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D2.1. Large Scale Deployment of Electric Vehicles (EVs) and Heat Pumps (HPs) in the Nordic Region

Subtitle

Author(s)
Zhaoxi Liu, Qiuwei Wu, Pauli Petersen
Other authors

DTU Elektro
Center of Electric Power and Energy (CEE)
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Danmarks Tekniske Universitet

Center for Electric Power and Energy (CEE)
Department of Electrical Engineering
Technical University of Denmark (DTU)

Address:
Elektrovej 325
2800 Kgs. Lyngby
DENMARK

Telephone:+45 45253500

cet@elektro.dtu.dk
www.cee.dtu.dk

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AUTHOR(S) Zhaoxi Liu, Qiuwei Wu, Pauli Petersen
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PREPARED BY
Zhaoxi Liu , Qiuwei Wu, Pauli Petersen

CHECKED BY
Qiuwei Wu

APPROVED BY
Ingeborg Graabak

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Executive Summary

This report describes the study results of large scale deployment of electric vehicles (EVs) and heat pumps (HPs) in the Nordic countries of Denmark, Norway, Sweden and Finland, focusing on the demand profiles with high peneration of EVs and HPs in 2050.

In the Danish EV study case, the driving pattern is based on the Danish transport survey data (TU data) while the passenger car number is obtained from Statistics Denmark. The annual energy consumption is then calculated with different penetration levels of EVs. The annual energy consumption of EVs with 100% penetration level is about 4.6 TWh in Denmark, and the peak electrical load of the EV charging is about 4.8 GWh/h with 1 phase 10 A timed charging. For Sweden the EV energy usage is calculated using statistic data of the number and the driving distance of passenger cars from Statistics Sweden. The annual energy consumption of EVs with 100% penetration level is about 6.6 TWh in Sweden and the peak electrical load of EV charging in Sweden is around 8.6 GWh/h with 1 phase 10 A timed charging. The Norwegian study case on EVs uses the the statistic data from Statistics Norway to obtain the driving profile. The annual energy consumption of EVs with 100% penetration level is about 5.4 TWh in Norway and the peak electrical load of EV charging is about 6.4 GWh/h with 1 phase 10 A timed charging. For the Finnish EV study case, the statistic data from the National Travel Survey and Statistics Finland are used to obtain the driving profile in Finland. The Finnish annual energy consumption of EVs with 100% penetration level is about 7.6 TWh, and the peak electrical load of EV charging is about 6.9 GWh/h with 1 phase 10 A timed charging.

Heating sectors are of great significance in the energy systems of the Nordic countries. The heating demands for premises and services of the four mentioned Nordic countries vary from each other in the range from about 45 TWh to 85 TWh per year. Denmark and Finland both hold high penetration of District Heating (DH), while Sweden emphasizes the usage of biomass and electric heating dominates the heating supply in Norway. With a calculation method from the European Standard EN 14825, the peak electrical power load and annual electricity consumption of HPs are obtained for both the individual space heating and DH of the four mentioned Nordic countries. The estimated heating demand of HPs for both individual heating and DH in Denmark is the lowest one. On the other hand, the highest estimated demand of HPs for both individual heating and DH with the 2GS85% scenario appears in the Norwegian case while that with the 2GS85%Flexflow scenario is in the Finnish case. The 2GS85% and 2GS85%Flexflow scenarios are two scenarios from the Nordic Energy Technology Perspectives (NETP) project which among other forecasts the heat generation by different sources in the heat plants in the Nordic region. 2DS85% refers to a scenario representing an objective of limiting the temperature rise to 2°C and CO_2 emissions falling by 85% by 2050; 2DS85%Flexflow refers to a scenario representing an objective of limiting the temperature rise to 2°C and CO_2 emissions falling by 85% by 2050 with a stronger emphasis on electrification. Furthermore, it is shown in the calculations that the selection of backup heating for HPs is of great significance to the peak electrical power load. With non-electrical supplemental heating, HPs have much lower electrical power load during low temperatures while the majority of heating is supplied by electricity within the whole heating season.

The studies in this report are based on a number of approximations and assumptions. The energy consumption of EV driving is assumed to be 150Wh/km and all EVs are assumed to begin charging at 9:00pm. The HP studies of all the four mentioned Nordic countries use the temperature profiles, typical Coefficient of Performance (COP) and capacity of HPs in the European Standard EN 14825. In order to improve the validity of the study results of EVs and HPs in the four mentioned Nordic countries, more systematic approaches with more detailed data will be used at the next stage of the project.

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List of Abbreviations

CHP	Combined Heat and Power
COP	Coefficient of Performance
DKEast	Denmark East
DKWest	Denmark West
DER	Distributed Energy Resources
EV	Electric Vehicle
GSHP	Ground Source Heat Pump
HP	Heat Pump
NETP	Nordic Energy Technology Perspectives
RES	Renewable Energy Resource
SCOP	Seasonal Coefficient of Performance
WD	Workdays

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1 Introduction

Further utilization of renewable energy resources (RES) is necessary to achieve electricity balance in a carbon neutral electric power system in the Nordic region. The electrification of heating and transport sectors by large scale deployment of electric vehicles (EVs) and heat pumps (HPs) offers possibilities for balancing and storage of electricity to cope with variability in load and RES production. However, the large scale deployment of EVs and HPs has strong impacts on the electrical power system. In order to study such impact of the electrification in transport and heating sectors, the demand profiles with high penetration of EVs and HPs need to be studied.

This report is to investigate the possible demand profiles of EVs and HPs in the Nordic countries including Denmark, Sweden, Norway and Finland without intelligent scheduling of EVs and HPs. Iceland is not included in the study because the Icelandic power system is not connected to the Nordic power system. By describing the electrical power load and energy consumption of EVs and HPs in the transport and heating sector, this report gives the basic estimate of the demand profiles with a high penetration level of EVs and HPs in 2050 in the four mentioned Nordic countries.

The studies in this report are based on a number of approximations and assumptions. The energy consumption of EVs is assumed to be constant 150Wh/km. For the EV studies, all the charging of vehicles is assumed to begin at 9:00pm. For the HP studies of all the mentioned Nordic countries, the temperature profiles, typical COP and capacity of HPs in the European Standard EN 14825 are used in the calculations. In the future work, more systematic approaches on more detailed and accurate data will be carried out to increase the validity of the results in this report.

This report is arranged as follows.

Chapter 2 describes the demand profiles with high penetration of EVs in the four Nordic countries. Scenarios with different penetration levels of EVs are studied and the electricity demand profiles are calculated. Chapter 3 describes the demand profiles with high penetration of HPs in the four Nordic countries. The heating sectors of the Nordic countries are introduced and statistic data are used to obtain the domestic heating demand for HPs in both individual space heating and District Heating (DH) sectors. A calculation method from the European Standard EN 14825 is then introduced, and the peak electrical demand and total electricity consumption are calculated using the method. Finally, in chapter 4, conclusions are drawn on the demand profiles of EVs and HPs.

2 Demand Profile with High EV Penetration

In this chapter, the methods to obtain the electrical demand profile with high EV penetration are introduced. Further, the electrical demand profiles of Denmark, Sweden, Norway and Finland with high EV penetration are determined respectively. Finally, a summary over the demand profiles of the four Nordic countries is given.

2.1 Method

For Denmark, the driving result is obtained from the detailed EV grid integration analysis in Denmark by Technical University of Denmark (DTU) [1]. The analysis offers detailed study on the driving pattern of passenger cars which is based on the Danish transport survey data (TU data). The obtained driving pattern consists of time periods when cars are driving, time periods when cars are parked, and driving distance of each trip for cars of different user groups and different days within one week. The number of the passenger cars in Denmark is obtained from Statistics Denmark.

For the Swedish study cases of EVs charging energy requirement, the average driving distance and the number of passenger cars are obtained from the Swedish National Statistics Authority.

For the Norwegian study cases of EVs charging energy requirement, the average driving distance and the number of passenger cars are obtained from Statistics Norway.

For the Finnish study cases of EVs charging energy requirement, the average driving distance of passenger cars is obtained from Finnish National Travel Survey and the number of passenger cars is obtained from Statistics Finland.

The charging energy requirements of EVs in the four Nordic countries are calculated according to the statistic data mentioned above respectively. The values of energy consumption are scaled to 50%, 70% and 100% of the total passenger cars to show the different situations with different penetration levels of EVs. Timed charging profiles of EVs are given based on the calculated energy requirements. All the charging is assumed to begin at 9:00pm in order to charge EVs during the normal low demand hours, which shows the worst charging situation to the electrical power grid.

For all the study cases of the four Nordic countries, the analysis is limited to registered private passenger cars. The energy used per km for a home passenger car is typically between 120 Wh/km and 180 Wh/km [1]. In this study, an average energy consumption rate of 150 Wh/km is used to calculate the energy consumption with the driving distance.

2.2 Demand Profile of EVs in Denmark

In order to facilitate the integration of EVs into the Danish power system, the driving data in Denmark were analyzed to extract the information of driving distances and driving time periods which were used to represent the driving requirements.

A detailed analysis on the driving pattern of Denmark passenger cars has been carried by DTU. The analysis is based on the Danish transport survey data (TU data), which are the interview data collected daily for over 15 years and comprise more than 100000 survey results. The average driving distance data are listed in Table 2-1. The overall average daily driving distance is 40 km. For Mondays, the average driving distance is 43.399 km. The average driving distance of Saturdays and Sundays are 34.074 km and 29.723 km, respectively [1].

