Appendix for the article: "The role of 4th generation district heating (4GDH) in a highly electrified hydropower dominated energy system – The case of Norway"

Inputs for 2016 Norwegian energy system model

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1. *Input variables in EnergyPLAN*

In the following tables, Table 1- 4, relevant inputs for the constructed 2016 EnergyPLAN model for the analysis presented in the paper "The role of 4th generation district heating (4GDH) in a highly electrified hydropower dominated energy system – The case of Norway" are presented.

Table 1: Demands in EnergyPLAN for the 2016 reference model

Demands			
Variable	**Value**	**Reference**	**Note**
Electricity [TWh/year]	132.6	[1]	Including network losses.
Individual heating [TWh/year]	56.42		Calculated as sum of all individual demands.
- Oil	6.12	[2]	Assuming all oil products used in service and household sectors are for heating purposes.
- Natural gas	0.3	[2]	Assuming all natural gas used in service and household sectors are for heating purposes.
- Biomass	3.7	[2]	Assuming all biofuels used in service and household sectors are for heating purposes.
- Heat pumps	7.4	[3][4]	Estimated based on reported electricity usage in [3] and using a COP of 2 for air-to-air heat pumps from [4].
- Direct electricity	35.2	[3]	
District heating [TWh/year]	5.26	[5]	Excluding network losses
Industrial fuel demand [TWh/year]			
- Coal	7.6	[2]	
- Oil	250.9	[2]	
- Natural gas	54.7	[2]	
- Biomass	2.4	[2]	

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Transport fuel demand [TWh/year]			
- JP (Jet fuel)	4.13	[2]	
- Diesel/DME fossil	34.2	[2]	
- Diesel/DME bio	3.8	[2]	
- Petrol/Methanol	8.6	[2]	
- Natural gas	1.3	[2]	
- LPG	0.13	[2]	
- Electricity	0.3	[2]	

Table 2: Electric supply capacities in EnergyPLAN for the 2016 reference model

Electricity Supply			
Variable	**Value**	**Reference**	**Note**
Wind power			
Installed capacity [MWe]	883	[6]	
Annual generation [TWh/year]	2.12	[6]	
Photo voltaic			
Installed capacity [MWe]	13.6	[7]	
Annual generation [TWh/year]	0.02	[7]	
River hydro (unregulated hydro)			
Installed capacity [MWe]	1,352	[8]	
Annual generation [TWh/year]	4.36		Estimated assuming a 0.37 capacity factor from [6, p.26]
Pumped hydropower			
Installed pump capacity [MWe]	1,392	[10]	
Reservoir hydro			
Installed turbine capacity [MWe]	30,274	[6]	Run-of-river hydro subtracted.
Storage capacity [GWh]	86,500	[11]	
Annual generation [TWh/year]	139.05	[1]	Subtracting estimated river hydro production.
Waste incineration			
Waste input [TWh/year]	4.21	[12], [13]	Number from 2017 as statistics only go back to this year. Average heating values for waste used for conversion.
Annual electricity generation [TWh/year]	0.36	[1], [12], [14]	Estimated based on data for thermal electricity production and share of thermal electricity production from waste incineration.
Annual heat generation [TWh/year]	2.76	[5]	
Natural gas CHP			
Generation capacity [MW]	473	[15]	

Electric efficiency [%]	36	[4]	
Interconnections			
Transmission line capacity [MW]	8,895	[16]	Including new transmission line capacity available from 2020 and 2021.

Table 3: Individual heating supply, capacities and efficiencies for the 2016 reference model

Individual heating supply			
Variable	**Value**	**Reference**	**Note**
Direct electric heating			
- Heat demand [TWh/year]	35.19		Estimated electricity demand in EnergyPLAN.
- Efficiency [%]	98	[4]	
Heat pumps			
- Heat demand [TWh/year]	3.7		Estimated electricity demand in EnergyPLAN.
- COP [-]	2	[4]	
Oil boiler			
- Fuel demand [TWh/year]	6.12		Calculated based on heat demand presented in Table 1 and efficiency.
- Efficiency [%]	92	[4]	
Natural gas boiler			
- Fuel demand [TWh/year]	0.1		Calculated based on heat demand presented in Table 1 and efficiency.
- Efficiency [%]	100	[4]	
Biomass boiler			
- Fuel demand [TWh/year]	3.7		Calculated based on heat demand presented in Table 1 and efficiency.
- Efficiency [%]	83	[4]	

Table 4: District heating supply, capacities and efficiencies for the 2016 reference model

