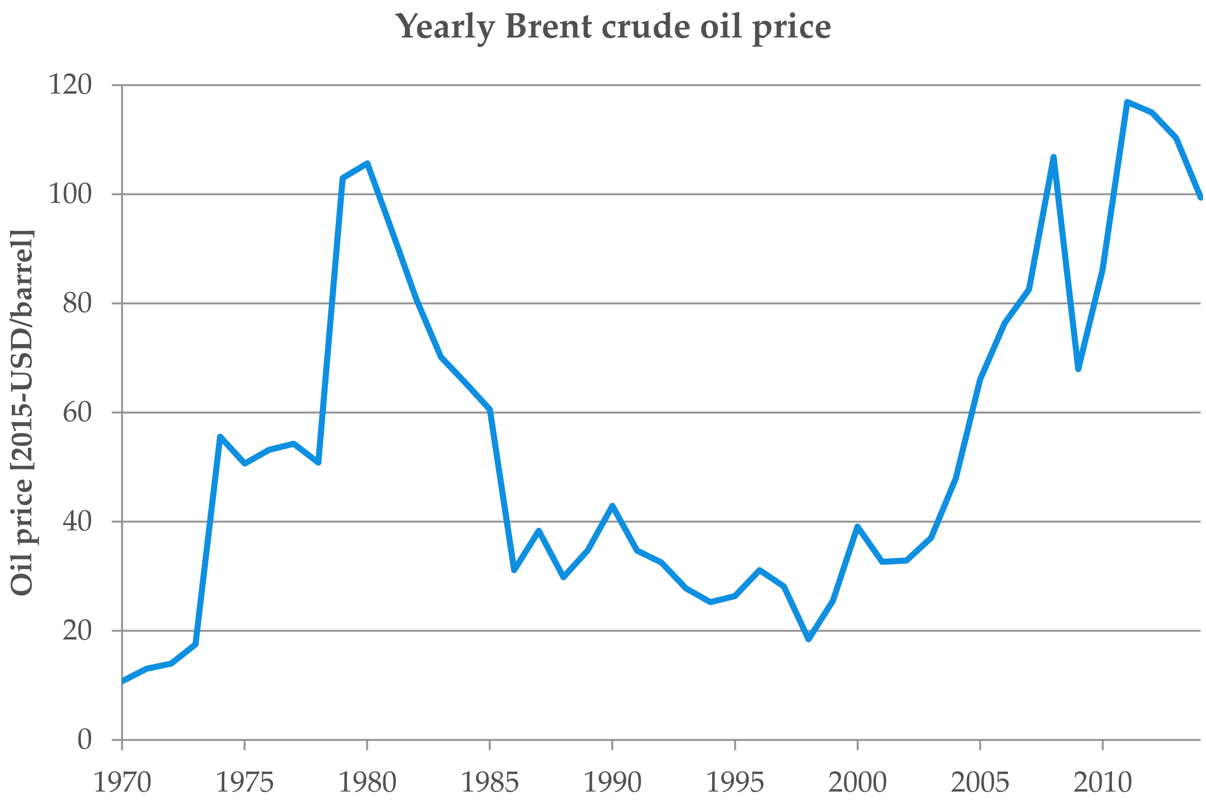

Figure C1 – Yearly Brent crude oil price in 2015-USD/barrel [1].

As can be seen in Figure C1 the crude oil price has fluctuated significantly since 1970, with a price peak in 1979-1980, due to the oil crisis, and a price peak in 2008 and again after 2009. The price drop in 2009 is due to the financial crises. The price drop seen at the end of graph has continued and the price has in the first half of 2015 been around 60 USD/barrel.

The historical development in the monthly price of crude oil and coal in Denmark since 1991 can be seen in Figure C2. The prices in Figure C2 are in current prices.

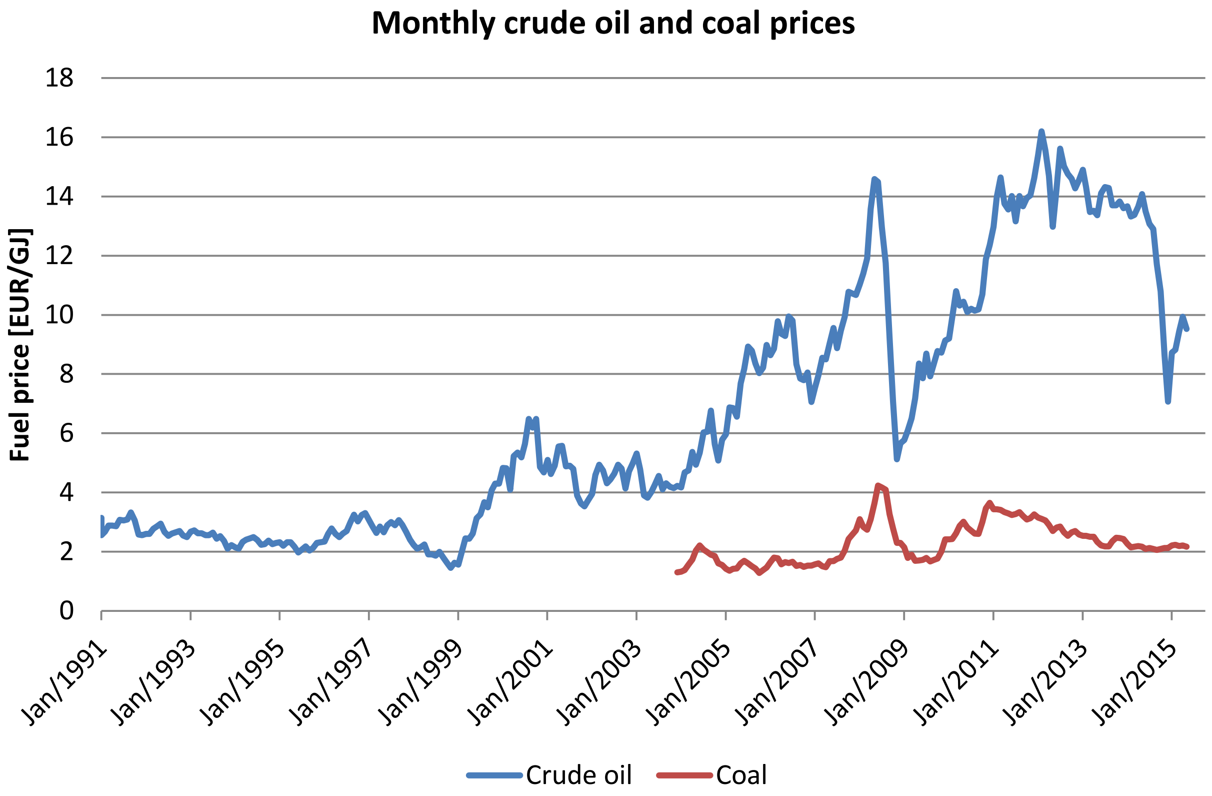

Figure C2 – Monthly market prices for Brent crude oil and coal [2]**.**

As can be seen in Figure C2, the price of oil in Denmark has seen a development similar to the development presented in Figure C1, though here the cost is also influenced by the USD to DKK/EUR exchange rate. The coal price has been fairly stable in comparison to the oil price, though the 2008 financial crises can also be seen on the coal price development.

These fluctuations in the crude oil price also underline the challenge of predicting the crude oil price, with international events potentially having huge effect on the price. Figure C3 shows the Danish Energy Authority's (DEA's) price forecast for crude oil from different years alongside IEA's price forecast from 2010 and the historic actual annual prices in each year.

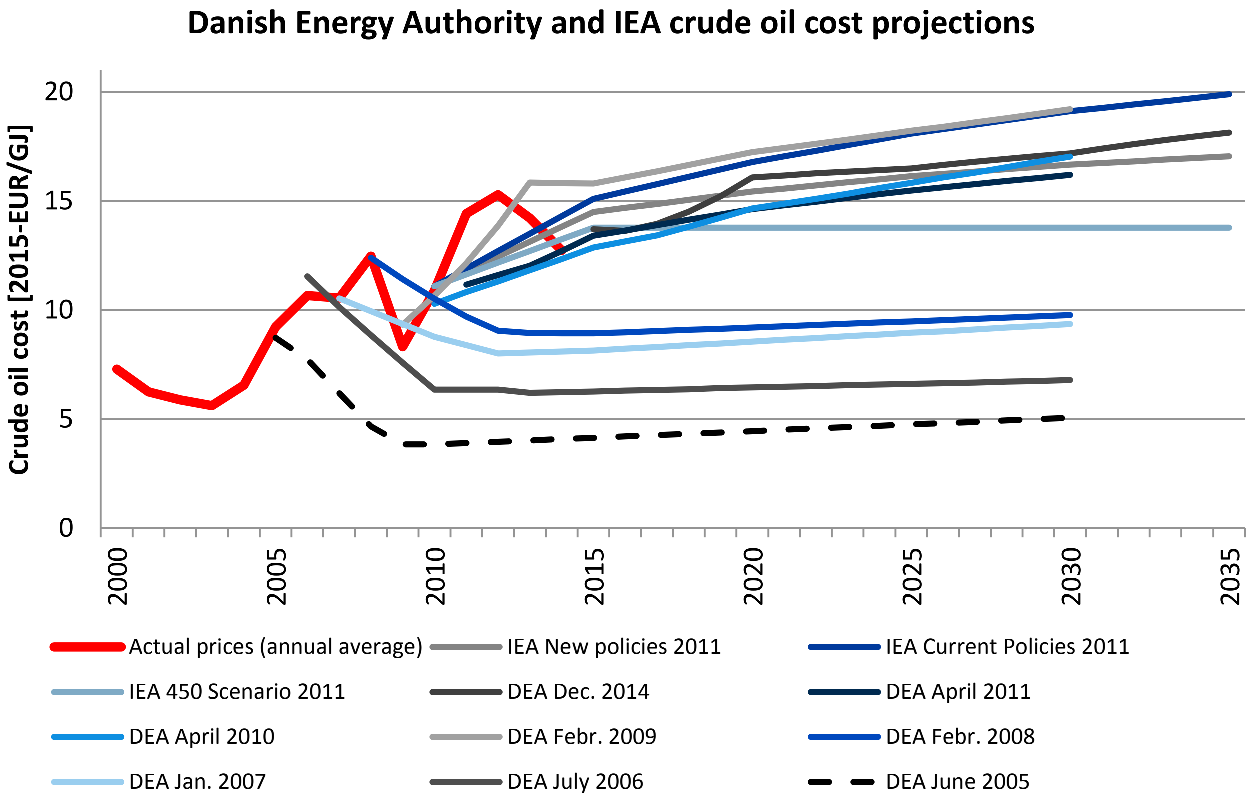

Figure C3 – Comparison of different crude oil price forecasts from DEA and IEA alongside the historic annual crude oil price [3] [2].

As shown in Figure C3, the DEA did in 2005-2008 expect that the crude oil price would decrease in the then coming years and hereafter slowly increase. The forecasts after 2008 predict that the crude oil price would continually increase. As the actual oil price shows both in Figure C3 but also in Figure C1 and Figure C2, the crude oil price has fluctuated through the years, and not only seen a continuous increase.

Figure C4 shows DEA's latest fuel cost forecast from December 2014 for each type of fuel excl. costs for transportation to the place of consumption. The forecast is based on IEA's forecast in World Energy Outlook from November 2013. Internationally the IEA is widely used as the point of departure for identifying future fuel prices.

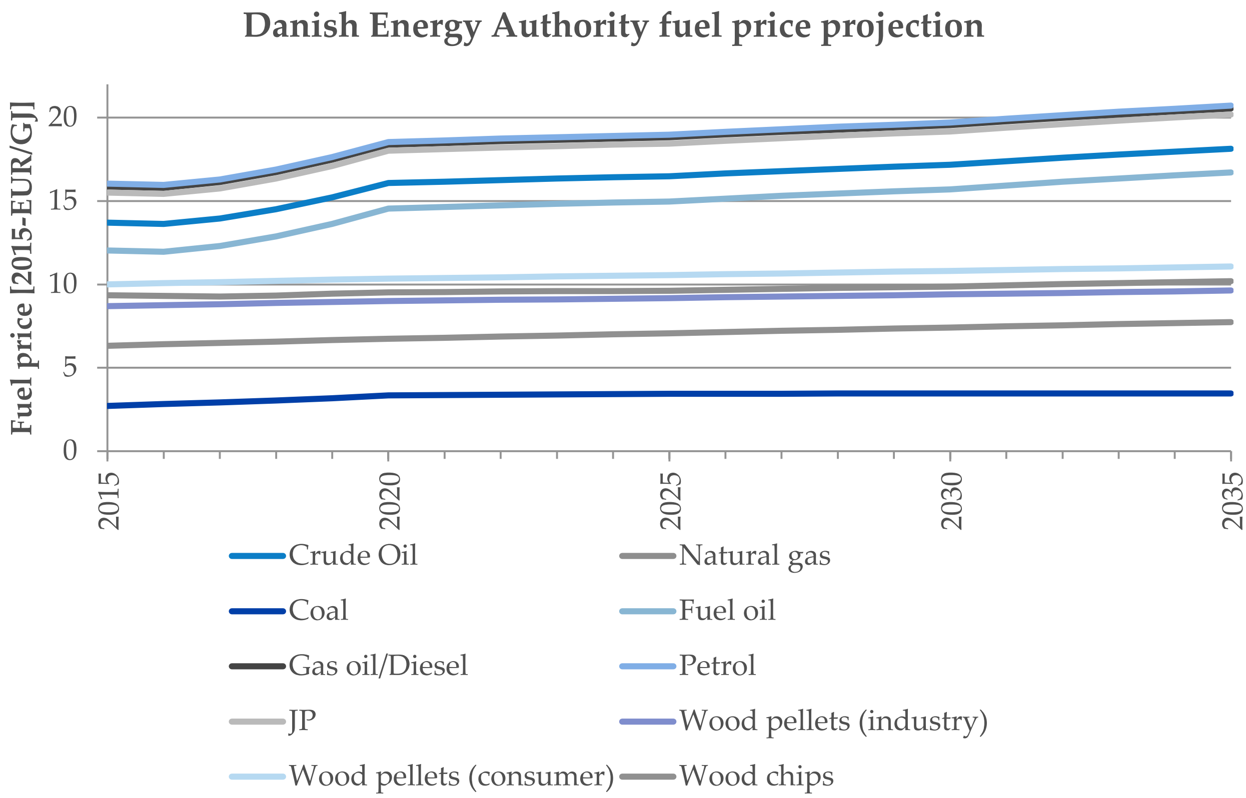

Figure C4 – DEA's fuel price forecast from December 2014 [4]**.**

As shown in Figure C4 the DEA expects that the fuel prices generally will increase until 2035. Though, especially coal, petrol, wood pellets and natural gas is in this price forecast expected to only see a minor increase.

Besides fuels another important price development is the electricity price on the international electricity market that Denmark is a part of, being Nord Pool Spot. The historic yearly average system prices on Nord Pool Spot alongside DEA's price forecast from different years are shown in Figure C5.