Table 2-1 Average Driving Distance Data in Denmark

Day Type	Average Driving Distance [km]
All days	40
Monday	43,399
Saturday	34,074
Sunday	29,723

According to the personal car number data from Danmarks Statistik [2], the personal car numbers in West Denmark region and East Denmark region are 1,206,441 and 888,494 respectively. These two numbers were used for the EV charging study. With the average driving data in Denmark, the annual energy consumptions of EVs in both Western Denmark and Eastern Denmark with different penetration levels are calculated. As shown in Table 2-2, the annual energy consumption of EVs in Denmark is about 4.6 TWh in all with 100% penetration of EVs.

Table 2-2 Annual Energy Consumption of EVs in Denmark

	West Denmark Region [GWh]	East Denmark Region [GWh]
100% EV Penetration	2650	1952
70% EV Penetration	1855	1366
50% EV Penetration	1325	986

The study of timed charging is to investigate what the EV charging demand will be if all the customers choose to charge their EVs at the same time during the normal low demand hours. It gives a rough image of the charging load in Denmark with different penetration levels of EVs. All the charging is assumed to begin at 9:00pm to illustrate the worst situation to the electrical power grid. For the EV timed charging, the proposed charging method in this study is 1 Ph 10 A charging. The corresponding charging power is 2.3 kW.

The DKWest and DKEast EV charging demands with 100%, 70% and 50% EV penetration are illustrated in Figure 2-1 and Figure 2-2. It is shown that with 100% EV penetration level, the charging time is about 2.83 hour with 1 Ph 10 A charging, and the peak charging loads for Western Denmark region and Eastern Denmark region are 2775 MWh/h and 2044 MWh/h repectively.

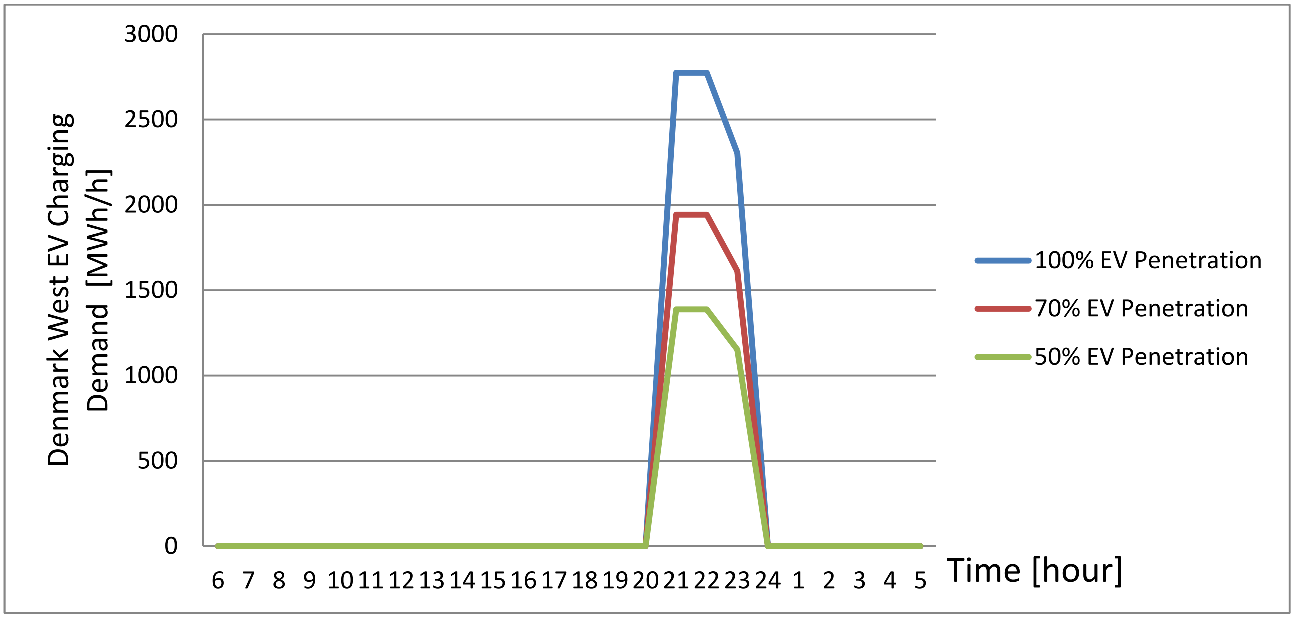


Figure 2-1 DKWest EV Charging Demand with 100%, 70% and 50% EV Penetration

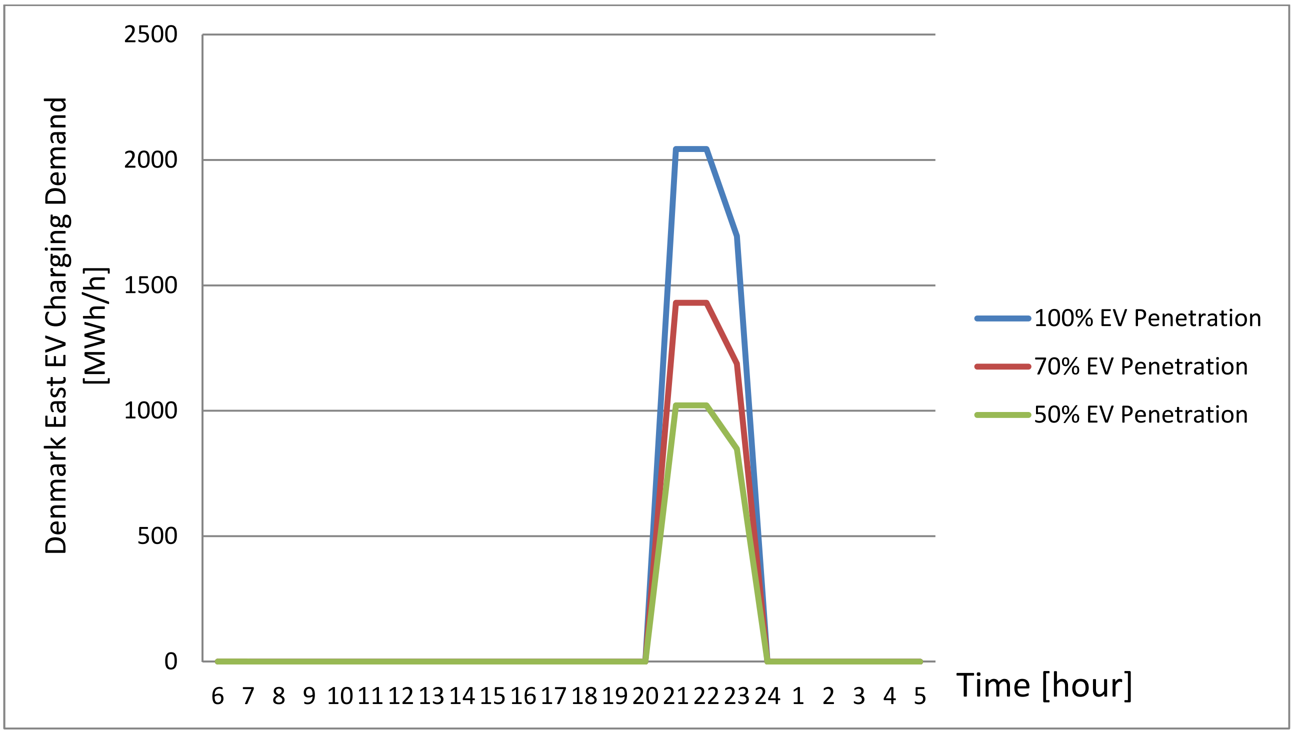


Figure 2-2 DKEast EV Charging Demand with 100%, 70% and 50% EV Penetration

2.3 Demand Profile of EVs in Sweden

Statistics Sweden is the Swedish government agency responsible for producing official statistics regarding Sweden. It carries out yearly transport analysis of Sweden which offers the comprehensive data about the transport system of Sweden. The driving distance and the number of passenger cars in Sweden are obtained from the analysis.

The driving distance and number of passenger cars in Sweden are shown in Table 2-3 [3]. The average driving distance of passenger cars in Sweden is 32km per day according to the data in Table 2-3. As this study focuses on the private passenger cars, the data for real persons is adopted in this study. Table 2-4 shows the driving distances for the different counties in Sweden, indicating a distribution with over 20% difference between the counties with the shortest to the longest driving distance [3].

Table 2-3 Distance Driven and Number of Passenger Cars in Sweden 2011

	Total number of driven miles		Number of passenger cars		Mean driving distance in miles		
	Real persons	Juristic persons	Real persons	Juristic persons	Real persons	Juristic persons	Total
Total	**4 376 830 863**	**1 736 599 944**	**3 748 370**	**1 269 133**	**1 168**	**1 368**	**1 218**

* Data for Distance is in Swedish mile, 1 Swedish mile = 10km.

Table 2-4 Average Distance by County and Type of Vehicle in Sweden 2011 **[miles/year]****

	Passenger	Lorries				
County	**Cars**	**-3 500**	**3 501 -**	**Total**	**Buses**	**Motorcycles ***
Stockholm	1 274	1 533	3 336	1 732	5 765	245
Uppsala	1 250	1 425	3 485	1 724	6 701	222
Södermanland	1 192	1 384	4 060	1 701	4 862	222
Östergötland	1 195	1 401	4 053	1 786	5 411	209
Jönköping	1 236	1 402	5 359	2 082	4 925	226
Kronoberg	1 231	1 398	6 077	2 243	5 478	224
Kalmar	1 195	1 324	4 998	1 859	5 685	212
Gotland	1 046	1 184	2 895	1 386	4 549	209
Blekinge	1 163	1 299	4 345	1 706	3 561	242
Skåne	1 199	1 433	5 403	2 142	5 692	224
Halland	1 221	1 403	5 308	2 047	5 166	213
Västra Götaland	1 232	1 397	4 481	1 895	5 960	228
Värmland	1 217	1 362	4 288	1 849	5 721	219
Örebro	1 187	1 356	4 705	1 893	4 766	217
Västmanland	1 183	1 368	3 711	1 743	4 518	219
Dalarna	1 173	1 313	3 842	1 696	5 406	215
Gävleborg	1 180	1 366	4 619	1 852	5 038	224
Västernorrland	1 190	1 336	4 171	1 819	5 619	230
Jämtland	1 226	1 402	4 080	1 844	6 409	237
Västerbotten	1 186	1 322	4 830	1 919	5 309	220
Norrbotten	1 192	1 354	3 630	1 720	4 995	245
Unknown	1 278	1 395	2 904	1 878	-	-
Total	**1 218**	**1 413**	**4 417**	**1 865**	**5 620**	**226**

* The figures for motorcycles concern the year 2010.