District heating supply			
Variable	**Value**	**Reference**	**Note**
Electric boilers			
- Capacity [MW-e]	313.7		Calculation based on reported production from [5] and 2500 full load hours as defined in [4].
- Thermal efficiency [%]	98	[4]	
- Production [TWh/year]	7.84	[5]	
Heat pumps			
- Capacity [MW-e]	49.5		Calculation based on reported production from [5] and 4000 full load hours as defined in [4].
- COP [-]	2.9	[4]	1 MW sea-water heat pump with 70°C output.
- *Production [TWh/year]*	*0.57*	[5]	*Not an input in EnergyPLAN.*
Oil boiler			
- Capacity [MW]	152.9		Calculation based on reported production from [5] and 1000 full load hours as defined in [4]. Includes bio oil. Assuming 20% excess capacity
- Efficiency [%]	92	[4]	
- Heat production [TWh/year]	0.13	[5]	*Not an input in EnergyPLAN.*
Natural gas boiler			
- Capacity [MW]	336.5		Calculation based on reported production from [5] and 1000 full load hours as defined in [4]. Assuming 20% excess capacity.
- Efficiency [MW]	92	[4]	
- Heat production [TWh/year]	0.26	[5]	*Not an input in EnergyPLAN.*
Biomass boiler			
- Capacity [MW]	364		Calculation based on reported production from [5] and 4000 full load hours as defined in [4].
- Efficiency [%]	85	[4]	
- Heat production [TWh/year]	1.24	[5]	*Not an input in EnergyPLAN.*
Excess heat [TWh/year]	0.184	[5]	

1. Time series

The most important time series used in the 2016 EnergyPLAN model are listed with references in Table 5.

Table 5: Overview of important time series used in the 2016 model in EnergyPLAN

Time series	Reference	Note
Electricity demand 2016	[17]	Reported hourly electricity demand in Norway in 2016.
Individual heat demand		Constructed. See section 2.1 for further description.
District heat demand		Constructed. See section 2.1 for further description.
Industrial excess heat		Assumed constant.
Waste incineration		Assumed constant.
Hydropower inflow	[18]	Based on measured and modelled inflow data to 82 measurement points in 2016.
Wind power production	[17]	Based on wind production in Western Denmark in 2015 under the assumption that wind conditions are similar on the west coast of Norway, where most turbines are placed.

1.1 Heating demands

The hourly distributions for heating demands, both individual and district heating, are constructed based on the degree days. For the district heating profile the annual demand is split into 366 inputs that are weighted according to the average number of degree days in every single day. The average number of degree days is found using temperature data from [19] and weighting these according to the amount of district heating demand in the different counties. See Table 6 for data used for the calculations. It is assumed that the heat losses and hot water demand in the network are constant throughout the year. A hot water demand share of 25% is assumed. An hourly profile is constructed assuming the same hourly demand in every hour of 1 specific day.

A similar approach is used for the construction of hourly demand time series for individual heat demand, but here the temperatures are weighted according to population instead of district heating demand. The resulting hourly demand series for district heating and individual heating demands can be seen plotted in Figure 1 and Figure 2 respectively.