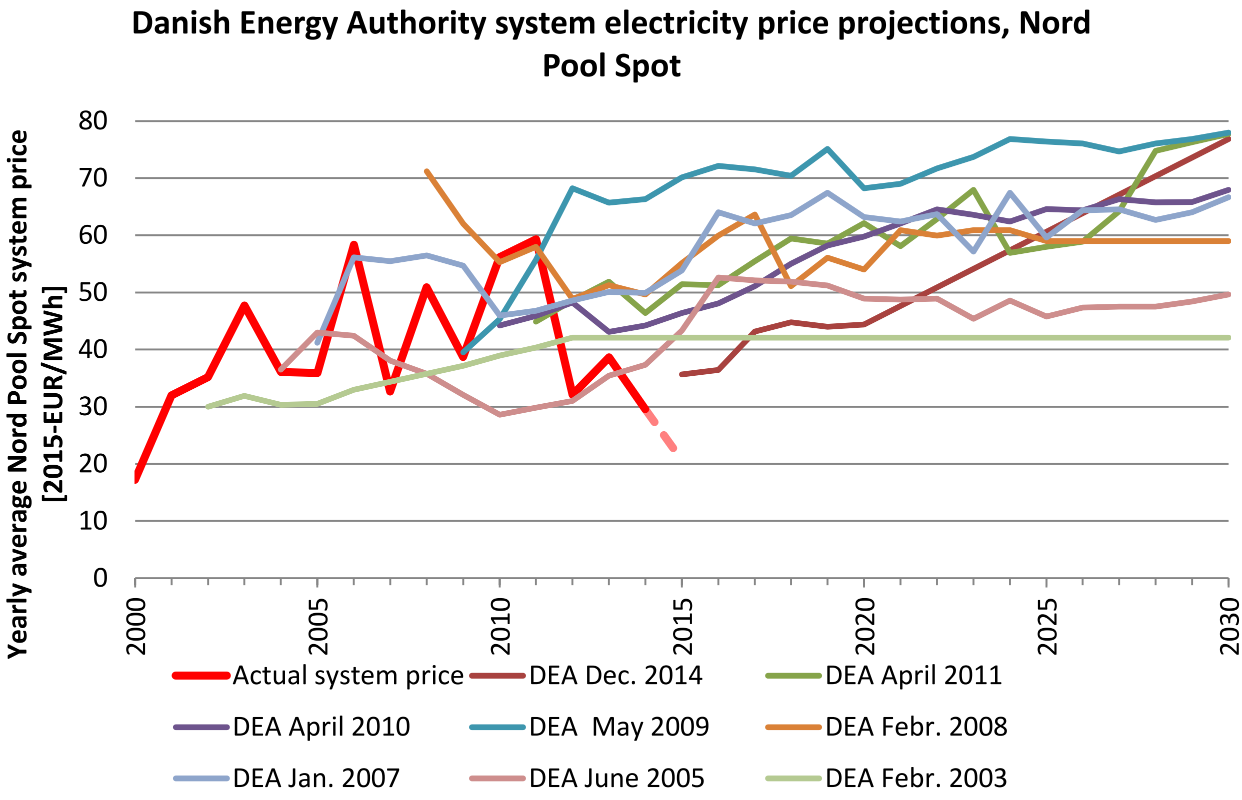

Figure C5 – Comparison of different Nord Pool Spot system price forecasts by the DEA alongside the historic system price. The actual system price for 2015 shown in the figure is the average in the first nine months. [5] [3]

As can be seen in Figure C5 the expectations to the future system price on Nord Pool Spot have changed significantly between the different DEA price forecasts. However, it has always been expected by the DEA that in fixed prices the Nord Pool System price will increase in the long-term. As can be seen from the actual system prices, the system price on Nord Pool Spot varies fairly significant from year to year and in the last couple of years the system price has seen a significant decrease.

C.2 Price forecasts in Energy Vision 2050

In the latest fuel price forecast from the DEA from December 2014, the DEA expects a crude oil price of 148 2015-USD/barrel in 2035 [4]. Based on the historical crude oil price shown in Figure C1, where it is shown that the yearly crude oil price never has been above 120 2015-USD/barrel, a crude oil price of 148 2015-USD/barrel must be considered high. As such, in the Energy Vision 2050 the DEA forecasts from December 2014 are seen as a high price forecast.

As was shown the fuel prices has historically seen periods of both low prices and high prices, and it is expected that the prices going forward will also vary. In Energy Vision 2050 three different cost scenarios for 2035 are used:

- Low fuel cost: Based on the fuel prices in 2015, where the crude oil price was about 62 USD/barrel. [6] [2] [7]

- Medium fuel cost: The average between the low and high cost scenario, where the crude oil price corresponds to about 105 2015-USD/barrel.
- High fuel cost: DEA's fuel price forecast for 2035 from December 2014, where the crude oil price is expected to be about 148 2015-USD/barrel [4].

The fuel cost excl. costs for transportation to the place of consumption for each of the fuel types are shown in Table C17.

Table C17 – Fuel cost by fuel type excl. costs for transportation to the place of consumption for each cost scenario.

[2015-EUR/GJ]	Crude oil	Coal	Natural gas	Fuel oil	Diesel fuel/ Gas Oil	Petrol/ JP1	Straw/ Wood chips	Wood pellets (general)	Energy Crops	$/barrel crude oil
Low	10	2	6	6	11	12	5	10	6	62
Medium	14	3	8	12	16	16	6	11	7	105
High	18	4	10	17	21	21	7	12	8	148

For the cost of transporting each fuel to the place of consumption DEA's price forecast from December 2014 is used. These costs are shown in Table C18, and are used in each of the three cost scenarios.

Table C18 – The cost of transporting each fuel to the place of consumption [4]

[2015-EUR/GJ]	Coal	Natural gas	Fuel oil	Diesel fuel/ Gas Oil	Petrol/ JP1	Straw/ Wood chips	Wood pellets (general)	Energy Crops
Power plants	0.05	0.21	0.29	0.29		0.68	0.29	1.65
Small plants and industry		0.94		1.78		0.55	0.91	1.65
Households		4.04		3.85			4.34	
Road transport				3.85	4.67			
Aviation					0.29			

In the fuel price forecast from December 2014 the DEA uses three estimates for the CO_2-quota price in 2035; a low of 24 2015-EUR/tonne, a medium of 42 2015-EUR/tonne and a high of 60 2015-EUR/tonne [4]. In the Energy Vision 2050 the medium CO_2-quota price forecast for 2035 of medium of 42 2015-EUR/tonne is used as the baseline.

In the price forest from December 2014 the DEA forecast a Nord Pool Spot system price in 2035 of 77 2015-EUR/MWh [4]. This is expected to be for a CO_2 cost of 42 2015-EUR/tonne. It is assumed that the Nord Pool Spot system price follows the same time distribution as in 2013. A price elasticity has been calculated for such electricity exchange, cf. the descriptions in "Local Energy Markets" [8].

Analyses of international electricity market exchange with consequences of changes in precipitation for the Norwegian and Swedish hydroelectric power systems have not been done in IDA's Energy Vision 2050. Such analyses were conducted in the IDA Energy Plan 2030 from 2006 [9].

It must be emphasised that the CO_2 quota costs employed here is used primarily to be able to evaluate incomes and costs from electricity market exchange. The use of 42 2015-EUR/tonne CO_2 reflects the costs of CO_2 reductions and is not an analysis of the socioeconomic impacts from the CO_2 emission.

Appendix D **Heat demand in buildings**

This appendix describes the development of heat demands in new and existing buildings and the development towards 2050. The first part describes the inputs and assumptions in the Danish Energy Agency's scenarios, while the second part describes the report "Heat Saving Strategies in Sustainable Smart Energy Systems" (NZEB report) [10] that represents the method to define heat demands in the IDA'S Energy Vision. Since the starting points are different in the DEA's scenarios and the NZEB report, the third section describes inputs for the IDA'S Energy Vision 2050, and the identification of heat saving costs.

D.1 Heat demands in the Danish Energy Agency's scenario

The Danish Energy Agency's development in heat demand in existing and new buildings are described in [11]. This describes the assumptions. The Danish Energy Agency has different scenarios for development in energy savings, but in their final scenarios, they only use the "large" savings. Thus, these form the basis for the description in this section.

D.1.1 Existing buildings

The Danish Energy Agency estimates that the current heat demand in existing buildings are 55.08 TWh. In the development towards 2050, they assume that 5 % of the existing buildings are replaced with new buildings by 2035 and 10 % by 2050. The demand should be reduced by 21 % in 2035 and 36 % in 2050 in existing buildings. This equals a demand of 34.99 TWh in 2050 and 43.26 TWh in 2035. The annualized costs for these improvements are shown in Figure D with a discount rate of 5 %.

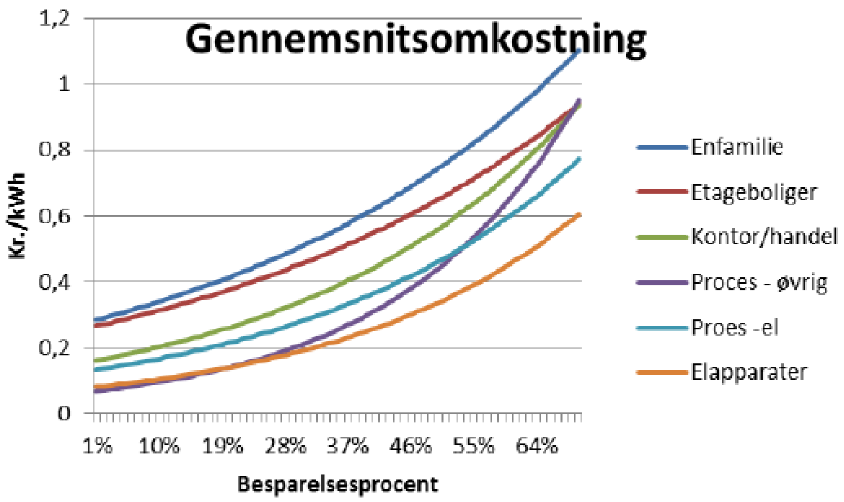

Figure D1 - Average annualized costs for savings in existing buildings in the Danish Energy Agency's Scenarios

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D.1.2 New buildings

The Danish Energy Agency estimates that the amount of new buildings grows based on the number of citizens in Denmark and the type and size of dwellings. This results in total new buildings of 112.95 mil m^2 in 2050 and 63.11 mil m^2 in 2035. In 2035, these new buildings have a consumption of 2.92 TWh and in 2050 a total consumption of 4.04 TWh. According to [11] the new buildings are built according to the Danish building code that the Energy demand requirements are reduced 75 % at least. The Danish Energy Agency assumes that since this is the current building code for 2020 and forward there are no additional costs related their performance of new buildings. Using the Danish building standards makes it uncertain to what extent production units help reducing these heat demands in the Danish Energy Agency's scenarios.

D.2 Identifying heat demands in ZEB

The NZEB report [10] identifies levels of savings in a Smart Danish Energy System based on the idea that at some point it becomes cheaper to produce energy than to save energy. It tries to identify a cost optimal point for savings. The data behind the NZEB report focus on reduction in single-family houses, but the results are scaled to account for the whole building mass. Because of this, the estimates are conservative.

The NZEB report includes both existing buildings [12] and new buildings . In existing buildings, it estimates the level of refurbishment in terms of reduction in energy demand. The energy demand in new buildings is identified through an analysis of what energy performance a new building should have. The study applies a marginal approach, meaning what are the costs of improving the efficiency on step more. The primary outcome is Figure D2.

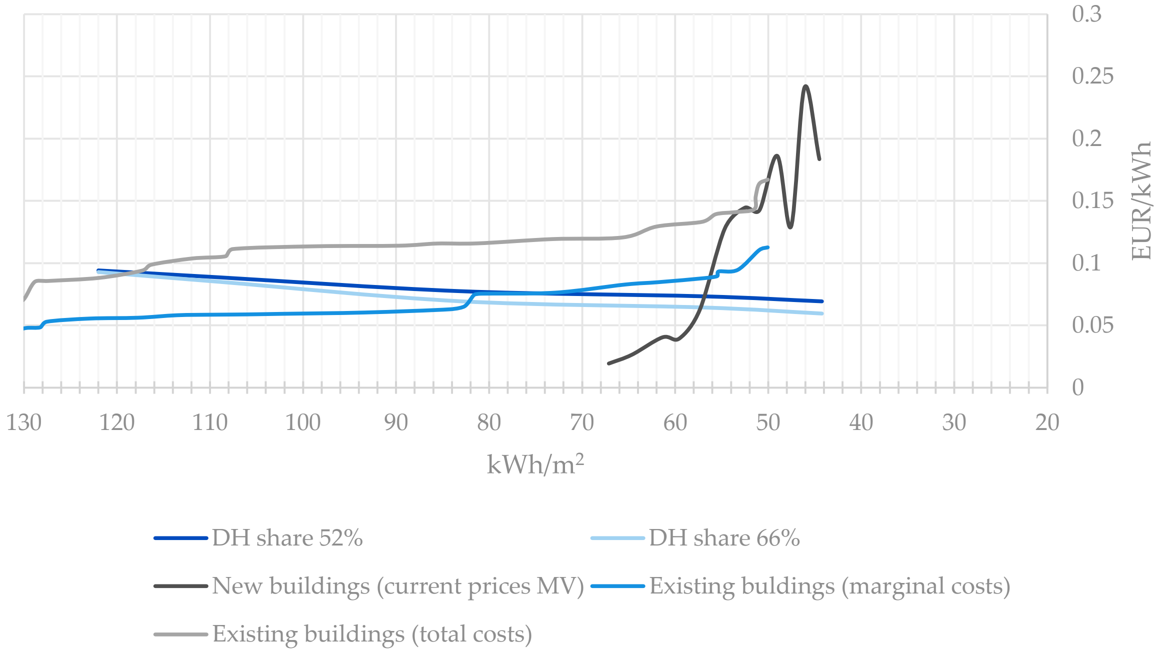

Figure D2 - Marginal costs for reducing heat demand in existing and new buildings compared to marginal costs of providing more energy in the CEESA 2050 energy system [1]

D.2.1 Existing buildings

Based on Figure D2 and the fact that the estimates are conservative, the existing buildings are refurbished from a level of 131.76 kWh/m^2 to 78.79 kWh/m^2. This includes a fixed hot water demand of 13.7 kWh/m^2 that is not reduced. It is important to note that the steps in the lines showing demand changes in existing buildings indicate each time a building category (defined by construction year and building type) is renovated extensively. Thus it is not every building that is renovated, only the most cost efficient categories. Another important point is that the savings should be carried out at the time when they are most feasible; this is when the buildings are going to be refurbished anyway. It will be too expensive to renovate the buildings twice.

D.2.2 New buildings

Based on Figure D2 the new buildings should be built at a standard with a net heat demand of 56 kWh/m^2. This again includes a hot water consumption of 13.7 kWh/m^2. This compares to a current standard for new buildings estimated to be 67.13 kWh/m^2 identified in the NZEB report with offset in [13]. The reason the lines move up and down is that each changes has different marginal costs, however the prerequisite for the next step is that the previous steps have been completed.

D.3 Inputs for IDA's Energy Vision 2050

Based on the numbers in DEA's scenarios and the cost curve from NZEB report it is possible to identify demands for IDA's Energy Vision in 2050. Again, these are divided into demand for existing buildings and demand for new buildings.