** Data for Distance is in Swedish mile per year, 1 Swedish mile = 10km.

According to the driving data of passenger cars in Sweden, the annual energy consumptions of EVs with different EV penetration levels are calculated. As shown in Table 2-5, the annual energy consumption of EVs in Sweden is about 6.6 TWh with 100% penetration of EVs.

Table 2-5 Annual Energy Consumption of EVs in Sweden

100% EV Penetration [GWh]	70% EV Penetration [GWh]	50% EV Penetration [GWh]
6565	4596	3283

The study of timed charging is to investigate what the charging demand will be if all the customers choose to charge their EVs during the normal low demand hours. It gives a rough image of the charging load in Sweden with different penetration levels of EVs. All the charging is assumed to begin at 9:00pm to illustrate the worst situation to the electrical power grid. For the EV timed charging, the proposed charging method in this study is 1 Ph 10 A charging. The corresponding charging power is 2.3 kW.

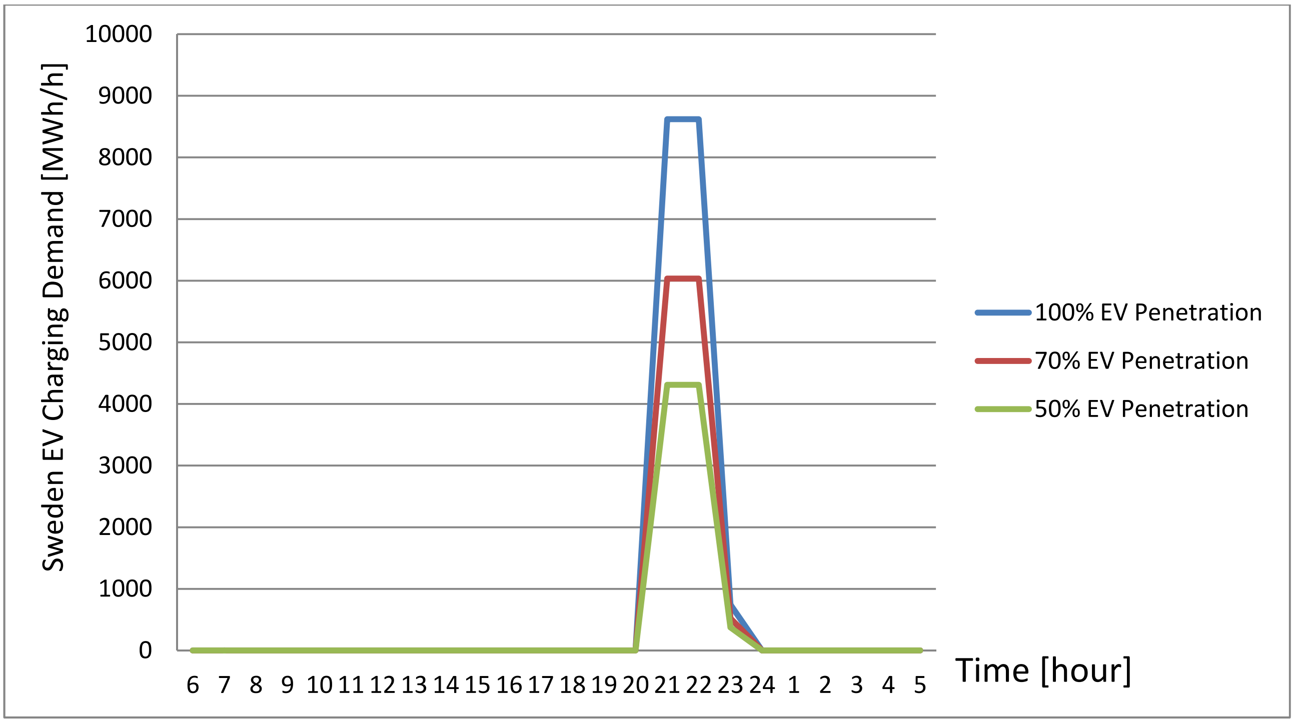


Figure 2-3 Swedish EV Charging Demand with 100%, 70% and 50% EV Penetration

Figure 2-3 shows the charging demand to Swedish electrical power system with 100%, 70% and 50% EV penetration levels. It is shown that with 100% EV penetration level, the charging time is about 2.09 hour with 1 Ph 10 A charging, and the peak charging loads for the system is about 8621 MWh/h.

2.4 Demand Profile of EVs in Norway

The driving data of Norway is obtained from the rolling statistic on transport by Statistic Norway, the Norwegian statistics bureau. In 2011 there were 2779119 cars in Norway, which corresponds to 557 cars per 1000 people [4]. For passenger cars the yearly mean driving distance for the whole country is 12985 km [5]. This distance is quite stable among the counties with Hedmark having longest distance of 13697 km, and Rogaland having the shortest distance driven of 12032 km. Table 2-6 shows the number, distance and time usage of trips of a person on average in Norway [6].

The driving energy usage is calculated based on the data mentioned above. As shown in Table 2-7 , the annual energy consumption of EVs in Norway is about 5.4 TWh with 100% penetration of EVs.

Table 2-6 Number of Trips and Distance at Different Days in Norway

Number, distance and time usage on all trips, weekdays and weekends	1992 Number Length Time usage	2001 Number Length Time usage	2005 Number Length Time usage	2009 Number Length Time usage
Number of trips per day, all days	3,12	3,09	3,33	3,3
Km per trip	10,3 km	11,9 km	11,1 km	12,0 km
Km per day	32,1 km	36,8 km	37,4 km	42,1 km
Min per trip	19 min	20 min	21 min	23 min
Min per day	59 min	62 min	70 min	76 min
Number of trips weekdays, Monday-Friday	3,35	3,33	3,6	3,6
Km per trip	9,4 km	11,1 km	10,4 km	11,1 km
Km per day	31,5 km	37,0 km	37,4 km	42,0 km
Min per trip	17 min	19 min	20 min	21 min
Min per day	57 min	63 min	72 min	76 min
Number of trips on Saturday and Sunday	2,6	2,46	2,65	2,56
Km per trip	13,2 km	14,9 km	13,3 km	14,6 km
Km per day	34,3 km	36,7 km	35,2 km	40,3 km
Min per trip	23 min	25 min	26 min	28 min
Min per day	60 min	62 min	69 min	72 min

* Data on length of each daily trip and how many trips people take on different days.

Table 2-7 Annual Energy Consumption of EVs in Norway

100% EV Penetration [GWh]	**70% EV Penetration [GWh]**	**50% EV Penetration [GWh]**
5413	3789	2707

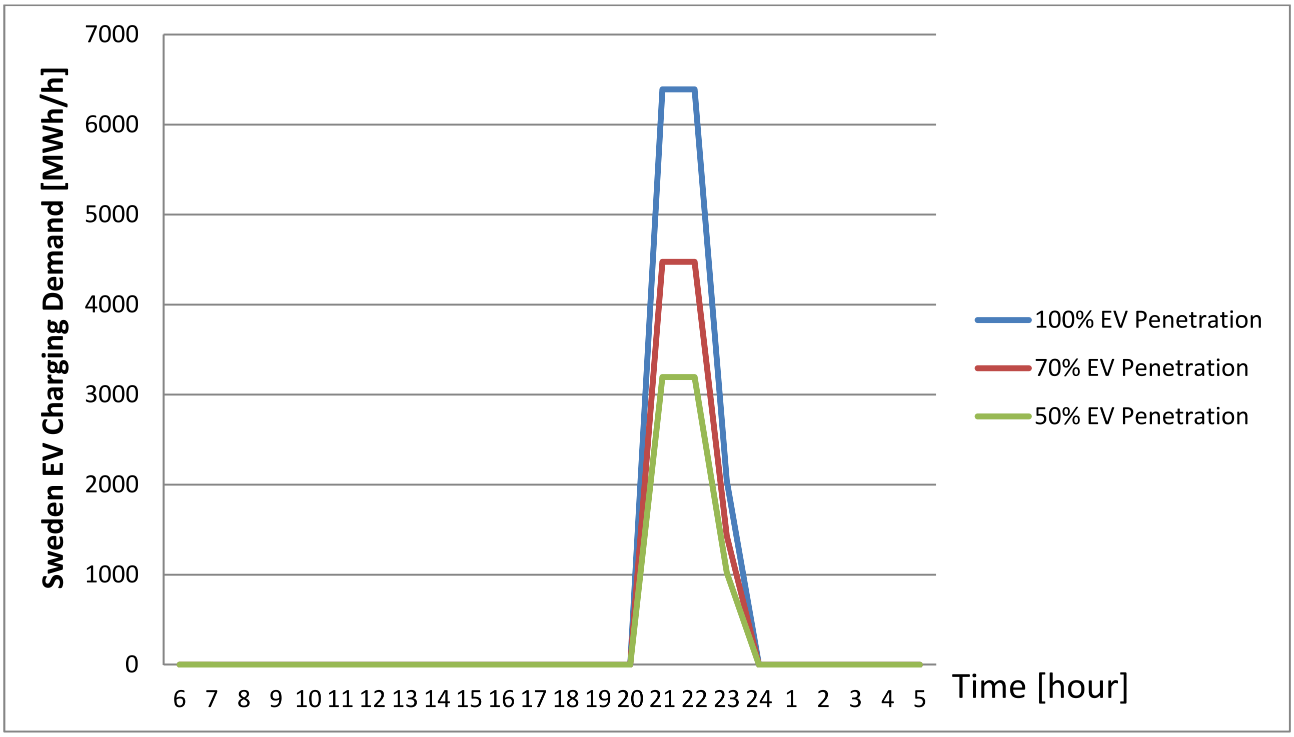


Figure 2-4 Norwegian EV Charging Demand with 100%, 70% and 50% EV Penetration

The study of timed charging is to investigate what the charging demand will be if all the customers choose to charge their EVs during the normal low demand hours. It gives a rough image of the charging load in Norway with different penetration levels of EVs. All the charging is assumed to begin at 9:00pm to illustrate the worst situation to the electrical power grid. For the EV timed charging, the proposed charging method in this study is 1 Ph 10 A charging. The corresponding charging power is 2.3 kW.