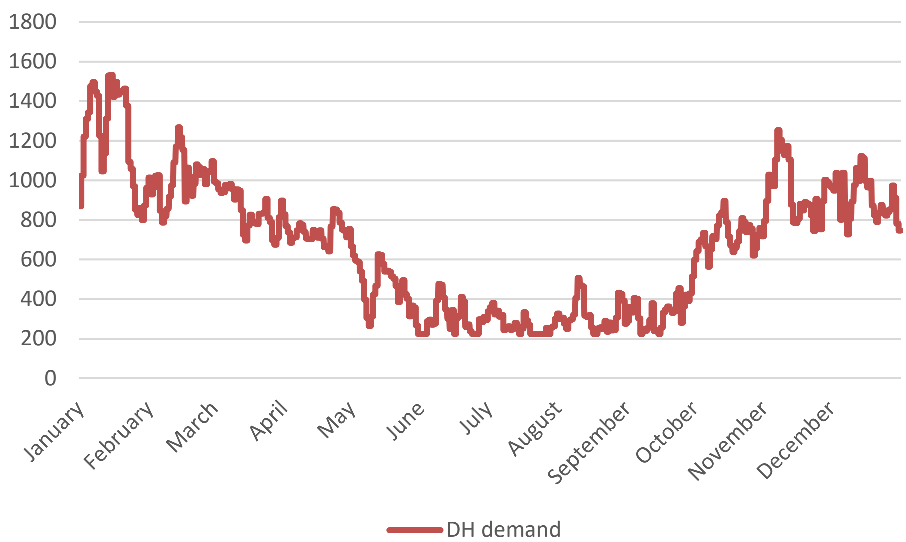

Figure 1: Hourly time series for DH demand

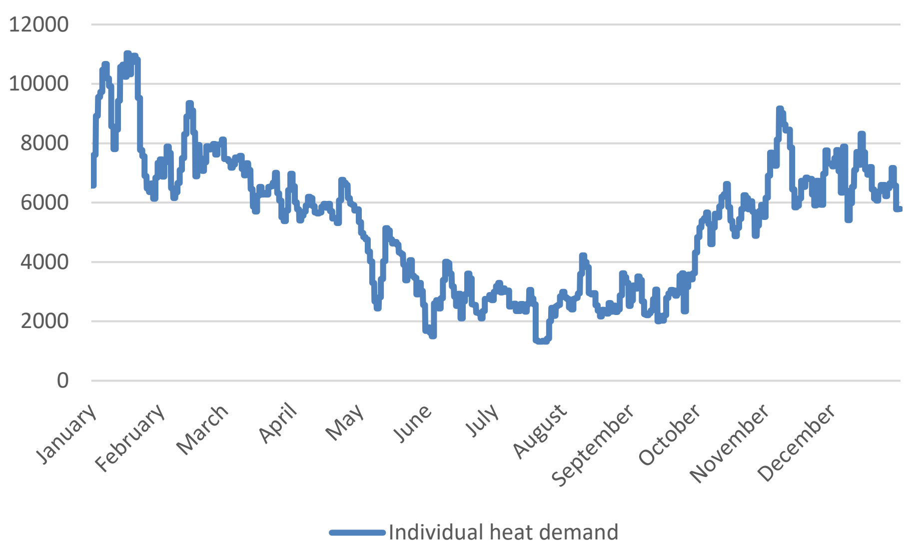

Figure 2: Hourly time series for individual heat demand

Table 6: Data used for construction of heat demand time series

County	DH production [TWh] [20]	Population [21]/ share of total population	Weather station code [19]
Akershus	520	601,789/ 11.46%	4200 – Kjeller
Aust-Agder	21	116,617/ 2.22%	36200 – Torungen Fyr
Buskerud	157	279,335/ 5.32%	26900 – Drammen - Berskog
Finnmark	8	76,062/ 1.45%	94280 – Hammerfest Lufthavn
Hedmark	332	195,942/ 3.73%	12320 – Hamar - Stavsberg
Hordaland	286	519,864/ 9.90%	50540 – Bergen - Florida
Møre og Romsdal	153	266,191/ 5.07%	60945 – Ålesund IV
Nordland	94	242,610/ 4.62%	79600 – Mo i Rana Lufthavn
Oppland	147	189,319 3.60%	12680 – Lillehammer - Sætherengen
Oslo	1,747	666,691/ 12.69%	18700 – Oslo - Blindern
Rogaland	135	472,513/ 9.00%	44640 – Stavanger - Våland
Sogn og Fjordane	0	110,362/ 2.10%	57420 – Førde – Tefre
Telemark	98	173,175/ 3.30%	30255 – Porsgrunn - Ås
Troms	151	165,334/ 3.15%	90450 - Tromsø
Trøndelag	703	453,538/ 8.64%	68125 - Sverresborg
Vest-Agder	136	183,835/ 3.50%	39040 - Kjevik
Vestfold	136	246,862/ 4.70%	27330 – Tønsberg - Taranrød
Østfold	165	292,127/ 5.56%	3290 - Rakkestad

1.2 Electricity demand

The electricity demand profile should reflect the hourly electricity demand in the country, however, excluding the electricity used for district heating. The basis for the electricity demand profile is the hourly demand profile reported by Nordpool, [17], for 2016. However, it must be assumed that this profile includes electricity used in district heating. The demand profile for electricity in district heating is endogenously defined in the model, and is thus a simulation outcome. In order to subtract the electricity demand in district heating from the total electricity demand profile, an iterative approach is required.

1. Run simulation with electricity profile for total electricity demand, including district heating
2. Subtract resulting hourly profiles for electricity for electric boilers in DH and heat pumps in DH from the electricity profile used in step 1.
3. Run simulation with new electricity profile from step 2.
4. Adjust electricity demand with resulting electricity demand for electric boilers in DH and heat pumps in DH from the electricity profile used in step 3.
5. Run simulation with new electricity profile from step 4.

Two iterations are run to minimise the difference between the resulting electricity in DH demand profile in the different iterations. There are differences in hourly demand profiles between the different iterations, as the resulting electricity demand in the DH sector depends on factors such as available electricity surplus, which changes between the iterations as adjustments are made to the exogenously defined electricity demand and demand profile. After 2 iterations, the resulting difference to the original resulting DH demand profile is reduced significantly. Thus, it is decided to stop after two iterations.

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