D.3.1 Existing buildings

The reference demand in existing buildings are 55.08 TWh based on the DEA scenario, based on the NZEB report this equals a demand of 131.76 kWh/m^2. Thus, the current building stock is estimated as 418.04 mil m^2. There is no assumption of existing buildings being demolished, thus all of the existing buildings mass could potentially be renovated. Based on NZEB report the 2050 demand in existing buildings should be 78.79 kWh/m^2. This means that IDA's Energy Vision estimates a net heat demand in 2050 in existing buildings of 32.94 TWh. In 2035, the same rate as the DEA's scenario is expected. The demand in IDA's Energy Vision is therefore 40.72 TWh in 2035. Table D1 compares IDA's Energy Vision and the DEA's scenarios.

D.3.2 New buildings

The expansion of new buildings is estimated based on the Danish Energy Agency's scenarios [11]. In 2035 the number of new buildings equal 63.11 mil m^2 and in 2050 112.95 mil m^2. The NZEB report identifies the cost-optimal level of demand in new buildings as 56 kWh/m^2. This results in a demand in new buildings 3.53 TWh in 2035 and of 6.33 TWh in 2050. Table D1 compares these numbers to the DEA's scenarios.

Table D1 - Comparison of IDA's Energy Vision and the Danish Energy Agency's Scenario

[TWh]	DEA 2035	DEA 2050	IDA 2035	IDA 2050
Existing buildings	43.26	34.99	40.72	32.94
New buildings	2.92	4.04	3.53	6.33
TOTAL	**46.18**	**39.03**	**44.26**	**39.26**

D.3.3 Costs

The definitions of costs are different in the NZEB report and the DEA's scenarios. Most important is that NZEB assumes marginal costs for improving new buildings, where the DEA does not. Furthermore, the costs in the DEA assumption paper only summarize annualized costs at a discount rate of 5 % with no lifetime specified. Thus, this study identifies costs for new and existing buildings based on the NZEB report. Based on the curves in Figure D, each step is translated to the reference starting point of 55.08 TWh for existing buildings and 7.58 TWh for new buildings (based on the reference building type for new buildings in the NZEB report). Each step is furthermore changed from annualized costs to total investment costs. Figure D2, D3 and D4 show this for respectively existing and new buildings.

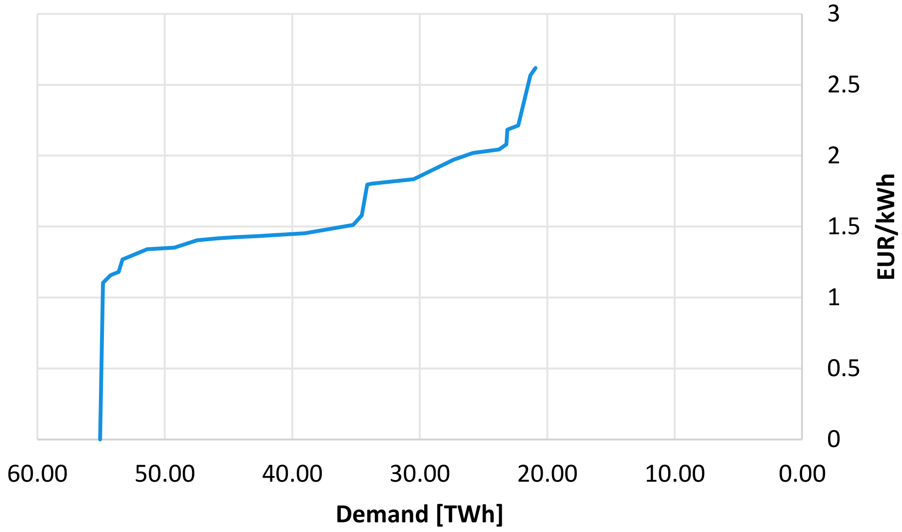

Figure D3 - Investment costs for savings in existing buildings

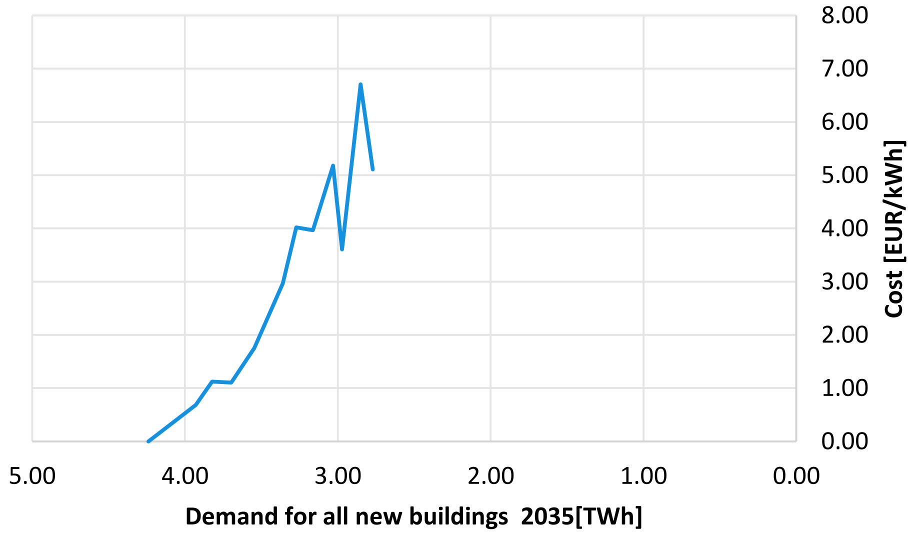

Figure D4 - Investment costs for savings in new buildings in 2035

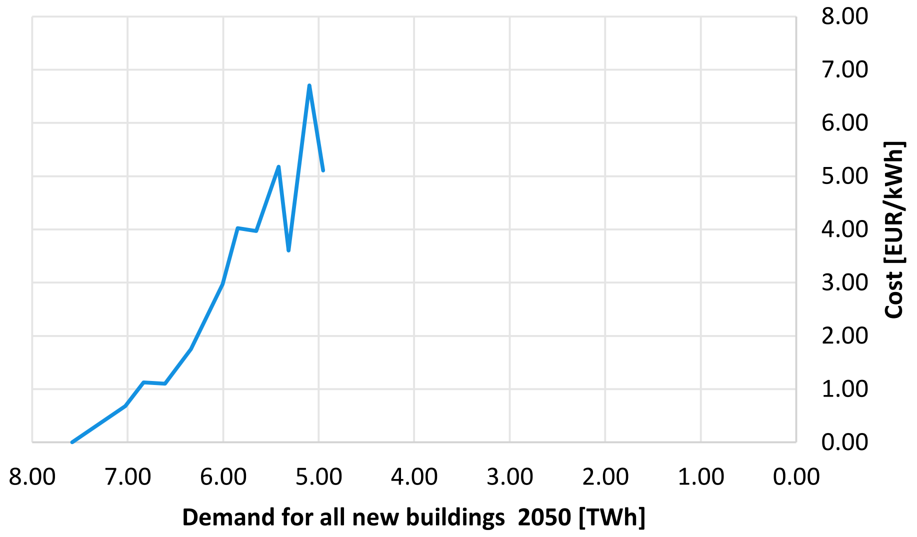

Figure D5 - Investment costs for demand reductions in new buildings in 2050

By multiplying the achieved saving in each step with the cost per kWh for each step, the study creates curves that show the increase in total investment costs. For each of these, a trend line has been added with a function that indicates the costs for lowering demands. These are shown in Figure D5 for existing buildings, and Figure D6 and Figure 6 for new buildings. The lifetime of all renovations are expected to be 50 years with 0 % Operation and Maintenance costs.

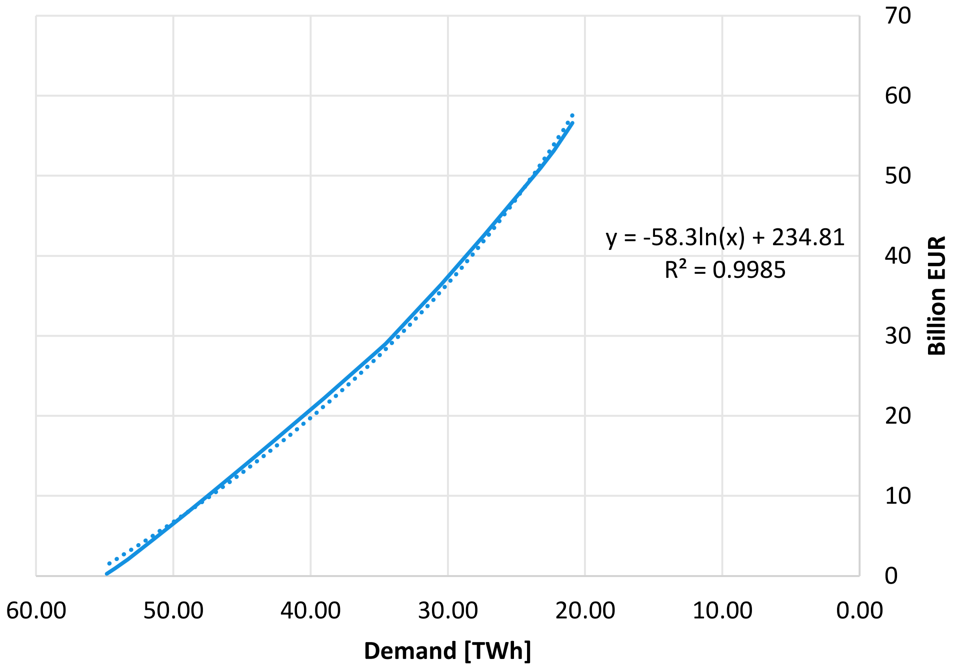

Figure D6 - Total investment costs for increased demand reductions in existing buildings

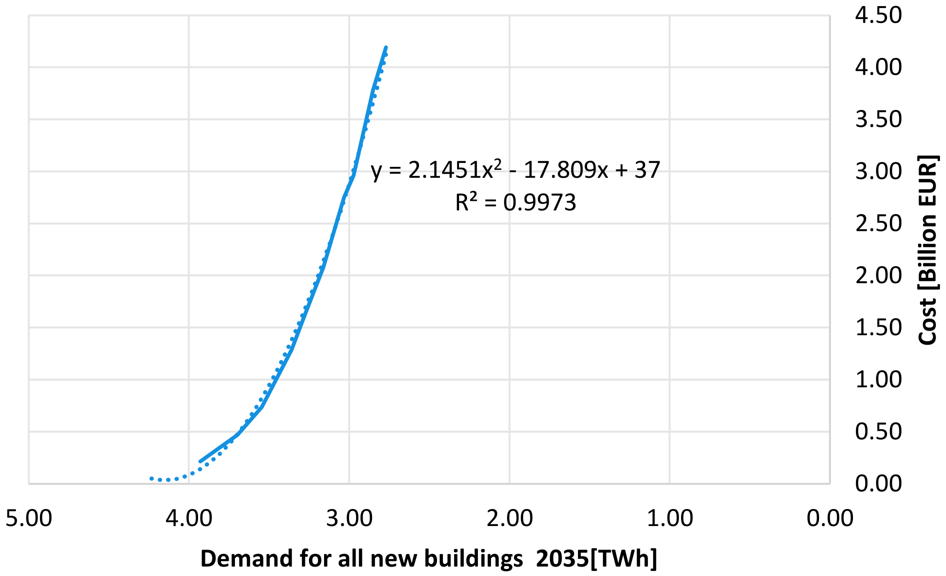

Figure 6 - Total investment costs for increased demand reductions in new buildings in 2035

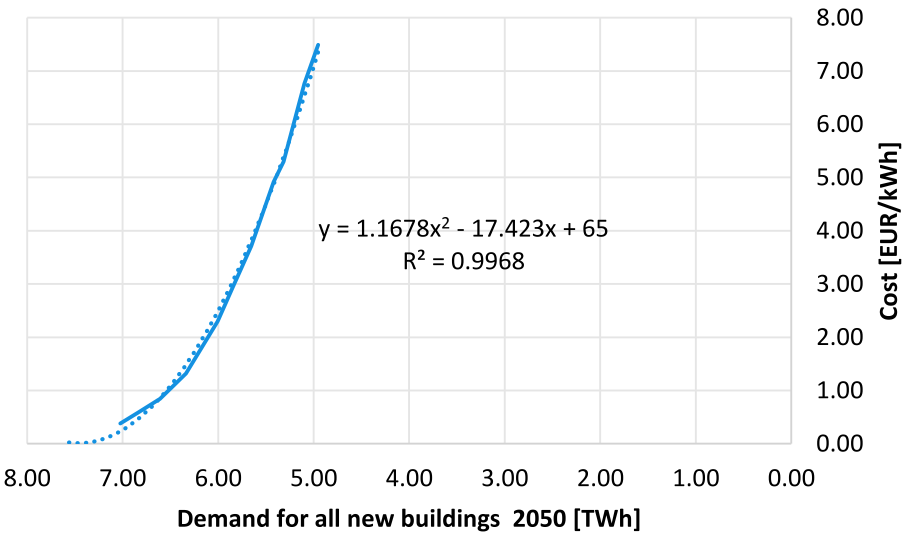

Figure 7 - Total investment costs for increased demand reductions in new buildings in 2050

Appendix E Transport sector modelling

In order to recreate transport scenarios from Danish Energy Agency (DEA) - Fossil and Wind 2035/2050 scenarios and to make IDA transport scenarios for same years, the tool developed for Coherent energy and environmental system analysis (CEESA) project was used [14]. The TransportPLAN is a very detailed national transport scenario modelling tool that consists of MS Excel Spreadsheet that enables users to created numerous transport scenarios relatively quickly and easy. Figure 8 shows a logical procedure for TransportPLAN tool that is based on some key parameters and resulting transport demands are available for different years. TransportPLAN enables the creation of transport and transport-energy demand scenarios related to passenger and freight activities. For the recreation of the scenarios starting year of 2011 was used. This starting year was chosen as DEA's projections of transport demands in 2035 and 2050 were based on this reference year.