Figure 2-4 shows the charging demand to Norwegian electrical power system with 100%, 70% and 50% EV penetration levels. With 100% EV penetration level, the charging time is about 2.32 hour with 1 Ph 10 A charging, and the peak charging loads for the system is about 6392 MWh/h.

2.5 Demand Profile of EVs in Finland

Data for the Finnish charging profiles is collected from the Finnish National Travel Survey [7]. The data of the survey was collected by means of telephone interviews during a time interval of 2010–2011, and there were about 12000 people answering the survey. The survey is a random survey and covers the whole country. According to the survey, the annual driving distance for passenger cars in Finland 2010-2011 is 17085 km/year as shown in Table 2-8 [7]. According to the statistics data from Statistics Finland, at the end of 2011 there were 3,494,357 automobiles registered in Finland, and of these there were 2,978,729 registered passenger cars [8].

Table 2-8 Average Driving Distance of Passenger Cars per Year by Regions in Finland

	Private Cars [km]			**Company Cars [km]**			**All Cars [km]**		
Residence	**1998-1999**	**2004-2005**	**2010-2011**	**1998-1999**	**2004-2005**	**2010-2011**	**1998-1999**	**2004-2005**	**2010-2011**
Uusimaa	18968	16999	17141	29548	28545	26073	20248	18214	18030
Itä-Uusimaa	18844	19842	18778	32224	33339	27581	19604	20901	19518
Varsinais-Suomi	17929	16637	16011	26242	31775	27708	18223	17257	16481
Satakunta	17499	17240	15690	31883	24133	36494	17858	17480	16441
Kanta-Häme	18823	17598	17043	32707	49697	27585	19300	19049	17289
Pirkanmaa	20546	17333	17070	37575	28262	28559	21277	17748	17549
Päijät-Häme	20040	18171	17492	30336	38444	27536	20553	19415	17765
Kymenlaakso	19247	17581	15968	26136	34916	32157	19553	18121	16216
Etelä-Karjala	21681	17082	16832	31503	25699	20410	21971	17306	16936
Etelä-Savo	20119	17455	16953	35018	37799	35459	20718	18604	17398
Pohjois-Savo	19139	17668	18586	34462	26502	28757	20013	18016	18853
Pohjois-Karjala	20250	16705	16148	38711	24209	20332	20590	16953	16267
Keski-Suomi	20797	18592	17524	41628	32968	37077	21438	19097	18338
Etelä-Pohjanmaa	20702	17581	16439	27363	31662	40778	20922	18188	17334
Vaasan rannikkoseutu	17221	14127	15879	32038	25260	27152	17775	14449	16194
Keski-Pohjanmaa	17797	16513	21675	27023	27522	15540	18216	17034	21482
Pohjois-Pohjanmaa	20519	18608	17580	31587	27264	37852	20916	18949	18441
Kainuu	21482	16805	18576	21007	32541	19055	21460	17539	18591
Lappi	22377	18200	17412	31254	40417	33787	22770	18920	18002
Total	**19552**	**17353**	**17085**	**30887**	**30544**	**28820**	**20177**	**18069**	**17661**

According to the driving data of passenger cars in Finland, the annual energy consumptions of EVs with different penetration levels are calculated. As shown in Table 2-9, the annual energy consumption of EVs in Sweden in about 7.6 TWh with 100% penetration of EVs.

Table 2-9 Annual Energy Consumption of EVs in Finland

100% EV Penetration [GWh]	70% EV Penetration [GWh]	50% EV Penetration [GWh]
7634	5344	3817

The study of timed charging is to investigate what the charging demand will be if all the customers choose to charge their EVs during the normal low demand hours. It gives a rough image of the charging load in Finland with different penetration levels of EVs. All the charging is assumed to begin at 9:00pm to illustrate the worst situation to the electrical power grid. For the EV timed charging, the proposed charging method in this study is 1 Ph 10 A charging. The corresponding charging power is 2.3 kW.

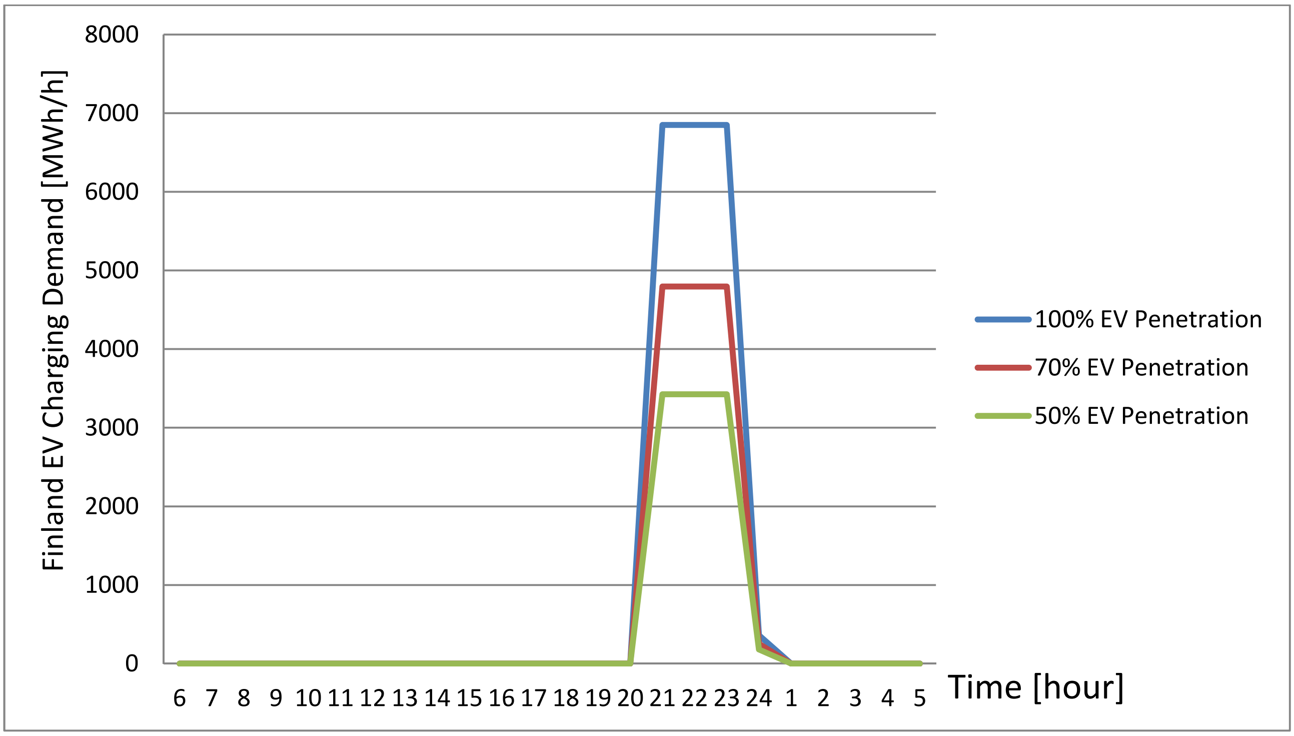


Figure 2-5 Finnish EV Charging Demand with 100%, 70% and 50% EV Penetration

Figure 2-5 shows the charging demand to Finnish electrical power system with 100%, 70% and 50% EV penetration levels. It is shown that with 100% EV penetration level, the charging time is about 3.05 hour with 1 Ph 10 A charging, and the peak charging loads for the system is about 6851 MWh/h.

2.6 Summary

The demand profiles with high EV penetration of the four Nordic countries are studied in this chapter. With different passenger car numbers and different driving patterns, the driving energy consumptions of the four Nordic countries vary from each other.

The average driving distances per day of passenger cars in Denmark, Sweden, Norway and Finland are 40km, 32km, 36km and 47km respectively. Such different driving distances lead to different energy consumptions. Table 2-10 shows the annual energy consumptions of EVs in the four Nordic countries with different penetration levels of EVs. With the longest average driving distance, the Finnish case sees the highest energy consumption. The Swedish consumption is the second highest because of the largest number of passenger cars.