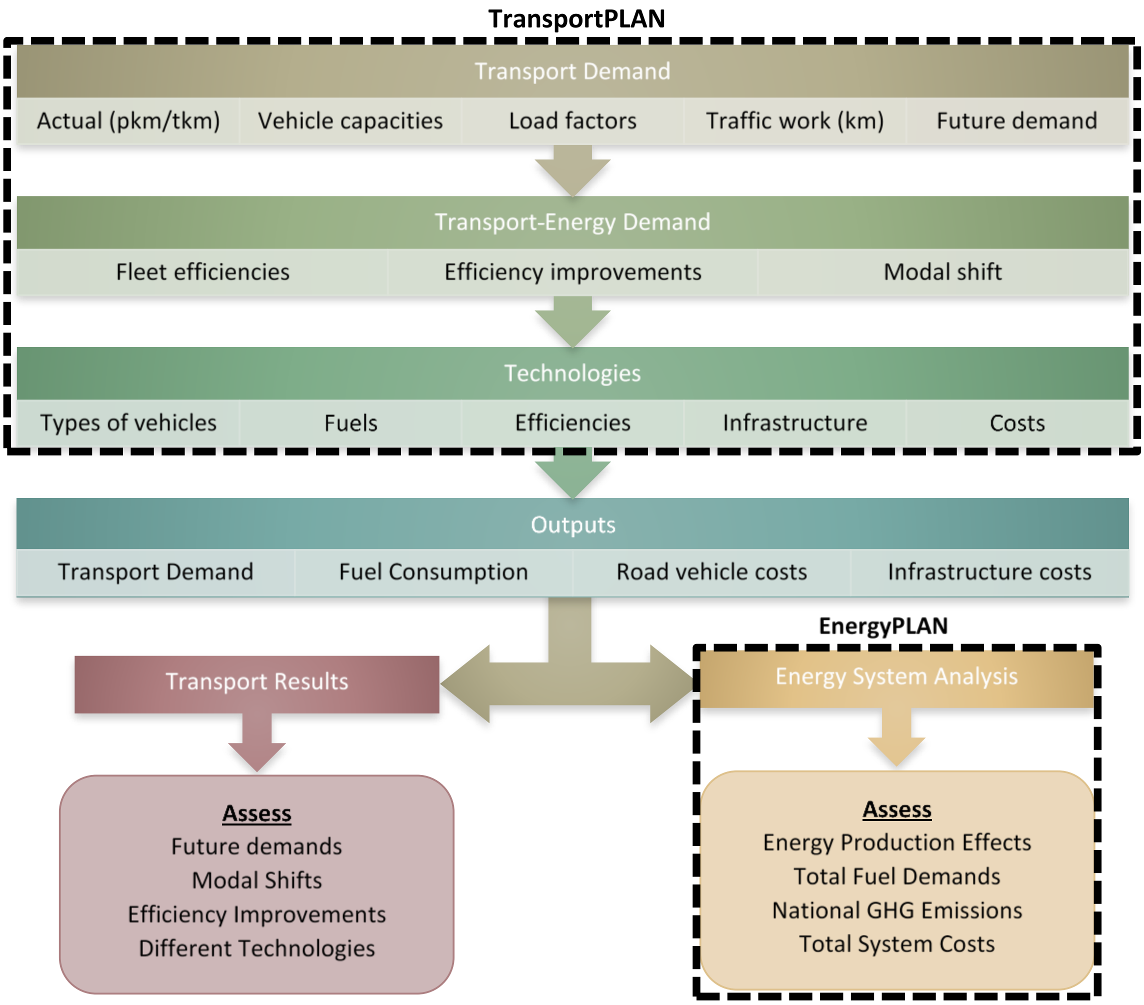

Figure 8. TransportPLAN methodology

The first inputs required for TransportPLAN are the transport demands for different modes. Figure 9 indicates what modes of transport were considered, and the main division is on passenger, freight and other transport of which only military transport was included to be comparable across models.

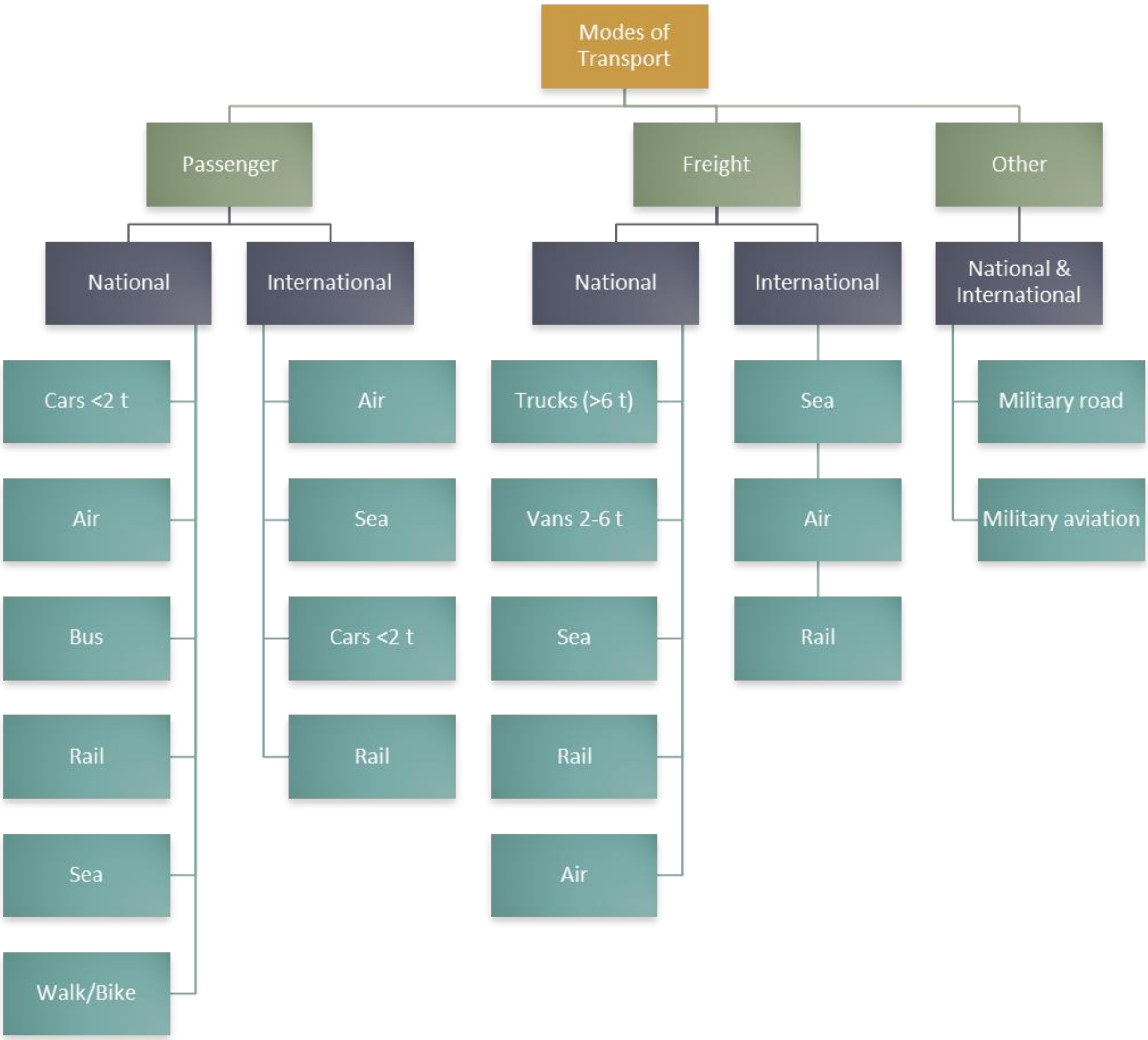

Figure 9. Modes of transport considered in transport scenarios

When creating a reference model based on a historical year the inputs used to profile the transport demand need to be adjusted to fit with the actual statistics. As this inputs were already available in the TransportPLAN for reference year of 2010, these inputs were adjusted to 2011 values based on the statistics available for this year [15]. The transport demand is measured in *pkm* for the passenger vehicles and in *tkm* for the freight vehicles. The Bicycle/walking demands were not available from statistics nor they were accounted in DEA scenarios, therefore the assumptions from 2010 were kept as inputs for 2011. Based on the statistics and inputs from DEA scenarios the international bus and trucks transport demands were excluded from the model as it was assessed that these modes are not included.

The Figure 10 and Figure 11 show the specific energy consumption for passenger and freight transport technologies for reference model 2011.

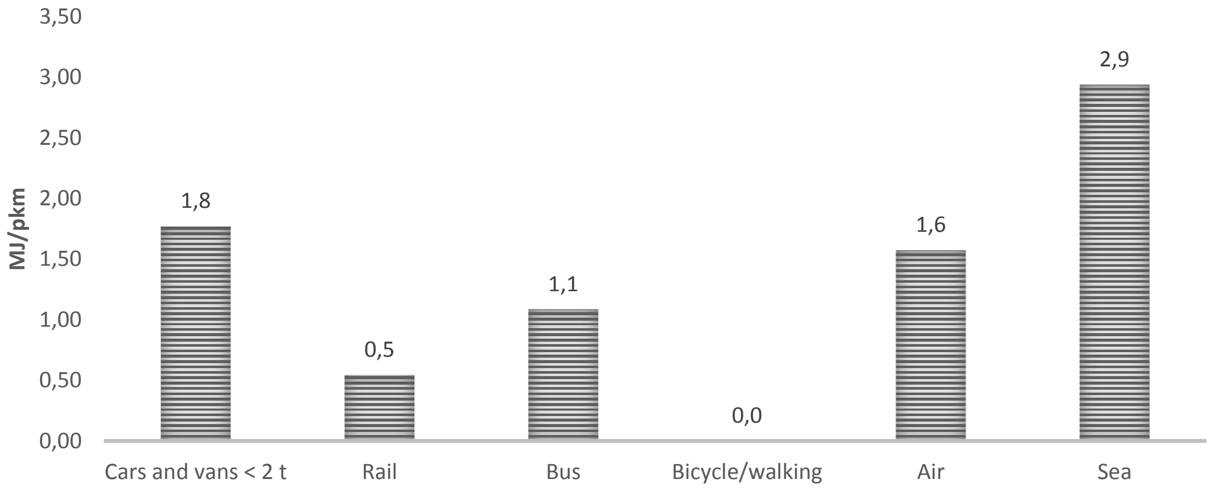

Figure 10. Specific energy consumption for passenger transport technologies for 2011

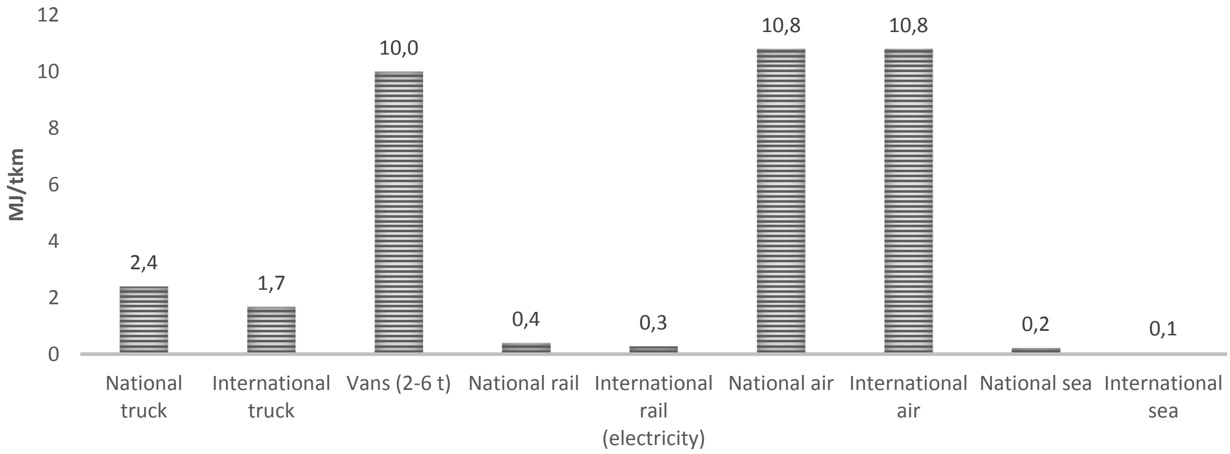

Figure 11. Specific energy consumption for freight transport technologies for 2011

The cars and vans, buses and aviation represent 88% of the demand for passenger transport in the 2011 Danish transport sector (from Table E2). However, as outlined in Figure 10, these are amongst the most inefficient forms of transportation accounting for 95% of the energy consumed (see Figure 12). Rail represents only 8% of the transport demand, but it is the most efficient form of passenger transport available, it also only accounts for 3% of the total energy demand.

If we look into freight transport and energy consumption we can see that vans represent only 4% of the demand for freight transport in 2011 (from Table E2), but account for 45% of energy consumed. Trucks on the other hand account for 13% of the transport demand using 38% of the energy consumed for freight transport. Ships are 100 times more efficient than vans and therefore consume only 6% of the energy for meeting 82% of the transport demand.

In general, different transport technologies used in road transport have the highest energy consumption.

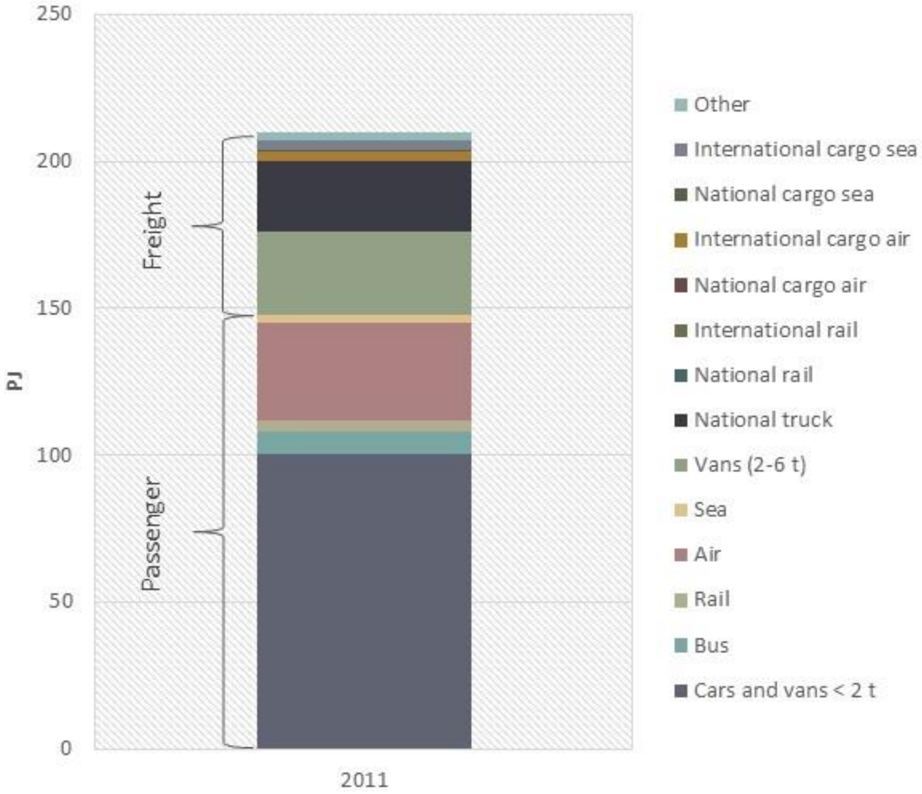

Figure 12. Energy consumption divided by mode of transport in 2011

For projecting the future transport demands it is necessarily to define the annual growth rate for each mode of transport for periods of growth that the data is available in transport demand growth module (TDGM) in TransportPLAN. The results are displayed for each period separately until 2050. It is important to note that the growth is based on the transport demand (i.e. pkm and tkm) and not on the traffic work (i.e. km). In this way user can model improvements in the vehicle utilisation and modal shift consequences. The growth rates are specified separately for passenger and freight transport.

For replication of DEA Fossil and Wind for both 2035 and 2050 the transport demand growth rates were adopted from their model. The IDA scenarios 2035 and 2050 have transport demand growth rates with different distributions than the growth in the DEA scenarios. The growth rates passenger transport in pkm and freight transport in tkm from 2011 to 2035 and 2050 for DEA and IDA scenarios are presented in Table E2 and Table E4.

It can be seen that the passenger transport growth rates in IDA scenario are in some cases negative or zero in period after 2030, while the DEA scenarios have constant increase in growth for passenger transport. This is as it is assumed in IDA scenarios that the DEA growth rates are too high for some modes of transport as for example the cars and vans transport demand in DEA scenarios increases by 60% (see Table E2).

Table E1. Growth rates for passenger transport for DEA and IDA scenarios

	DEA			ID		
	2011-2020	2020-2035	2030-2050	2011-2020	2020-2030	2030-2050
Passenger transport	Growth Rate (%/year)					
Cars and vans < 2 t	1.27%	1.88%	0.79%	1.40%	0.87%	-0.75%
Rail	0.61%	0.71%	0.36%	3.17%	6.29%	2.37%
Bus	0.31%	0.47%	0.23%	0.83%	2.22%	-0.10%
Bicycle /walking	0.00%	0.00%	0.00%	4.23%	1.22%	0.89%
Air	1.56%	2.35%	1.00%	2.12%	1.80%	-0.31%
Sea	0.12%	0.18%	0.09%	0.90%	0.90%	0.00%
Total	**1.16%**	**1.75%**	**0.76%**	**1.77%**	**1.77%**	**0.00%**

Table E2. Transport demands for passenger transport for 2011, DEA scenarios and IDA scenarios

		DEA			IDA		
	2011	2020	2035	2050	2020	2030	2050
Passenger transport	Transport Demand (Mpkm)						
Cars and vans < 2 t	56,500	64,084	77,211	90,441	64,936	70,806	60,896
Rail	7,278	7,737	8,301	8,919	9,943	18,305	29,238
Bus	7,251	7,479	7,834	8,207	7,878	9,813	9,616
Bicycle/walking	3,248	3,248	3,248	3,248	4,917	5,553	6,634
Air	21,170	24,714	31,174	38,007	26,116	31,211	29,304
Sea	925	936	953	970	1,011	1,106	1,106
Total	**96,372**	**108,199**	**132,923**	**149,792**	**114,800**	**136,794**	**136,794**

The growth rates for freight transport are rather different in IDA scenarios in comparison with DEA scenarios (see Table E3). DEA has a very low growth rates resulting in only 15% increase in freight transport demand. It is anticipated rather unrealistic to have such a low growth rates in freight transport for a period until 2050. Therefore, IDA scenarios have higher growth rates resulting in almost double transport demand in comparison to 2011 (see Table E4).

Table E3. Growth rates for freight transport for DEA and IDA scenarios

	DEA			IDA		
	2011-2020	**2020-2035**	**2030-2050**	**2011-2020**	**2020-2035**	**2035-2050**
Freight transport	Growth Rate (%/year)					
National truck	1.17%	1.76%	0.89%	2.16%	2.11%	1.00%
Vans (2-6 t)	1.32%	1.99%	1.18%	2.20%	2.20%	1.10%
National rail	0.49%	0.74%	0.35%	2.44%	4.75%	3.52%
International rail (electricity)	0.47%	0.47%	0.48%	2.30%	2.30%	1.15%
Cargo air	1.56%	1.56%	1.33%	1.15%	0.00%	0.00%
National cargo sea	0.12%	0.12%	0.12%v	0.95%	0.95%	0.48%
International cargo sea	0.12%	0.12%	0.12%	2.30%	2.30%	1.15%
Total	**0.32%**	**0.51%**	**0.29%**	**2.27%**	**2.24%**	**1.12%**

Table E4. Transport demands for freight transport for 2011, DEA scenarios and IDA scenarios

		DEA			IDA		
	2011	**2020**	**2035**	**2050**	**2020**	**2030**	**2050**
Freight transport	Transport Demand (Mtkm)						
National truck	10,002	11,237	13,379	15,976	12,391	15,270	18,650
Vans (2-6 t)	2,800	3,192	3,886	4,909	3,481	4,327	5,385
National rail	167	167	167	167	213	338	675
International rail (electricity)	378	396	425	457	779	978	1,229
National cargo air	1	1	1	1	1	1	1
International cargo air	300	350	442	539	336	336	336
National cargo sea	2,073	2,098	2,136	2,175	2,279	2,505	2,754
International cargo sea	59,694	60,414	61,511	62,627	74,935	94,068	118,239
Other	N/A	0	0	0	0	0	0
Total	**75,416**	**77,875**	**81,948**	**86,852**	**94,416**	**117,824**	**147,270**

The transport energy demand is evaluated based on the fleet efficiencies, the improvements in efficiency and modal shift. The fleet efficiencies and energy efficiency improvements were taken from the DEA model and implemented in all scenarios. The energy efficiency improvements were entered as annual energy efficiency improvement during the specified periods (see Table E5).

Table E5. Annual efficiency improvements for all scenarios

	Annual Energy Efficiency Improvement (%/year)			Total Improvement (%)
Period	**2011-2020**	**2020-2035**	**2035-2050**	**2011-2050**
Cars and Vans	0.25%	0.25%	0.17%	8%
Busses	0.05%	0.05%	0.03%	2%
Trucks	0.05%	0.05%	0.03%	2%
Rail (el)	0%	0%	0%	0%
Aviation	0.60%	0.60%	0.50%	20%
Sea	0.00%	0.00%	0.00%	0%
Other (military)	0.00%	0.00%	0.00%	0%

The specific energy consumption for passenger transport and freight transport technologies for 2035 and 2050 are illustrated in Figure 13 and Figure 14 for DEA scenarios. IDA scenarios have same specific energy consumption as DEA scenarios for passenger transport technologies. However, in freight transport technologies the vans and trucks have lower specific energy consumption 1.7 and 1.4 MJ/tkm, respectively, than in DEA scenarios where the specific energy consumption for vans and trucks are 2.4 and 1.6 MJ/tkm. This is due to the different load factors (t/vehicle) that are higher in IDA scenarios.

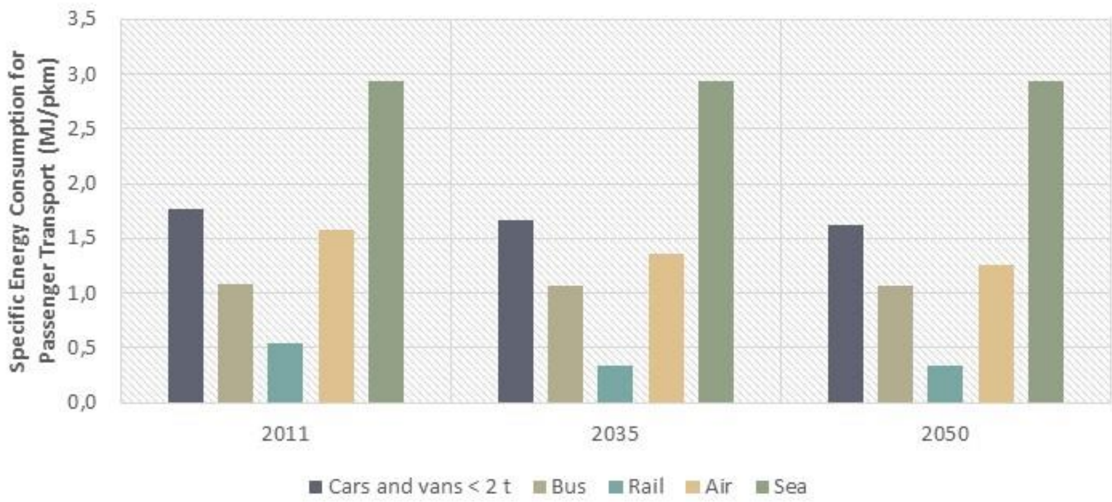

Figure 13. Specific energy consumption for passenger transport technologies for 2011, DEA 2035 and 2050

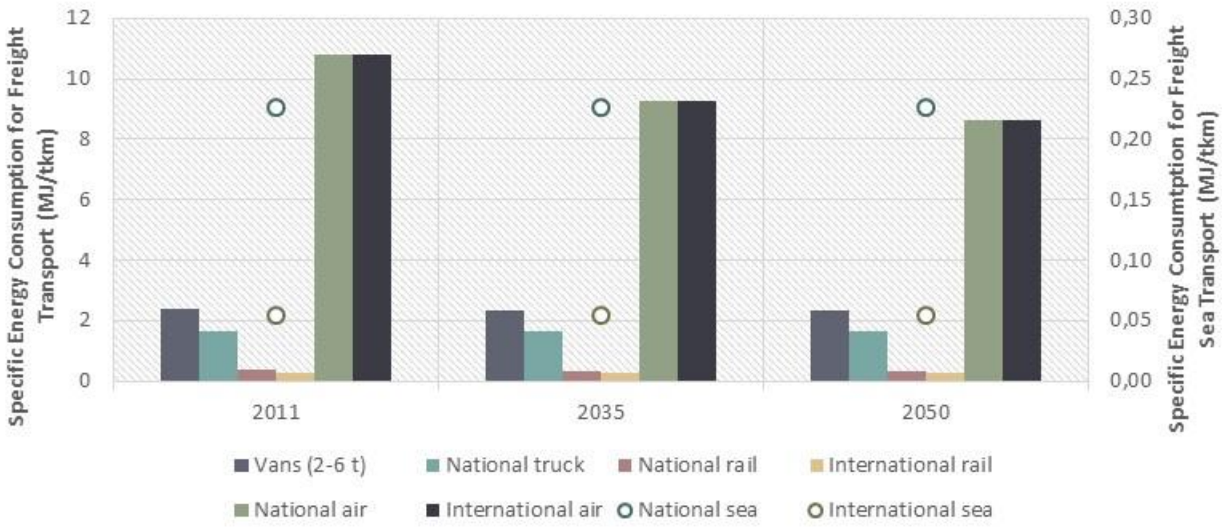

Figure 14. Specific energy consumption for freight transport technologies for 2011, DEA 2035 and 2050

The TransportPLAN tool has integrated modal shift module that allows the user to shift transport demand from one mode of transport to another. The starting point is 0% for a reference model and the modal shifts are introduced for each period but accounted so that if there was a modal shift in the first period it is included in the next one. All DEA scenarios Fossil and Wind for 2035 and 2050 have no modal shift included. This is as it was not possible to identify from the data on DEA scenarios was there any modal shift, to which extent and in what transport modes. The IDA transport scenario includes modal shift (see Figure 15) and they are mostly focused on passenger transport and to some extent on freight transport. The modal shift in passenger transport is highest for shifting from car and air travel to rail. This is as rail is the most efficient form of passenger technologies; therefore the high priority is given to it. For example, 100% of national aviation is in 2050 shifted to rail.

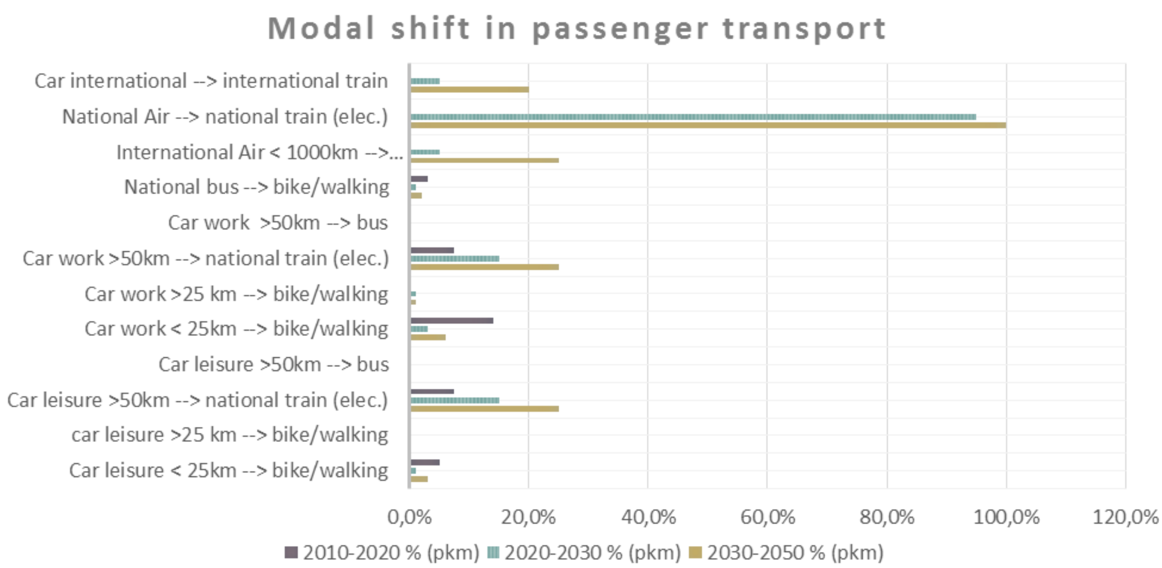

Figure 15.Modal shift rates applied for passenger transport in IDA scenario

TransportPLAN includes variety of different transport modes, therefore vehicle costs are important to consider. Due to the lack of data availability for different vehicles, only road vehicles were accounted in the model and the associated costs. In order to calculate total investment costs for road vehicles the following data for defined: number of vehicles, investment costs, O&M costs, lifetime and charging stations required (based on investment costs, lifetime and number per vehicle). All vehicle costs are connected to the demand for transport linking the number of road vehicles to the total traffic work and to make this possible the number of vehicles in reference year was identified and it was assumed that the number of vehicles increase over time proportionately to the traffic work. This means that if the traffic work was increased the total number of vehicles and the total vehicle costs increase accordingly.

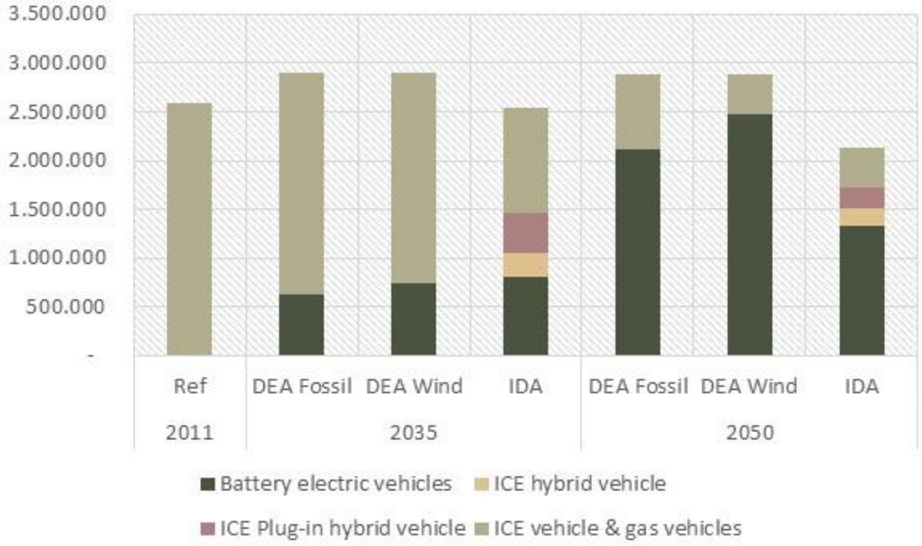

Figure 16. Number and type of vehicles in cars and van category

The vehicle count is based on the reference year and connected to growth over the years. The overview of the number of vehicles in the scenarios is visible on Figure 16 and Figure 17 for cars, vans busses and trucks. Here we can see the rise in battery electric vehicles as we switch from DEA fossil to DEA wind and from 2035 to 2050, while internal combustion vehicles and gas vehicles are reduced.

It was not possible to determine in DEA scenarios what amount of electricity in transport is used for battery electric vehicles and which amount for plug-in hybrids, therefore all of the EVs are modelled as battery electric vehicles and the efficiency was modified so it is aligned with electricity consumption for cars and vans. The similar was for busses and trucks. It needs to be noted that TransportPLAN does not model electric trucks so the electricity demand for trucks was added to vans. Both IDA scenarios 2035 and 2050 have lower number of vehicles in cars and van category and this is related to modal shifts of personal vehicle transportation towards rail. The division between different types of electric vehicles is more detailed in these scenarios.