Table 2-10 Annual Energy Consumption of EVs in Nordic Countries

	West Denmark [GWh]	**East Denmark [GWh]**	**Sweden [GWh]**	**Norway [GWh]**	**Finland [GWh]**
100% EV Penetration	2650	1952	6565	5413	7634
70% EV Penetration	1855	1366	4596	3789	5344
50% EV Penetration	1325	986	3283	2707	3817

Table 2-11 illustrates the peak electrical demand of the four Nordic countries with 1 Ph 10A timed charging. For all the four Nordic countries, the electrical power loads are on GWh/h level if the 100% penetration scenarios are applied. The electrical demand of Sweden is the highest for the reason of the largest number of passenger cars. All the charging is assumed to begin at 9:00pm to illustrate the worst situation to the electrical power grid. Such study on timed charging is to investigate what the system demand will be if all the customers choose to charge their EVs during the normal low demand hours and gives a rough image of the charging load in the Nordic countries with different penetration levels of EVs.

Table 2-11 Peak Charging Demand of EVs in Nordic countries with 1Ph 10A Charging

	West Denmark [GWh/h]	**East Denmark [GWh/h]**	**Sweden [GWh/h]**	**Norway [GWh/h]**	**Finland [GWh/h]**
100% EV Penetration	2.78	2.04	8.62	6.39	6.85
70% EV Penetration	1.94	1.43	6.04	4.74	4.80
50% EV Penetration	1.39	1.02	4.31	3.20	3.43

It should be noticed that the charging methods impact the electrical power load significantly. With different charging patterns, the electrical load curves vary accordingly. Further investigation on charging schedule is necessary to limit the charging power demand and increase the penetration level of EVs. The charging schedule study will be carried out in the next stage of the project.

3 Demand Profile with High HP Penetration

In this chapter, the heating sectors of Denmark, Sweden, Norway and Finland are introduced. Further, the algorithm for the calcution of HPs' electrical power demand and annual electricity consumption is presented. Then the demand profiles with high HP penetration of the four Nordic countries are presented respectively. A summary is given at the end of this chapter.

3.1 Heating Sectors of the Nordic Countries

3.1.1 Denmark

Heating sector is one of the most important energy consumptions in Denmark. In year 2010, the observed energy consumption in Denmark was 235 TWh with an energy self-sufficiency of 121%, which means the energy production was 21% more than the energy consumption. In the same year, heating took up 64 TWh of energy, which was over 27% of the total observed energy consumed in Denmark.

DH is well developed in Denmark and supports a considerable proportion of the heating demand to the Danish public. It is now responsible for about half of the net heat demand of Denmark. Further, Combined Heat and Power Units (CHP) play an important role in the DH and electrical supply. 77.2% of DH and 61.0% of thermal electricity production are supplied by CHP in 2010. According to the data from Danish Energy Agency, throughout Denmark, there are about 16 centralized CHP, 285 decentralized CHP and 130 decentralized HP plants for the public-heat supply; there are about 380 CHP and 100 DH plants for private-heat supply; there are about 500000 wood-burning stoves, 70000 wood-burning boilers, 30000 wood-pellet furnaces and 9000 straw furnaces for individual heat installations [9]. Figure 3-1 shows the CHP share of thermal power and DH production since 1980 [10].

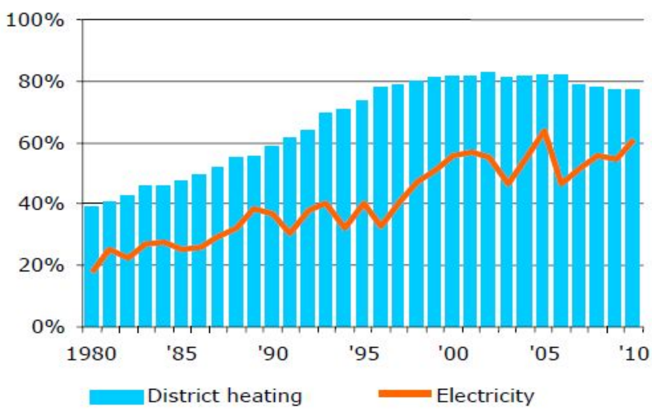


Figure 3-1 CHP Share of Thermal Electricity Production and DH Production in Denmark

The final heating consumption of Denmark in 2010 was 63702 GWh. As shown in Figure 3-2, DH took up 48% of the heating demand in Denmark in 2010 while the percentages of renewable waste and natural gas are 21% and 18% respectively. DH, together with renewable waste and natural gas, dominates the heating supply of Denmark at present. Figure 3-3 indicates the trend of fuel share of the heating consumption of Denmark during last decade. It is shown that the renewable waste supply was on an increase during the decade and came to a plateau since 2007. On the other hand, fossil fuels for heating supply were shrinking generally during the same period, exclusive to natural gas, the consumption of which stayed more or less the same from 2001 and saw a considerable increase in 2010. The decline of oil consumption for space heating was most significant, for over 40% in ten years. Please refer to Table 3-1 for the detailed data on the energy distribution of Danish heating supply described in Figure 3-2 and Figure 3-3 [11].

Up to year 2010, the heating demand in Denmark supplied by fossil fuels including oil, natural gas, coal and coke amounted to 17603 GWh/year, taking up about 28% of the total space heating energy consumption.

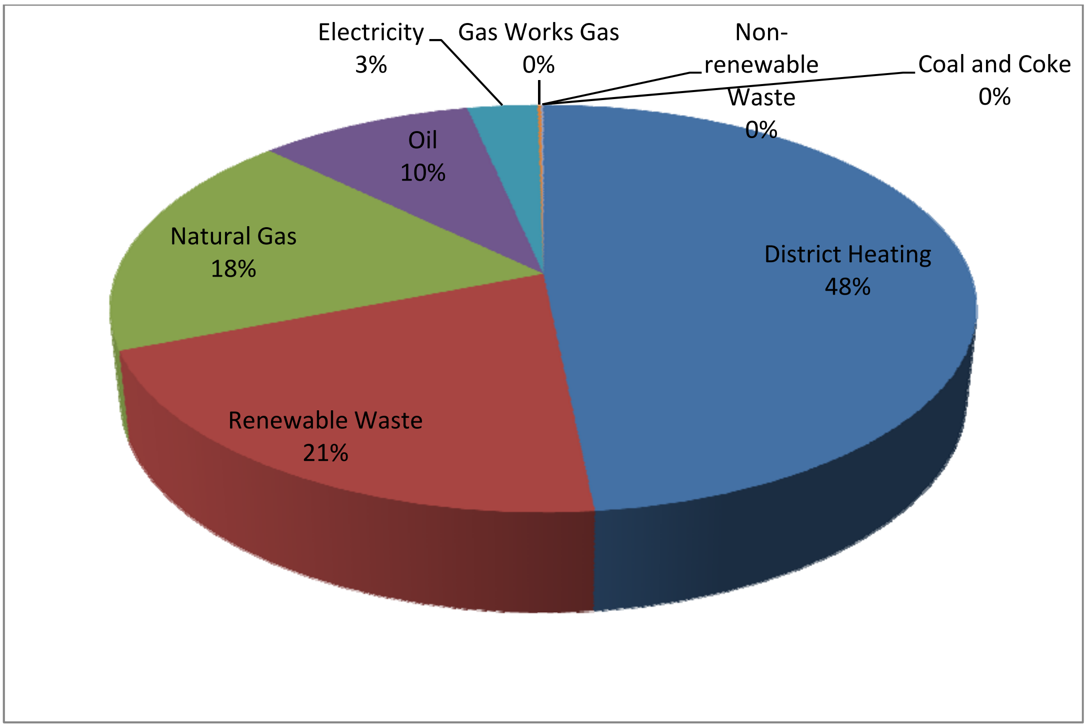


Figure 3-2 Fuel Share of Heating Consumption in Denmark 2010

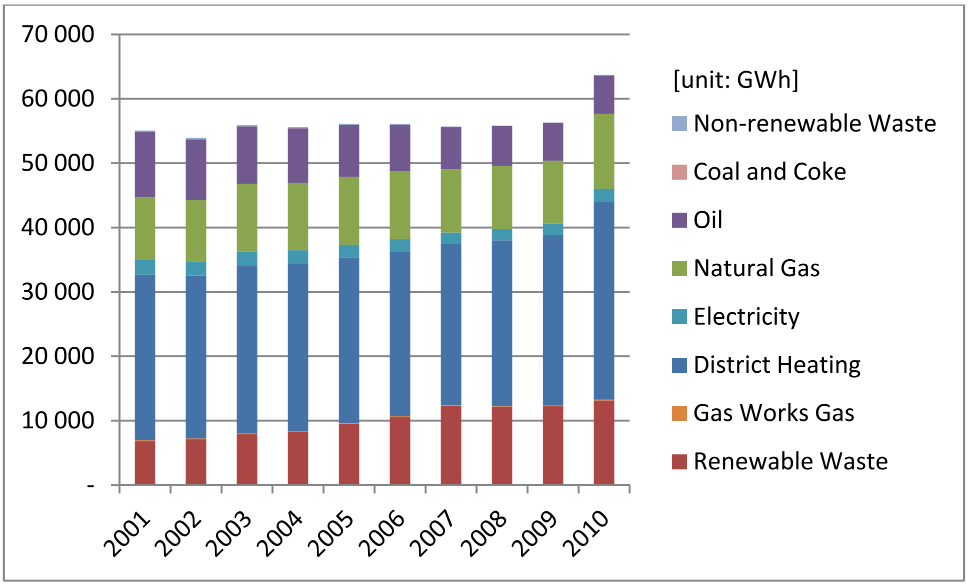


Figure 3-3 Trend of Heating Consumption from 2001 to 2010 in Denmark

Table 3-1 Fuel Share of Heating Consumption in Denmark

Observed Space Heating Consumption [GWh]										
Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Total	55 087	53 924	55 930	55 594	56 093	56 100	55 706	55 847	56 319	63 702
Oil	10 225	9 450	8 948	8 500	8 070	7 184	6 526	6 206	5 876	6 000
Natural Gas	9 795	9 561	10 499	10 453	10 513	10 524	9 820	9 773	9 734	11 595
Coal and Coke	14	10	8	8	2	1	2	5	6	9
Non-renewable Waste	135	199	202	160	160	165	113	78	45	48
Renewable Waste	6 833	7 116	7 878	8 264	9 534	10 574	12 335	12 192	12 247	13 150
Electricity	2 239	2 129	2 207	2 087	2 029	1 993	1 758	1 769	1 794	1 966
District Heating	25 710	25 342	26 066	26 004	25 676	25 561	25 068	25 742	26 524	30 833
Gas Works Gas	136	117	120	119	109	97	82	82	93	102

* Excludes space heating within agriculture and industry.