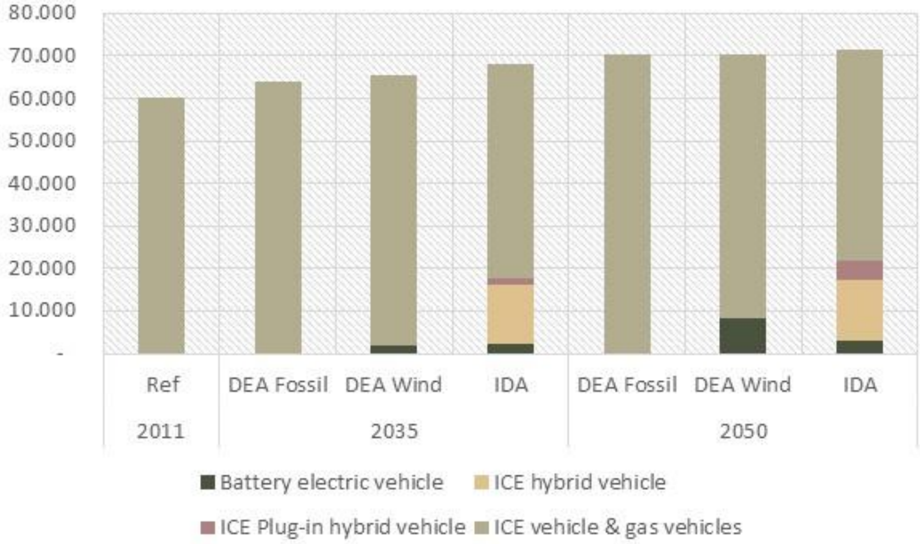

Figure 17. Number and type of vehicles in bus and truck category

The infrastructure costs accounted only road and rail costs since it is assumed that these infrastructure costs represent the majority of the total infrastructure costs in the transport sector. The infrastructure costs were calculated based on the total investment costs in new infrastructure and annual O&M costs in renewal of infrastructure. The costs are presented and accounted as marginal costs as it is important to consider economic implications of increasing the rail network or road infrastructure. A marginal cost per 1 km of traffic work was calculated based on existing infrastructure costs. Hence, when the traffic work was altered, the corresponding infrastructure costs for both road and rail were also altered.

The transport infrastructure and vehicle costs are presented in Figure 18. We can see from the costs that IDA scenarios have lower vehicle costs due to the lower number of vehicles have lower vehicle costs due to the assumed modal shifts of road transport to rail. Also due to the modal shifts IDA scenarios have higher costs for bike and pedestrian infrastructure that is represented in “Other”.

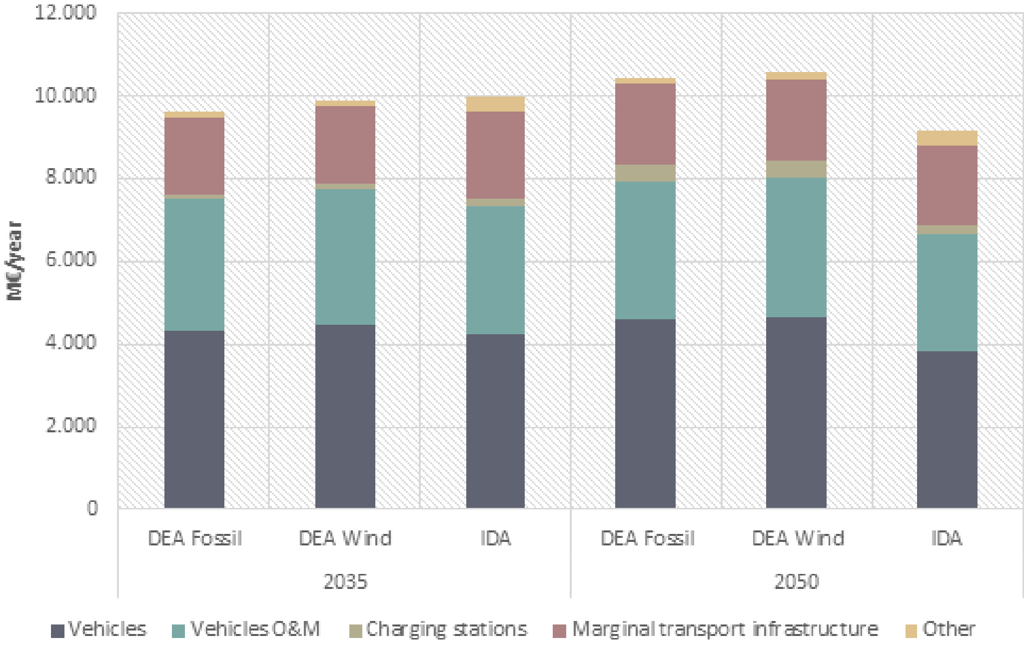

Figure 18. Annualized transport infrastructure and vehicle costs for DEA and IDA scenario

As an output, the tool provides the future projections of the transport fuel demands. The overview of energy demand required for meeting transport demand. We can see that IDA scenarios have lower energy demand than DEA scenarios. In 2050, IDA scenario has 17% lower energy demand than DEA Wind scenario and 25% lower than DEA Fossil scenario.

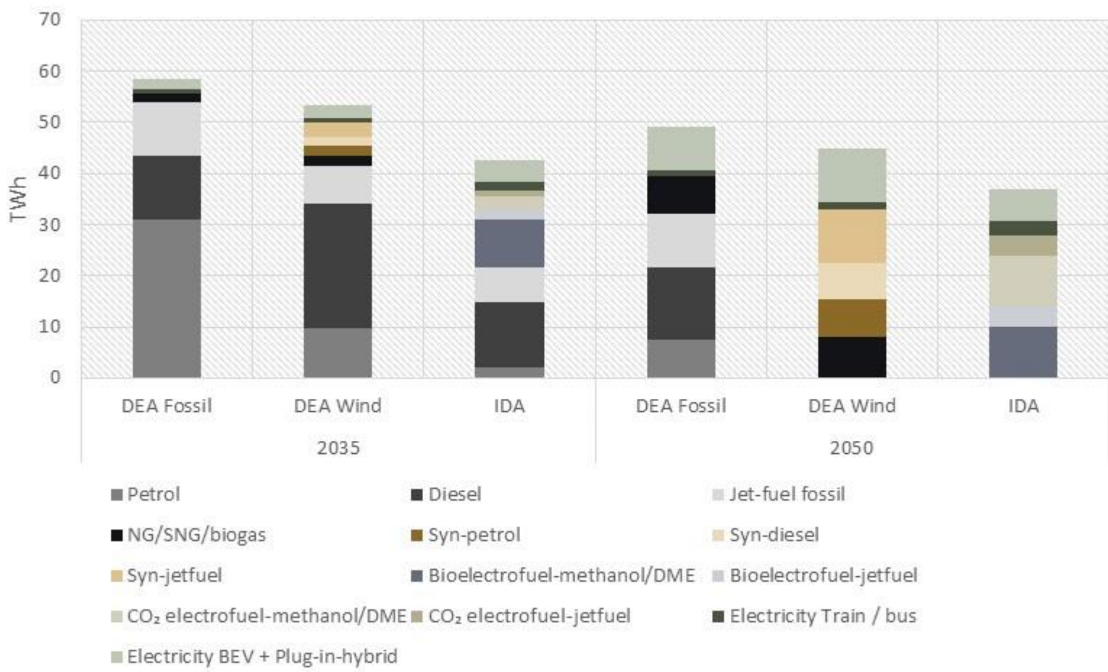

Figure 19. Energy consumed by fuel type for DEA and IDA scenarios

More detailed subdivisions of electricity demand for different transport modes are given Figure 20. Here it is visible that IDA scenarios have lower electricity consumption for different modes due to the lower share of EVs in personal transportation.

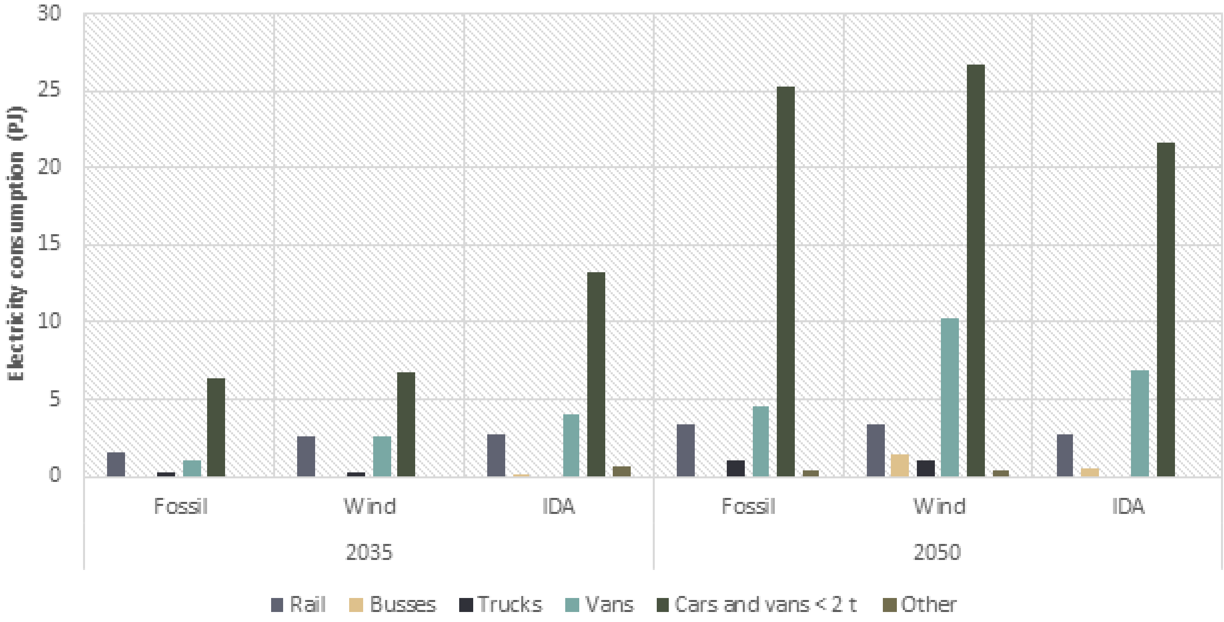

Figure 20 - Electricity powered modes of transport

Appendix F Scenario results

Table F1 - Primary energy demand by fuel for different scenarios for reference year 2015, 2035 and 2050

Scenario	Primary Energy Demand (TWh)									
	Coal	Oil	Gas	Biomass/waste	Onshore	Offshore	PV	Wave/tidal	Geothermal	Solar-thermal
Reference 2015	24,40	103,44	37,27	34,46	7,19	4,35	0,57	0,02	0,00	0,39
DEA Fossil 2035	72,11	56,17	15,69	28,44	10,74	8,89	0,68	0,00	0,20	1,68
DEA wind 2035	0,00	46,00	18,44	67,05	10,78	20,69	0,86	0,00	1,00	1,64
IDA 2035	0,64	28,93	10,40	86,41	12,50	26,30	3,80	0,00	5,00	4,72
DEA Fossil 2050	54,89	32,06	13,84	25,57	10,80	20,70	0,68	0,00	0,00	3,13
DEA wind 2050	0,00	0,00	0,01	86,89	10,78	57,60	1,70	0,00	1,23	3,13
IDA 2050	0,00	0,00	-0,01	64,64	16,20	63,76	6,35	0,00	4,64	4,59

Table 19 - Electricity demand for different scenarios for reference year 2015, 2035 and 2050

Scenario	Electricity Demand (TWh)								
	Conventional demand	Cooling demand	Flexible demand+dump transport electricity	Smart transport electricity	Heat pumps	Electrolysers	Electric boiler	Import	Export
Reference 2015	30,68	1,67	0,39	0	0,39	0	1,09	-4,39	7,79
DEA Fossil 2035	31,1	1,67	0,6	2,18	2,06	0	0	-0,02	15,84
DEA wind 2035	32,49	1,67	0,6	2,81	3,86	7,84	0	-1,37	7,03
IDA 2035	30,33	1,61	5,50	4,13	5,30	16,85	0,00	-0,11	19,49
DEA Fossil 2050	30,21	1,67	0,90	8,72	1,96	0,00	0,00	-0,67	13,80
DEA wind 2050	32,82	1,67	0,90	11,12	4,71	29,25	0,00	-4,41	10,40
IDA 2050	33,36	1,55	6,08	6,46	4,59	40,93	0,00	-0,84	14,56

Table 20 - Electricity capacity consumption for different scenarios for reference year 2015, 2035 and 2050

Scenario	Electricity Capacity Consumption (MW)								
	Conventional demand	Cooling demand	Flexible demand+dump transport electricity	Smart transport electricity	Heat pumps	Electrolysers	Electric boiler	Import	Export
Reference 2015	5548	2628	134	0	145	0	405	-4986	6150
DEA Fossil 2035	5617	338	133	2225	790	0	0	-3133	4111
DEA wind 2035	5875	338	133	4407	1450	1634	0	-5489	3222
IDA 2035	5477	326	1930	2908	1738	2263	0	-4140	4140
DEA Fossil 2050	5456	338	200	8761	784	0	0	-4140	5277
DEA wind 2050	5935	338	200	9696	1779	6561	0	-7316	10611
IDA 2050	6003	314	2011	4583	1623	9267	0	-4947	5378

Table 21 - Electricity production by technologies for different scenarios for reference year 2015, 2035 and 2050

Scenario	Electricity Production (TWh)												
	Onshore	Offshore	PV	River/wave	CSP	Hydro	Industry and waste	CHP	Power plant	Nuclear	Geothermal	Import	Export
Reference 2015	7,19	4,35	0,57	0,02	0,00	0,00	3,59	14,33	7,58	0,00	0,00	4,39	-7,79
DEA Fossil 2035	10,74	8,89	0,68	0,00	0,00	0,00	5,08	12,01	16,04	0,00	0,00	0,02	-15,84
DEA wind 2035	10,78	20,69	0,86	0,00	0,00	0,00	5,18	10,90	6,53	0,00	0,00	1,37	-7,03
IDA 2035	12,50	26,30	3,80	0,07	0,00	0,00	2,96	14,15	23,31	0,00	0,00	0,11	-19,49
DEA Fossil 2050	10,80	20,70	0,68	0,00	0,00	0,00	6,57	11,18	6,65	0,00	0,00	0,67	-13,80
DEA wind 2050	10,78	57,60	1,70	0,00	0,00	0,00	5,28	2,23	8,93	0,00	0,00	4,41	-10,40
IDA 2050	16,20	63,76	6,35	0,12	0,00	0,00	3,09	8,68	8,51	0,00	0,00	0,84	-14,56

Table 22 - Electricity production capacities by technologies for different scenarios for reference year 2015, 2035 and 2050

Scenario	Electricity Production Capacities (MW)											
	Onshore	Offshore	PV	River/ wave	CSP	Hydro	Industry and waste	CHP and power plant	Nuclear	Geothermal	Import	Export
Reference 2015	3759	1271	629	4	0	0	408	8974	0	0	4986	-6150
DEA Fossil 2035	3500	2150	625	0	0	0	579	5200	0	0	3133	-4111
DEA wind 2035	3500	5000	783	0	0	0	589	3347	0	0	5489	-3222
IDA 2035	3875	5887	2715	176	0	0	337	5526	0	0	4140	-4140
DEA Fossil 2050	3500	5000	625	0	0	0	748	4399	0	0	4140	-5277
DEA wind 2050	3500	14000	1562	0	0	0	601	5284	0	0	7316	-10611
IDA 2050	5000	14000	4388	300	0	0	352	6000	0	0	4947	-5378

Table 23 - District heating production by technologies for different scenarios for reference year 2015, 2035 and 2050

Scenario	District Heating Production (TWh)													
	District Heating solar thermal	Decentralised industry and geothermal	Decentra-lised CHP	Decentra-lised HP	Decentra-lised boilers	Decentra-lised Electric Heating	Decentra-lised District heat Imbalance	Centralised industry and geothermal	Centra-lised waste	Centra-lised CHP	Centra-lised HP	Centra-lised boilers	Centra-lised Electric Heating	Centra-lised District heat Imbalance
Reference 2015	0,28	0,35	5,33	0,00	2,55	0,00	-0,53	0,96	2,87	13,01	0,00	0,17	0,00	0,01
DEA Fossil 2035	0,98	0,80	4,06	0,00	6,69	0,00	0,00	0,91	7,60	9,85	0,00	0,00	0,00	-0,32
DEA wind 2035	0,95	1,96	5,47	1,42	2,71	0,00	0,00	3,34	7,60	6,38	0,50	1,21	0,00	-0,98
IDA 2035	2,33	2,27	2,39	5,36	2,25	0,00	0,00	7,52	4,82	8,23	2,27	0,82	0,00	-0,13
DEA Fossil 2050	1,73	0,60	4,04	0,00	4,90	0,00	0,00	0,96	8,66	6,30	0,00	0,52	0,00	-1,02

DEA wind 2050	1,73	3,96	1,96	2,27	1,35	0,00	0,00	13,25	8,16	0,00	1,29	0,76	0,00	-8,04
IDA 2050	2,35	2,52	2,55	5,57	0,55	0,00	0,00	11,97	5,18	3,96	1,91	0,11	0,00	-1,43

Table 24 - Carbon emissions for different scenarios for reference year 2015, 2035 and 2050

Scenario	Carbon Emissions (Mt)
	CO_2
Reference 2015	45
DEA Fossil 2035	43
DEA wind 2035	16
IDA 2035	10
DEA Fossil 2050	30
DEA wind 2050	0
IDA 2050	0

Table 25 - Electricity exchange for different scenarios for reference year 2015, 2035 and 2050

Scenario	Electricity exchange (TWh)			
	Electricity Import	Electricity Export	Critical Excess Electricity Production	Net export
Reference 2015	4,39	-7,79	0,00	-3,40
DEA Fossil 2035	0,02	-15,84	0,00	-15,82
DEA wind 2035	1,37	-7,03	0,00	-5,66
IDA 2035	0,11	-19,49	0,00	-19,38
DEA Fossil 2050	0,67	-13,80	-0,02	-13,13
DEA wind 2050	4,41	-10,40	-0,47	-5,99
IDA 2050	0,84	-14,56	-0,01	-13,72

Appendix G **EnergyPlan cost database**

G.1 Preface

The EnergyPLAN cost database is created and maintained by the Sustainable Energy Planning Research Group at Aalborg University, Denmark. It is constructed based on data from a wide variety of sources, with many of the inputs adjusted to fit with the required fields in the EnergyPLAN model. Below is a list of all the different sources currently used to construct the cost database. The result is a collection of investment, operation & maintenance, and lifetimes for all technologies for the years 2020, 2030, and 2050. Where data could not be obtained for 2030 or 2050, a 2020 cost is often assumed.

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- Danish Energy Agency. Forudsætninger for samfundsøkonomiske analyser på energiområdet (Assumptions for socio-economic analysis on energy). Danish Energy Agency, 2011. Available from: http://www.ens.dk.
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- Danish Energy Agency and Energinet.dk. Technology Data for Energy Plants: Generation of Electricity and District Heating, Energy Storage and Energy Carrier Generation and Conversion. Danish Energy Agency and Energinet.dk, 2012. Available from: http://www.ens.dk/.
- Joint Research Centre. Technology Map of the European Strategic Energy Technology Plan (SET-Plan): Technology Descriptions. European Union, 2011. Available from: http://setis.ec.europa.eu/.

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- Mathiesen BV, Ridjan I, Connolly D, Nielsen MP, Hendriksen PV, Mogensen MB, Jensen SH, Ebbesen SD. Technology data for high temperature solid oxide electrolyser cells, alkali and PEM electrolysers. Aalborg University, 2013. Available from: http://vbn.aau.dk/.
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- Danish Energy Agency and Energinet.dk. Technology Data for Energy Plants: Individual Heating Plants and Technology Transport. Danish Energy Agency and Energinet.dk, 2012. Available from: http://www.ens.dk/.
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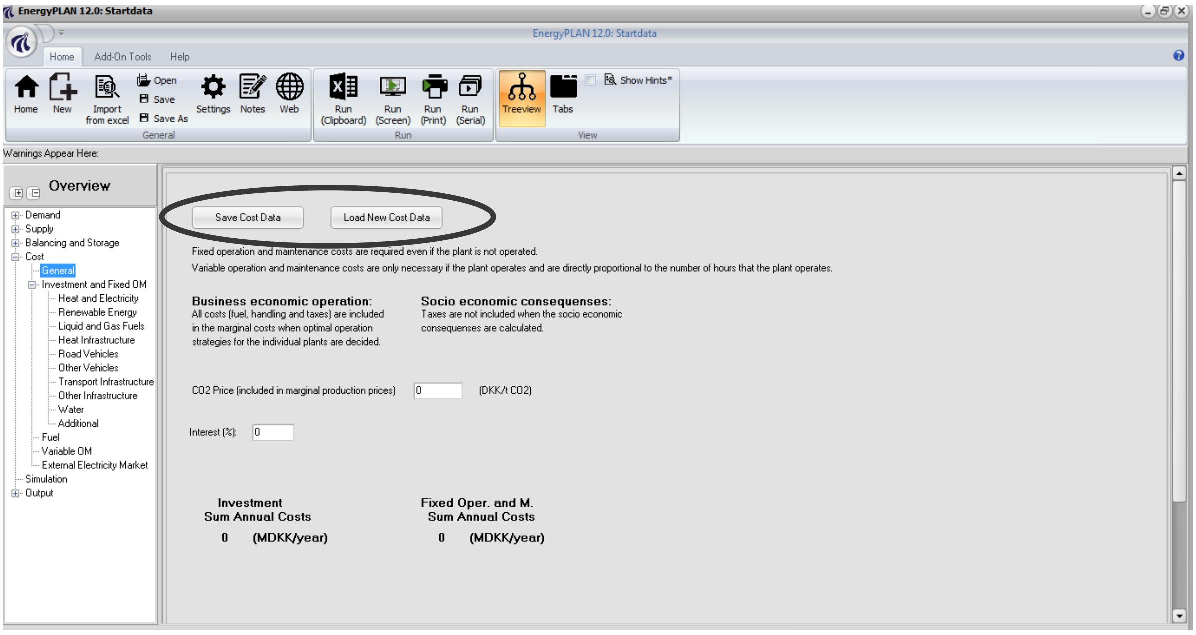
G.2 Introduction

The EnergyPLAN tool contains five tabsheets under the main ‘Cost’ tabsheet, which are:

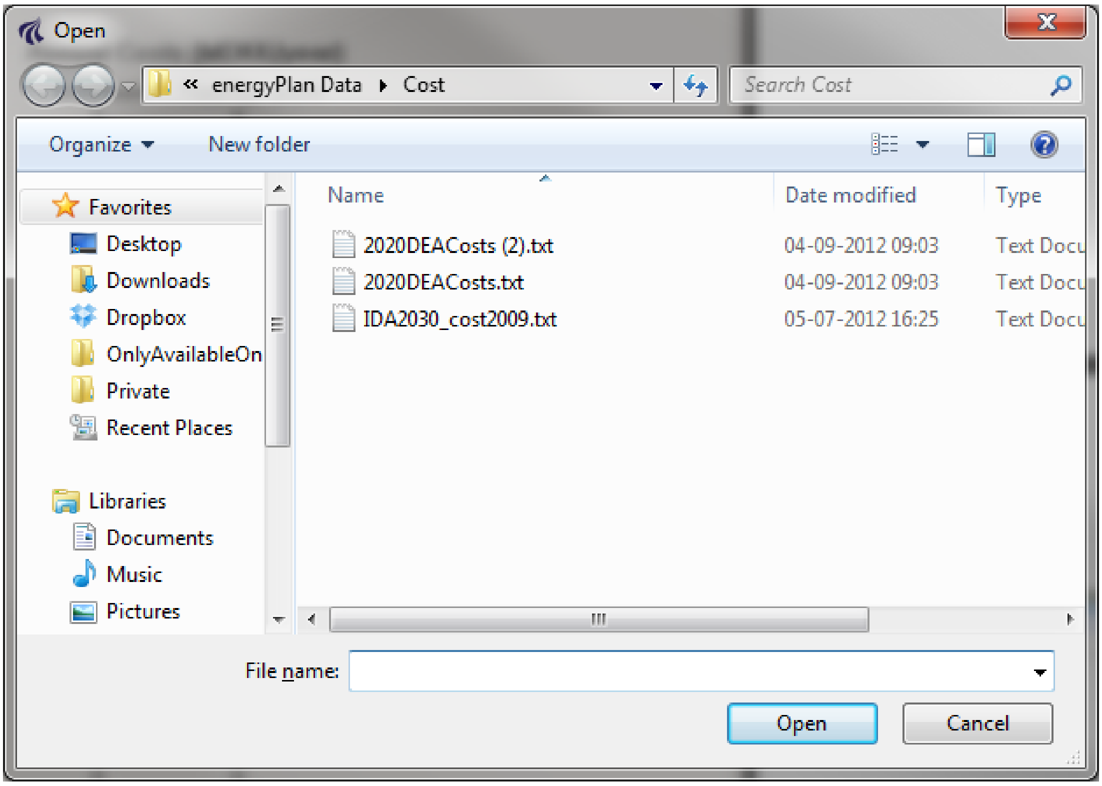
- General
- Investment and Fixed OM
- Fuel
- Variable OM
- External electricity market

The Investment and Fixed OM tabsheet further contains ten sub-tabsheets that relates to different technology groups such as Heat and Electricity, Renewable Energy, Heat infrastructure, Road vehicles, Additional, etc.

Within each of these, the user can enter over 200 inputs depending on the range of technologies being considered in an analysis. When completing an energy systems analysis, it is often necessary to change the cost data in EnergyPLAN for a variety of reasons: for example, to analyse the same system for a different year or to analyse the sensitivity of the system to different costs. To accommodate this, EnergyPLAN enables the user to change the cost data within a model, without changing any of the data under the other tabsheets. To do so, one has to go to the Cost-> General tabsheet and activate one of the two buttons “Save Cost Data” or “Load New Cost Data”.



When activating one of these buttons, the user will be brought to the ‘Cost’ folder where one can either save a new cost data file or load an existing one. It is important to note that when you are saving a file, you should always specify a filename with .txt at the end of the name, as otherwise it may not save correctly.



Even with this function, collecting cost data is still a very time-consuming task and hence, the EnergyPLAN Cost Database has been developed. This database includes cost data for almost all of the technologies included in EnergyPLAN based primarily on publications released by the Danish Energy Agency. This document gives a brief overview of this data.

G.3 EnergyPLAN Cost Database

To date, the EnergyPLAN Cost Database consists of the following files:

- 2020EnergyPLANCosts.txt
- 2030EnergyPLANCosts.txt
- 2050EnergyPLANCosts.txt

The file name represents the year which the costs are for. These are recommended based on the literature reviewed by the EnergyPLAN team and it is the user's responsibility to verify or adjust them accordingly. To date, the principal source for the cost data has been the Danish Energy Agency (DEA) [1], although a variety of other sources have been used where the data necessary is not available. Below is an overview of the data used to create the EnergyPLAN Cost Database, although it should be noted that this data is updated regularly, so there may be slight differences in the files provided.

G.3.1 Fuel Costs

The fuel prices assumed in the EnergyPLAN Cost Database are outlined in Table 26. Since the DEA only project fuel prices to 2030, the fuel prices in 2040 and 2050 were forecasted by assuming the same trends as experiences in the period between 2020 and 2030. These forecasts can change dramatically from one year to the next. For example, between January and August of 2012, the average oil price was $106/bbl, which is much closer to the oil price forecasted for 2020 than for the 2011 oil price.

Table 26: Fuel prices for 2011, 2020, 2030, 2040, and 2050 in the EnergyPLAN Cost Database [2, 3].

(2009 - €/GJ) Year	Oil (US$/bbl)	Natural Gas	Coal	Fuel Oil	Diesel	Petrol	Jet Fuel	Straw	Wood Chips	Wood Pellets	Energy Crops
2011	82.0	5.9	2.7	8.8	11.7	11.9	12.7	3.5	4.5	9.6	4.7
2035	105.0	8.3	2.8	11.6	16.0	16.4	16.4	6.0	6.0	10.9	6.9
2050	105.0	8.3	2.8	11.6	16.0	16.4	16.4	6.0	6.0	10.9	6.9

Fuel handling costs were obtained from the Danish Energy Agency [3]. They represent the additional costs of handling and storing fuels for different types of consumers as well as expected profit margins.

Table 27: Fuel handling costs for 2020 in the EnergyPLAN Cost Database [3].

2009 - €/GJ Fuel	Centralised Power Plants	Decentralised Power Plants & Industry	Consumer
Natural Gas	0.21	0.94	4.04
Coal	0.05	-	-
Fuel Oil	0.29	-	-
Diesel/Gas Oil	0.29	1.78	3.85
Petrol/Jet Fuel	-	-	-
Straw	0.68	0.55	-
Wood Chips	0.68	0.55	-
Wood Pellets	0.29	0.91	4.34
Energy Crops	1.65	1.65	-

The cost of emitting carbon dioxide is displayed in Table 28 and the CO_2 emission factors used for each fuel are outlined in Table 29.

G.3.2 Carbon Dioxide Costs and Emissions

Table 28: Carbon dioxide prices for 2011, 2035 and 2050 in the EnergyPLAN Cost Database [3].

2009-€/Ton	**CO2 Price**
2011	15.2
2035	28.51
2050	42.15

Table 29: Carbon dioxide emission factors for different fuels in the EnergyPLAN Cost Database [4].

Fuel	Coal/Peat	Oil	Natural Gas	Waste	LPG
Emission Factor (kg/GJ)	98.5	72.9	56.9	32.5	59.64

G.3.3 Variable Operation and Maintenance Costs

In the Operation tabsheet, the user inputs the variable operation and maintenance costs for a range of technologies. Variable O&M costs account for the additional costs incurred at a plant when the plant has to run such as more replacement parts and more labour. Those available in the EnergyPLAN Cost Database are outlined in Table 30.

Table 30: Variable operation and maintenance costs assumed for 2020 in the EnergyPLAN Cost Database.