DH is the most important heating supply for the Danish public. Figure 3-4 shows the production of DH in Denmark from 2001 to 2010. Similar to the trend of Danish space heating, the renewable energy for the production in DH, especially bio-mass including straw, wood, bio-oil and renewable waste, rose rapidly in the decade. Figure 3-5 illustrates the fuel share of DH in Denmark in year 2010. In spite of the sharp increase of renewable energy, fossil fuels including natural gas, oil and coal supplied 57% of the total energy for DH, amounting to 23661 GWh/year. The detailed data about the distribution of different fuels for DH is shown in Table 3-2 [11].

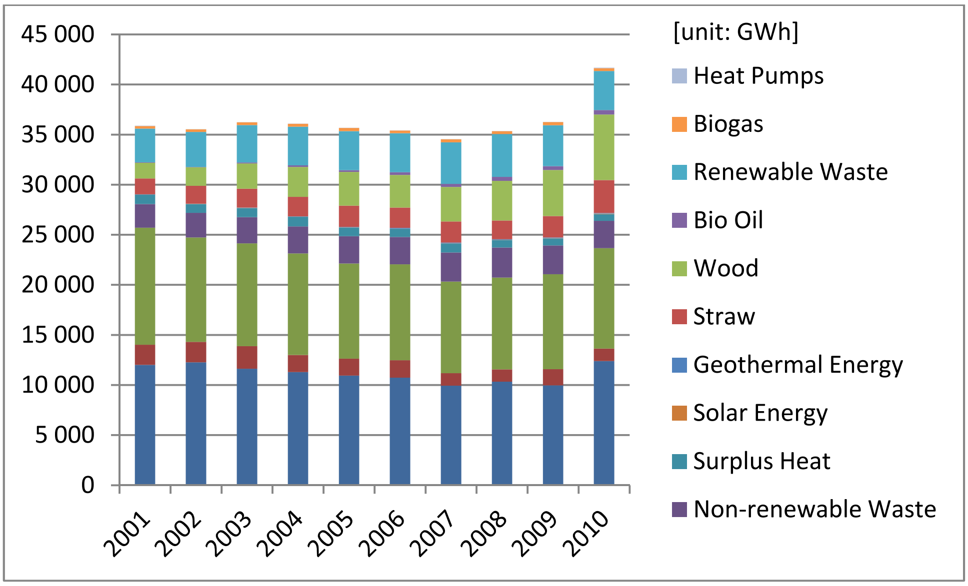


Figure 3-4 Trend of Fuel Share of DH from 2001 to 2010 in Denmark

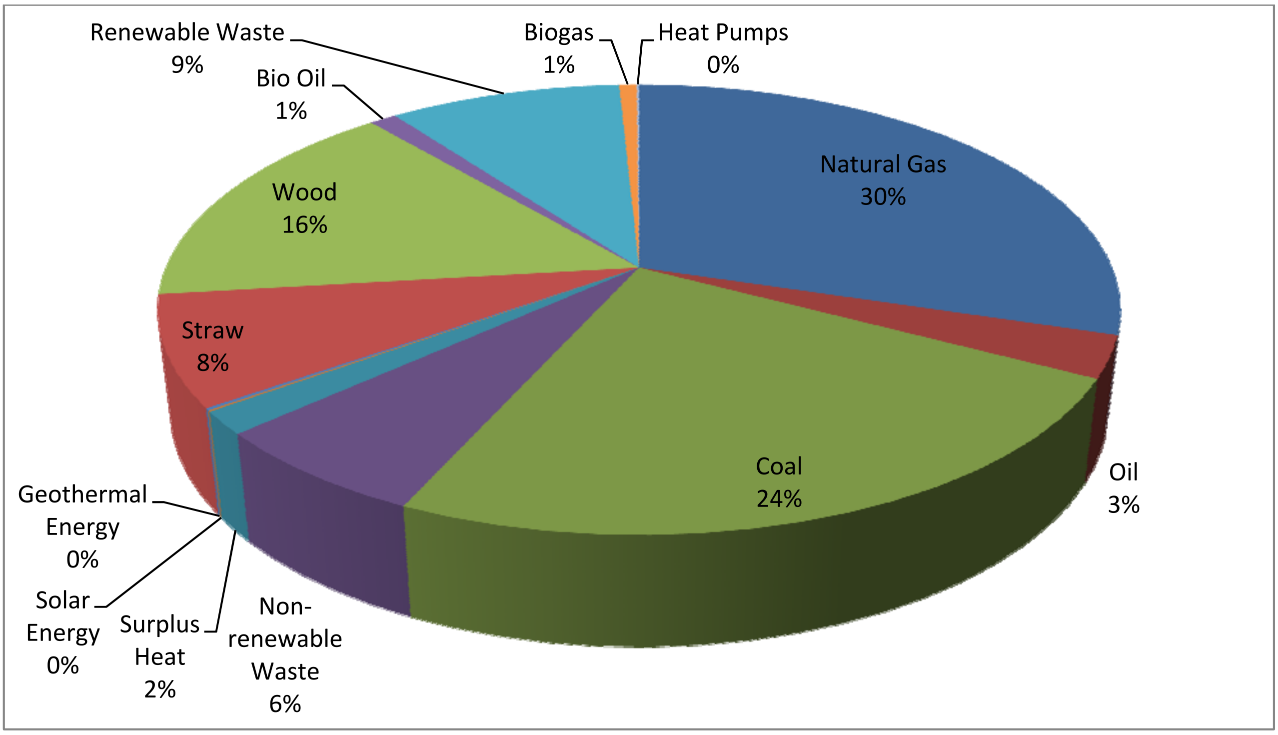


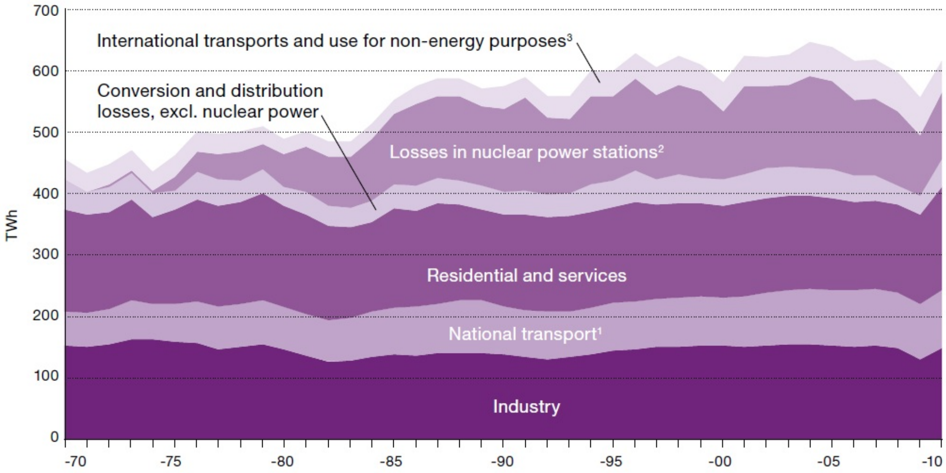
Figure 3-5 Fuel Share of DH in Denmark 2010

Table 3-2 DH Production in Denmark

District Heating Production [GWh]										
Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Total	35 883	35 543	36 236	36 097	35 685	35 428	34 548	35 361	36 273	41 674
Natural Gas	12 005	12 260	11 626	11 296	10 938	10 742	9 941	10 341	9 967	12 397
Oil	2 020	2 054	2 252	1 710	1 695	1 741	1 244	1 218	1 616	1 250
Coal	11 684	10 425	10 260	10 122	9 497	9 568	9 146	9 164	9 483	10 014
Non-renewable Waste	2 352	2 447	2 612	2 710	2 724	2 736	2 901	3 002	2 861	2 724
Surplus Heat	947	886	925	958	864	805	893	746	706	684
Solar Energy	8	10	14	14	15	13	16	19	28	39
Geothermal Energy	20	24	23	23	48	80	80	69	67	59
Straw	1 584	1 779	1 891	1 952	2 134	2 028	2 112	1 869	2 147	3 294
Wood	1 567	1 852	2 516	2 983	3 357	3 257	3 450	3 949	4 584	6 542
Bio Oil	50	32	101	156	181	267	300	400	399	451
Renewable Waste	3 357	3 492	3 728	3 868	3 888	3 905	4 141	4 284	4 083	3 888
Biogas	268	266	268	279	325	264	299	283	311	293
Heat Pumps	20	17	18	25	20	22	25	18	21	40

3.1.2 Sweden

Figure 3-6 shows the total energy use in Sweden from 1970 to 2010. Sweden's total energy use stayed on a plateau around 600 TWh for the past 20 years. Variations between individual years may be due to fluctuations in the economy and cold winters. Total energy use in 2010 amounted to 616 TWh: of this, the total final energy use in industry, transport and residential sector amounted to 411 TWh. The remainder, 205 TWh, consisted of losses, the use of fuel oils for overseas transport, and use for non-energy purposes. In 2010, energy use in the residential and sector was 166 TWh, representing 40% of the total final energy use. Almost 60% of the sector's energy use is for heating and hot water, which is one of the most important energy demand in Sweden [12].