Sector	Unit	Variable O&M Cost (€/MWh)
District Heating and CHP Systems	Boiler*	0.15
	CHP*	2.7
	Heat Pump	0.27
	Electric Heating	0.5
Power Plants	Hydro Power	1.19
	Condensing*	2.654
	Geothermal	15
	GTL M1	1.8
	GTL M2	1.008
Storage	Electrolyser	0
	Pump	1.19
	Turbine	1.19
	V2G Discharge	
	Hydro Power Pump	1.19
Individual	Boiler	Accounted for under individual heating costs in the Additional tabsheet
	CHP	
	Heat Pump	
	Electric Heating	

***These costs need to be calculated based on the mix of technologies in the energy system, which can vary substantially from one system to the next.**

G.3.4 Investment Costs

Table 31 outlines the investment costs in the EnergyPLAN Cost Database for the different technologies considered in EnergyPLAN. Note that different technology costs are expressed in different units, so when defining the capacity of a technology, it is important to use the same unit in for the technical input as in the cost input.

Table 31: Investment costs for 2020, 2030, and 2050 in the EnergyPLAN Cost Database.

	Unit: M€/Unit	Unit	2020	2030	2050
Heat & Electricity	Small CHP	MWe	1.2	1.2	1.2
	Large CHP	MWe	0.8	0.8	0.8
	Heat Storage CHP	GWh	3.0	3.0	3.0
	Waste CHP	TWh/year	215.6	215.6	215.6
	Absorption Heat Pump	MWth	0.4	0.4	0.4
	Heat Pump Group 2	MWe	3.4	3.4	2.9
	Heat Pump Group 3	MWe	3.4	3.3	2.9
	DHP Boiler Group 1	MWth	0.100	0.100	0.100
	Boilers Group 2 & 3	MWth	0.075	0.100	0.100
	Electric Boiler	MWth	0.075	0.075	0.075
	Large Power Plants	MWe	0.99	0.98	0.9
	Nuclear	MWe	3.6	3.6	3.0
	Interconnection	MWe	1.2	1.2	1.2
	Pump	MWe	0.6	0.6	0.6
	Turbine	MWe	0.6	0.6	0.6
	Pump Storage	GWh	7.5	7.5	7.5
	Industrial CHP Electricity	TWh/year	68.3	68.3	68.3
	Industrial CHP Heat	TWh/year	68.3	68.3	68.3
Renewable Energy	Wind Onshore	MWe	1.1	1.0	0.9
	Wind Offshore	MWe	2.9	2.4	2.1
	Photovoltaic	MWe	1.0	0.8	0.7
	Wave Power	MWe	6.4	3.4	1.6
	Tidal	MWe	6.5	5.3	5.3
	CSP Solar Power	MWe	6.0	6.0	6.0
	River Hydro	MWe	3.3	3.3	3.3
	Hydro Power	MWe	3.3	3.3	3.3
	Hydro Storage	GWh	7.5	7.5	7.5
	Hydro Pump	MWe	0.6	0.6	0.6
	Geothermal Electricity	MWe	4.6	4.0	4.0
	Geothermal Heat	TWh/year	0.0	0.0	0.0

	Solar Thermal	TWh/year	386.0	307.0	307.0
	Heat Storage Solar	GWh	3.0	3.0	3.0
	Industrial Excess Heat	TWh/year	40.0	40.0	40.0
Liquid and Gas Fuels	Biogas Plant	TWh/year	240	240	240
	Gasification Plant	MW Syngas	0.4	0.3	0.3
	Biogas Upgrade	MW Gas Out	0.3	0.3	0.3
	Gasification Gas Upgrade	MW Gas Out	0.3	0.3	0.3
	2nd Generation Biodiesel Plant	MW-Bio	3.4	2.5	1.9
	Biopetrol Plant	MW-Bio	0.8	0.6	0.4
	Biojetpetrol Plant	MW-Bio	0.8	0.6	0.4
	CO2 Hydrogenation Electrolyser	MW-Fuel	0.9	0.6	0.4
	Synthetic Methane Electrolyser	MW-Fuel	0.0	0.0	0.0
	Chemical Synthesis MeOH	MW-Fuel	0.6	0.6	0.6
	Alkaline Electrolyser	MWe	2.5	0.9	0.9
	SOEC Electrolyser	MWe	0.6	0.4	0.3
	Hydrogen Storage	GWh	20.0	20.0	20.0
	Gas Storage	GWh	0.1	0.1	0.1
	Oil Storage	GWh	0.0	0.0	0.0
	Methanol Storage	GWh	0.1	0.1	0.1
Heat Infrastructure	Individual Boilers	1000 Units	6.1	0.0	0.0
	Individual CHP	1000 Units	12.0	0.0	0.0
	Individual Heat Pump	1000 Units	14.0	0.0	14.0
	Individual Electric Heat	1000 Units	8.0	0.0	0.0
	Individual Solar Thermal	TWh/year	1700.0	1533.3	1233.3
Road Vehicles	Bicycles	1000 Vehicles	0.0	0.0	0.0
	Motorbikes	1000 Vehicles	6.0	6.0	6.0
	Electric Cars	1000 Vehicles	18.1	18.1	18.1
	Conventional Cars	1000 Vehicles	20.6	20.6	20.6
	Methanol/DME Busses	1000 Vehicles	177.2	177.2	177.2
	Diesel Busses	1000 Vehicles	177.2	177.2	177.2
	Methanol/DME Trucks	1000 Vehicles	99.2	99.2	99.2
	Diesel Trucks	1000 Vehicles	99.2	99.2	99.2
Wat	Desalination	1000 m3 Fresh Water/hour	0.1	0.1	0.1

	Water Storage	Mm3	0.0	0.0	0.0

**Power plant costs need to be calculated based on the mix of technologies in the energy system, which can vary substantially from one system to the next.*

G.3.5 Fixed Operation and Maintenance Costs

	Unit: % of Investment	Unit	2020	2030	2050
Heat & Electricity	Small CHP	MWe	3.75	3.75	3.75
	Large CHP	MWe	3.66	3.66	3.80
	Heat Storage CHP	GWh	0.70	0.70	0.70
	Waste CHP	TWh/year	7.37	7.37	7.37
	Absorption Heat Pump	MWth	4.68	4.68	4.68
	Heat Pump Group 2	MWe	2.00	2.00	2.00
	Heat Pump Group 3	MWe	2.00	2.00	2.00
	DHP Boiler Group 1	MWth	3.70	3.70	3.70
	Boilers Group 2 & 3	MWth	1.47	3.70	3.70
	Electric Boiler	MWth	3.70	1.47	1.47
	Large Power Plants	MWe	3.12	3.16	3.26
	Nuclear	MWe	2.53	2.49	1.96
	Interconnection	MWe	1.00	1.00	1.00
	Pump	MWe	1.50	1.50	1.50
	Turbine	MWe	1.50	1.50	1.50
	Pump Storage	GWh	1.50	1.50	1.50
	Industrial CHP Electricity	TWh/year	7.32	7.32	7.32
	Industrial CHP Heat	TWh/year	7.32	7.32	7.32
Renewable Energy	Wind Onshore	MWe	2.51	2.59	2.88
	Wind Offshore	MWe	2.56	2.94	3.22
	Photovoltaic	MWe	1.00	1.00	1.01
	Wave Power	MWe	0.59	1.04	1.97
	Tidal	MWe	3.00	3.66	3.66
	CSP Solar Power	MWe	8.21	8.21	8.21
	River Hydro	MWe	2.00	2.00	2.00
	Hydro Power	MWe	2.00	2.00	2.00
	Hydro Storage	GWh	1.50	1.50	1.50

	Hydro Pump	MWe	1.50	1.50	1.50
	Geothermal Electricity	MWe	3.50	3.50	3.50
	Geothermal Heat	TWh/year	0.00	0.00	0.00
	Solar Thermal	TWh/year	0.13	0.15	0.15
	Heat Storage Solar	GWh	0.70	0.70	0.70
	Industrial Excess Heat	TWh/year	1.00	1.00	1.00
Liquid and Gas Fuels	Biogas Plant	TWh/year	6.96	6.96	6.96
	Gasification Plant	MW Syngas	5.30	7.00	7.00
	Biogas Upgrade	MW Gas Out	15.79	17.65	18.75
	Gasification Gas Upgrade	MW Gas Out	15.79	17.65	18.75
	2nd Generation Biodiesel Plant	MW-Bio	3.01	3.01	3.01
	Biopetrol Plant	MW-Bio	7.68	7.68	7.68
	Biojetpetrol Plant	MW-Bio	7.68	7.68	7.68
	CO2 Hydrogenation Electrolyser	MW-Fuel	2.46	3.00	3.00
	Synthetic Methane Electrolyser	MW-Fuel	0.00	0.00	0.00
	Chemical Synthesis MeOH	MW-Fuel	3.48	3.48	3.48
	Alkaline Electrolyser	MWe	4.00	4.00	4.00
	SOEC Electrolyser	MWe	2.46	3.00	3.00
	Hydrogen Storage	GWh	0.50	0.50	0.50
	Gas Storage	GWh	1.00	1.00	1.00
	Oil Storage	GWh	0.63	0.63	0.63
	Methanol Storage	GWh	0.63	0.63	0.63
Heat Infrastructure	Individual Boilers	1000 Units	1.79	0.00	0.00
	Individual CHP	1000 Units	0.00	0.00	0.00
	Individual Heat Pump	1000 Units	0.98	0.00	0.98
	Individual Electric Heat	1000 Units	1.00	0.00	0.00
	Individual Solar Thermal	TWh/year	1.22	1.35	1.68
Road Vehicles	Bicycles	1000 Vehicles	0.00	0.00	0.00
	Motorbikes	1000 Vehicles	5.00	5.00	5.00
	Electric Cars	1000 Vehicles	6.99	4.34	4.34
	Conventional Cars	1000 Vehicles	4.09	4.09	4.09
	Methanol/DME Busses	1000 Vehicles	9.14	9.14	9.14
	Diesel Busses	1000 Vehicles	9.14	9.14	9.14

	Methanol/DME Trucks	1000 Vehicles	21.10	21.10	21.10
	Diesel Trucks	1000 Vehicles	21.10	21.10	21.10

G.3.6 Lifetimes

	Unit: Years	Unit	2020	2030	2050
Heat & Electricity	Small CHP	MWe	25	25	25
	Large CHP	MWe	25	25	25
	Heat Storage CHP	GWh	20	20	20
	Waste CHP	TWh/year	20	20	20
	Absorption Heat Pump	MWth	20	20	20
	Heat Pump Group 2	MWe	25	25	25
	Heat Pump Group 3	MWe	25	25	25
	DHP Boiler Group 1	MWth	35	35	35
	Boilers Group 2 & 3	MWth	20	35	35
	Electric Boiler	MWth	35	20	20
	Large Power Plants	MWe	27	27	27
	Nuclear	MWe	30	30	30
	Interconnection	MWe	40	40	40
	Pump	MWe	50	50	50
	Turbine	MWe	50	50	50
	Pump Storage	GWh	50	50	50
	Industrial CHP Electricity	TWh/year	25	25	25
	Industrial CHP Heat	TWh/year	25	25	25
Renewable Energy	Wind Onshore	MWe	20	25	30
	Wind Offshore	MWe	20	25	30
	Photovoltaic	MWe	35	40	40
	Wave Power	MWe	20	25	30
	Tidal	MWe	20	20	20
	CSP Solar Power	MWe	25	25	25
	River Hydro	MWe	50	50	50
	Hydro Power	MWe	50	50	50
	Hydro Storage	GWh	50	50	50

	Hydro Pump	MWe	50	50	50
	Geothermal Electricity	MWe	20	20	20
	Geothermal Heat	TWh/year	0	0	0
	Solar Thermal	TWh/year	30	30	30
	Heat Storage Solar	GWh	20	20	20
	Industrial Excess Heat	TWh/year	30	30	30
Liquid and Gas Fuels	Biogas Plant	TWh/year	20	20	20
	Gasification Plant	MW Syngas	25	25	25
	Biogas Upgrade	MW Gas Out	15	15	15
	Gasification Gas Upgrade	MW Gas Out	15	15	15
	2nd Generation Biodiesel Plant	MW-Bio	20	20	20
	Biopetrol Plant	MW-Bio	20	20	20
	Biojetpetrol Plant	MW-Bio	20	20	20
	CO2 Hydrogenation Electrolyser	MW-Fuel	20	15	15
	Synthetic Methane Electrolyser	MW-Fuel	0	0	0
	Chemical Synthesis MeOH	MW-Fuel	20	20	20
	Alkaline Electrolyser	MWe	28	28	28
	SOEC Electrolyser	MWe	20	15	15
	Hydrogen Storage	GWh	30	30	30
	Gas Storage	GWh	50	50	50
	Oil Storage	GWh	50	50	50
	Methanol Storage	GWh	50	50	50
Heat Infrastructure	Individual Boilers	1000 Units	21	0	0
	Individual CHP	1000 Units	10	0	0
	Individual Heat Pump	1000 Units	20	0	20
	Individual Electric Heat	1000 Units	30	0	0
	Individual Solar Thermal	TWh/year	25	30	30
Road Vehicles	Bicycles	1000 Vehicles	0	0	0
	Motorbikes	1000 Vehicles	15	0	15
	Electric Cars	1000 Vehicles	16	16	16
	Conventional Cars	1000 Vehicles	16	16	16
	Methanol/DME Busses	1000 Vehicles	6	6	6
	Diesel Busses	1000 Vehicles	6	6	6

	Methanol/DME Trucks	1000 Vehicles	6	6	6
	Diesel Trucks	1000 Vehicles	6	6	6

G.3.7 Additional Tabsheet

The additional tabsheet under the Investment and Fixed OM tabsheet can be used to account for costs which are not included in the list of technologies provided in the other tabsheets. Typically these costs are calculated outside of the EnergyPLAN tool and subsequently inputted as a total. In the past, this section has been used to include the costs of the following technologies:

- Energy efficiency measures
- Electric grid costs
- Individual heating costs
- Interconnection costs
- Costs for expansion of district heating and cooling

Some of these costs vary dramatically from one energy system to the next and hence they are not included in the cost files which can be loaded into EnergyPLAN. However, below are some costs which may provide a useful starting point if additional costs need to be estimated.

Heating

Individual heating can be considered automatically by EnergyPLAN or added as an additional cost. To use the automatic function, you must specify an average heat demand per building in the Individual heating tabsheet. Using this, in combination with the total heat demand, EnergyPLAN estimates the total number of buildings in the energy system. This is illustrated in the Cost->Investment and Fixed OM ->Heat infrastructures window. The price presented in Table 31 above represents the average cost of a boiler in a single house, which is used to automatically estimate the cost of the heating infrastructure. This is a fast method, but it can overlook variations in the type of boilers in the system. For example, some boilers will be large common boilers in the basement of a building rather than an individual boiler in each house.

To capture these details, we recommend that you build a profile of the heating infrastructure outside of the EnergyPLAN tool and insert the costs as an additional cost. Below in Table 32 is a list of cost assumptions you can use if you do this.

Table 32: Individual heating unit costs for 2020 in the EnergyPLAN Cost Database [17].

Parameter	Oil boiler	Natural gas boiler	Biomass boiler	Heat pump air-to-water	Heat pump brine-to-water	Electric heating	District heating substation
Capacity of one unit (kW_{th})	15-30	3-20	5-20	10	10	5	10
Annual average efficiency (%)	100	100-104	87	330	350	100	98
Technical lifetime (years)	20	22	20	20	20	30	20
Specific investment (1000€/unit)	6.6	5	6.75	12	16	4	2.5
Fixed O&M (€/unit/year)	270	46	25	135	135	50	150
Variable O&M (€/MWh)	0.0	7.2	0.0	0.0	0.0	0.0	0.0