Source: Swedish Energy Agency and Statistics Sweden.
Note: 1. International aviation is included until year 1989.
2. In accordance with the method used by UN/ECE to calculate the nuclear fuel energy input.
3. International aviation is included since 1990.

Figure 3-6 Total Energy Use in Sweden

In 2010, a total of 85 TWh was used for heating and hot water in residential and non-residential premises. Of this 42% were used in house building, 31.5% in multi-dwelling buildings and 26.5% in offices, shops and public buildings. Please refer to Table 3-3 for the detailed data [13].

In house buildings, electricity is the most common form of energy used for heating and hot water, 16 TWh were used in 2010. The greastest increase for past few years was in biofuels, including firewood, wood chips, sawdust and pellet. In 2010, the use of biofuels in this sector was over 12 TWh while DH use was less than 6 TWh. Oil use declined steadily from 9 TWh in 2002 to 1.3 TWh in 2010 . It is worth pointing out that in 2010, a HP of some kind was used in 805,000 house buildings in Sweden, amounting over 95% of all the HPs in residential and non-residential premises.

DH is the most dominant form of energy used for heating and hot water in multi-dwelling buildings as well as non-residential premises. In 2010, use of DH was 24.9 TWh in multi-dwelling buildings and 18.5 TWh in non-residential premises, taking up 93.3% and 82.6% of the total energy use in corresponding sectors.

Table 3-3 Distributed Energy Use According to Building Type in Sweden

Distributed Energy Use According to Building Type [TWh]	2002	2003	2004	2005	2006	2007	2008	2009	2010
Total	89,2	90,1	88,9	85,3	80,9	78,2	75,3	79,1	84,9
- Houses	38,6	38,4	37,9	36,0	34,1	31,8	31,9	34,7	35,8
- Multi-dewelling Buildings	27,9	28,5	27,4	26,8	25,5	25,2	24,0	23,9	26,7
- Non-residential Premises	22,6	23,2	23,6	22,5	21,3	21,2	19,4	20,4	22,4
Oil	14,8	13,7	12,6	8,6	6,1	4,7	3,3	2,8	2,5
- Houses	9,0	8,1	7,8	5,4	3,4	2,6	2,0	1,5	1,3
- Multi-dewelling Buildings	2,5	2,4	1,9	1,3	1,1	0,7	0,5	0,4	0,4
- Non-residential Premises	3,3	3,2	2,9	1,9	1,6	1,4	0,8	0,9	0,9
District Heating	41,0	42,1	41,9	42,4	41,8	42,4	42,5	43,4	49,2
- Houses	3,0	3,6	3,7	3,7	4,7	4,2	5,4	5,2	5,8
- Multi-dewelling Buildings	23,3	23,3	22,8	23,1	22,4	22,8	22,3	21,9	24,9
- Non-residential Premises	14,7	15,2	15,5	15,5	14,7	15,4	14,8	16,3	18,5
Electric	21,8	21,8	22,6	20,6	20,7	18,2	16,6	18,0	19,4
- Houses	16,5	15,8	16,3	15,3	15,3	13,7	12,9	14,6	16,1
- Multi-dewelling Buildings	1,5	2,1	2,1	1,7	1,5	1,2	0,8	1,1	1,0
- Non-residential Premises	3,8	3,9	4,2	3,6	3,9	3,3	2,9	2,2	2,2
Firewood, Wood Chips, Sawdust, Pellets	10,4	11,4	10,9	12,0	11,1	11,9	12,1	13,9	13,0
- Houses	9,9	10,7	10,0	11,2	10,4	11,1	11,4	13,0	12,4
- Multi-dewelling Buildings	0,2	0,3	0,2	0,3	0,2	0,2	0,2	0,2	0,2
- Non-residential Premises	0,3	0,4	0,6	0,4	0,5	0,6	0,5	0,6	0,5
Gas	1,2	1,2	0,9	1,4	1,0	0,9	0,7	0,8	0,7
- Houses	0,3	0,2	0,2	0,4	0,3	0,2	0,2	0,2	0,2
- Multi-dewelling Buildings	0,4	0,4	0,4	0,4	0,3	0,3	0,2	0,2	0,2
- Non-residential Premises	0,5	0,5	0,4	0,6	0,4	0,4	0,3	0,4	0,3
Other	-	-	-	0,4	0,2	0,1	0,1	0,2	0,1
- Houses	-	-	-	-	-	-	-	0,1	0,1
- Multi-dewelling Buildings	-	-	-	-	0,0	0,0	0,0	0,0	0,0
- Non-residential Premises	-	-	-	0,4	0,2	0,1	0,1	0,1	0,0

As is indicated in Table 3-3, DH, electric heating and biofuels are the most important heating supplies in Sweden. The non-sustainable fuel for heating are shrinking over the past ten years. In 2010, the total energy for heating residential and non-residential premises from oil, gas and other heating sources was only 3.3 TWh.

DH is the most improtant heating supply in Sweden. Table 3-4 shows the energy supplied to the DH of Sweden [12]. As shown in Table 3-4, biofuels take the dominant position in the energy supply in DH production.

As shown in Figure 3-7, in 2010, biofuels amounted to 68% of the total DH production. HPs took the second largest energy source among all, accounting for 5.3 TWh in 2010. For the non-sustainable energy, including gas, oil and coal, supplied for 5.8 TWh for DH in 2010.

Table 3-4 Fuel Share of DH production in Sweden

District Heating Production in Sweden [TWh]										
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Total	**50,9**	**51,8**	**52,2**	**51,6**	**50,1**	**52,2**	**51,0**	**51,5**	**55,6**	**68,3**
Natural Gas	3,2	3,3	3,3	2,8	2,4	2,4	2,2	2,1	5,1	4,2
Oil	4,1	4,4	4,8	3,7	3,2	3,4	2,0	1,3	2,4	4,9
Coal	2,0	2,1	2,1	3,6	3,2	3,9	3,0	2,9	2,7	3,3
Waste Heat	4,9	4,3	5,3	6,4	5,4	5,7	5,4	4,9	3,1	3,8
Biofuels, Waste, Peat	27,4	28,6	29,7	28,1	29,4	30,7	32,3	34,5	36,8	46,6
Electric Boilers	1,7	1,3	0,5	0,4	0,3	0,2	0,3	0,2	0,2	0,1
Heat Pumps	7,6	7,7	6,6	6,7	6,2	5,9	5,8	5,7	5,4	5,3

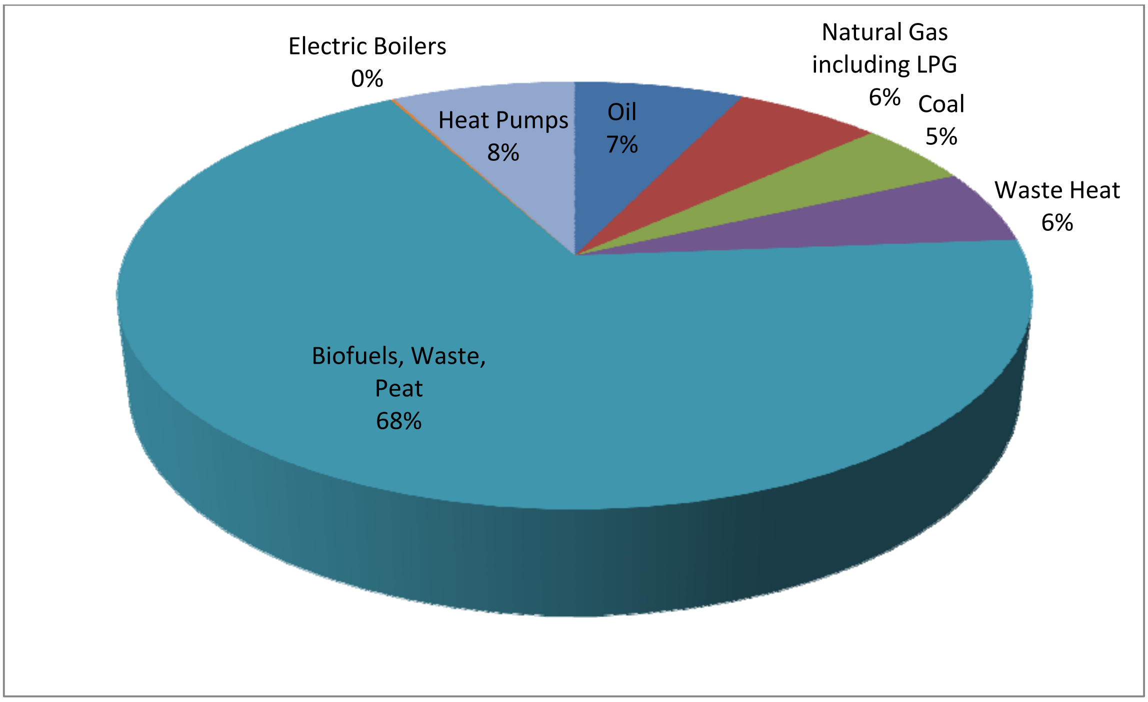


Figure 3-7 Fuel Share of DH in Sweden 2010

3.1.3 Norway

The total energy consumption of Norway in 2010 made up 247 TWh. This was broken down into manufacturing industries, transport and households, with 69, 57 and 50 TWh respectively. 48 TWh of energy was used in services, primary industries and construction. The remaining 23 TWh of energy was used for non-energy purspses. Electricity is the main energy carrier for Norway. 51% of the energy consumption in Norway was electricity in 2010. This percentage was 35% for oil production [14]. The need for building heating accounts for about 45 TWh per year in Norway [15]. The major heating supply in Norway is in the form of electric heating. The market share of DH in Norway is relatively low around the Nordic area, with a total consumption of only 4.3 TWh in year 2010.

Electricity dominates the energy source for the heating in Norwegian households. Over 90% of the households in Norway use electric heating due to the low price of electricity price in Norway. However, 80% of households also have other heating technology, mainly wood fuelled [16]. Table 3-5 shows the percentages of households with different types of heating equipments.

Table 3-5 Households with Different Kinds of Heating Equipment in Norway

Households with Different Kinds of Heating Equipments [%]								
	2001	**2004**	**2006**	**2009**				
	Total	**Total**	**Total**	**Total**	**Farmhouses**	**Detached Houses**	**Terraced, etc.**	**Block**
Electric Space Heaters or Electric Floor Heating	97	97	98	94,8	93	97	93	92
Stove for Oil / Kerosene	15	11	16	5,0	4	7	7	0
Stove for Solid Fuels / Open Fire Place	69	65	69	67,3	96	88	64	26
Stove for Pellets	-	-	0,3	0,7	0	1	1	0
Open Fire Place	-	-	13	9,5	14	14	6	4
Closed Stove for Fuel Wood	-	-	67	64,6	94	84	62	24
Combined Stove for Fuel Wood and Oil	10	8	7	10,5	19	12	14	3
Stove for Oil / Kerosene and / or Combined Stove for Fuel Wood and Oil *	20	17	19	13,7	20	16	19	3
Stove for Solid Fuels / Open Fire Place and / or Combined Stove for Fuel Wood and Oil *	72	68	70	71,9	100	92	73	27
Open Fire Place + Other Heating Equipment, but Not Closed Stove for Fuel Wood	-	-	2	2,7	2	4	2	2
Common or Individual Central Heating Total, excl. District Heating	7	9	9	8,0	8	6	4	15
Common Cetral Heating, excl. District Heating	5		4	4,2	0	0	2	15
Individual Central Heating	2		5	3,9	8	6	2	0
District Heating	1	1	1	2,0	0	0	2	6
Heat Pump Total	-	4	8	18,5	17	33	8	2
Ambient - Air Heat Pump	-	3	7	16,8	12	31	8	1
Geothermal or Ground - Source Heat Pump	0,1	0,8	1	1,8	4	2	1	1
Heat Recovery			5	7,3	3	8	9	7
Gas Stove			2	2,5	0	3	3	3
Other	2	2	-	-	-	-	-	-

* Some households have combined stove for oil and wood in addition to stove for only fuel wood or oil.
These are added up here in order to better illustrate the share of households who in reality can use oil or fuel wood.

The consumption of DH in Norway was 4.3 TWh in 2010, an increase of 31% from 2009. Among all the DH supply, 88% is supplied for households and services. The sharp increase of the DH consumption is mainly due to the high investments in 2008 and 2009. A further growth of DH in Norway in the following years is underexpetation. Table 3-6 shows the net production of DH by fuel in 2009 and 2010 [17]. Even though the share of production from refuse incineration decreased by 3.6% from 2009 to 2010, refuse incinerations remained the most important input for the DH production. Production from refuse incineration accounted for 32.4% of net production of DH in 2010. Both oil and electric boilers accounted for about 14% of production in 2010. The share of oil boilers in production increased by 7.2%, while the share of electric boilers was reduced by 5.6%. This can be viewed in conjunction with higher electricity prices in 2010, which increased the costs associated with electric boilers in production. The share of wood waste and bio fuel increased by 3.5% to 19% in 2010, while gas, waste heat and HPs accounted for 8.3%, 4.3% and 8.6% respectively.

Table 3-6 Net production of DH by Types of Heat Supply in Norway

Net Production of District Heating [GWh]	2009	2010
Total	**3 644**	**4 833**
Refuse incineration plant	1 313	1 564
Oil boilers	251	684
Wood waste and bio fuel	550	899
Electric boilers	703	662
Heat Pumps	385	414
Gas	270	402
Waste Heat	174	208

Table 3-7 Consumption of Fuel Used for Gross Production of DH in Norway

Consumption of fuel used for gross production of DH [GWh]	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Total	**2612,3**	**2733,3**	**3210,6**	**3248,0**	**3309,8**	**3532,6**	**3887,8**	**4010,0**	**4582,8**	**6161,6**
Gas-/ Diesel Oils, Heavy Fuel Oils	217,9	398,8	647,2	244,2	150,7	224,2	237,5	165,1	305,9	780,2
Wood Chips, Bark and Biofuel*	259,7	338,2	390,5	484,9	532,0	613,2	630,1	751,6	847,2	1358,5
Waste	1361,7	1351,5	1760,3	1744,8	1706,3	1749,2	1911,7	2025,7	2192,4	2606,5
Electricity	586,0	466,4	237,3	604,7	700,1	617,7	733,1	671,8	798,9	837,6
Waste Heat	151,8	122,9	63,4	86,0	119,2	149,2	190,8	151,5	173,7	198,2
Gas	35,1	55,4	112,0	83,4	101,6	179,2	184,6	244,3	264,8	380,6

* Biofuel is included in 2010.

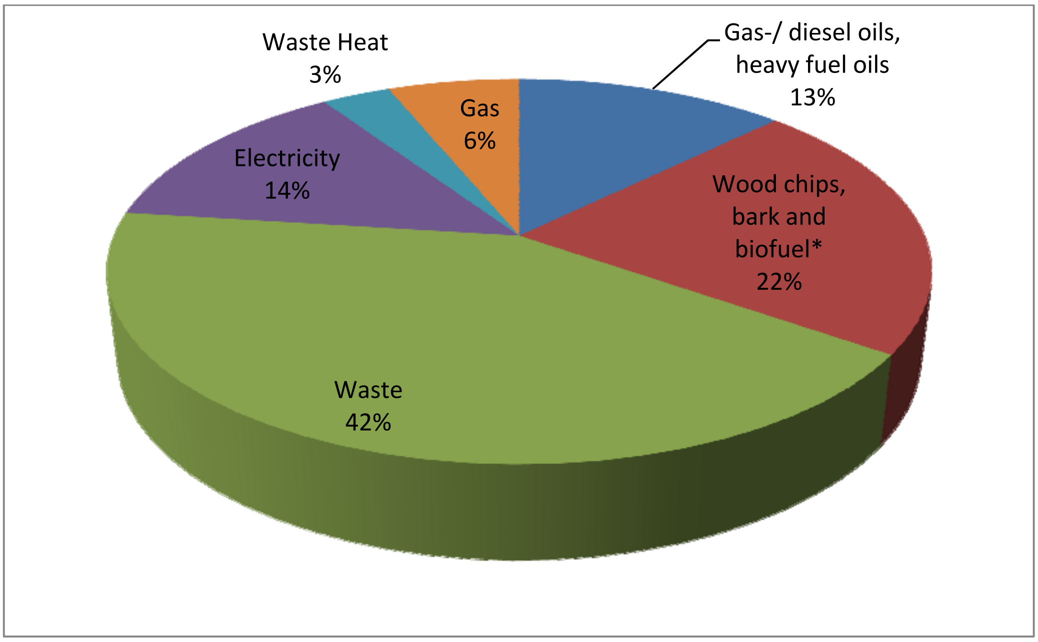


Figure 3-8 Fuel Share of DH Gross Production in Norway 2010

Table 3-7 shows the consumption of fuel used for gross production of DH in Norway from 2001 to 2010 [18]. As the total gross production of DH was climbing up during the period, the consumption of wood chips, bark and biofuels together with waste were increasing for the decade and took up 64% of the total fuel consumption in 2010. The non-sustainable fuels, including gas, diesel oils and heavy fuel oils, amount to 1160.8 GWh in 2010, which was 18.8% of the total gross production of DH in Norway.

3.1.4 Finland

Heating is one of the most important energy demands in Finland. In 2010, as shown in Figure 3-9, space heating accounted for 26% of the final energy consumption in Finland [19]. Figure 3-10 shows the fuel consumption in heating for the last two decades. It indicates an increasing trend of the heating demand.

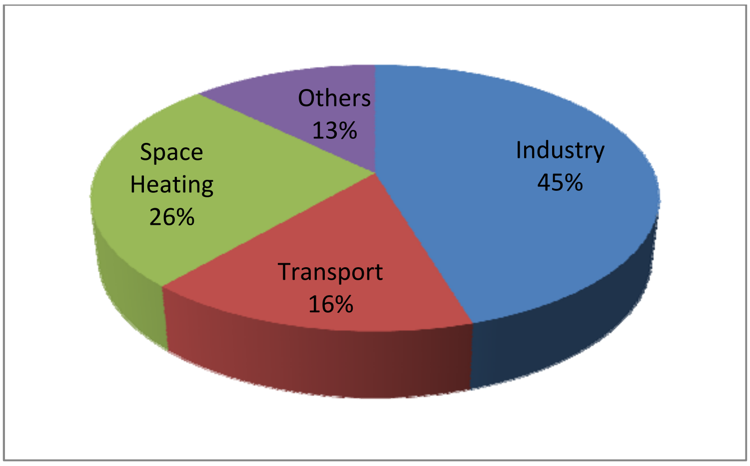


Figure 3-9 Final Energy Consumption by Sectors in Finland 2010

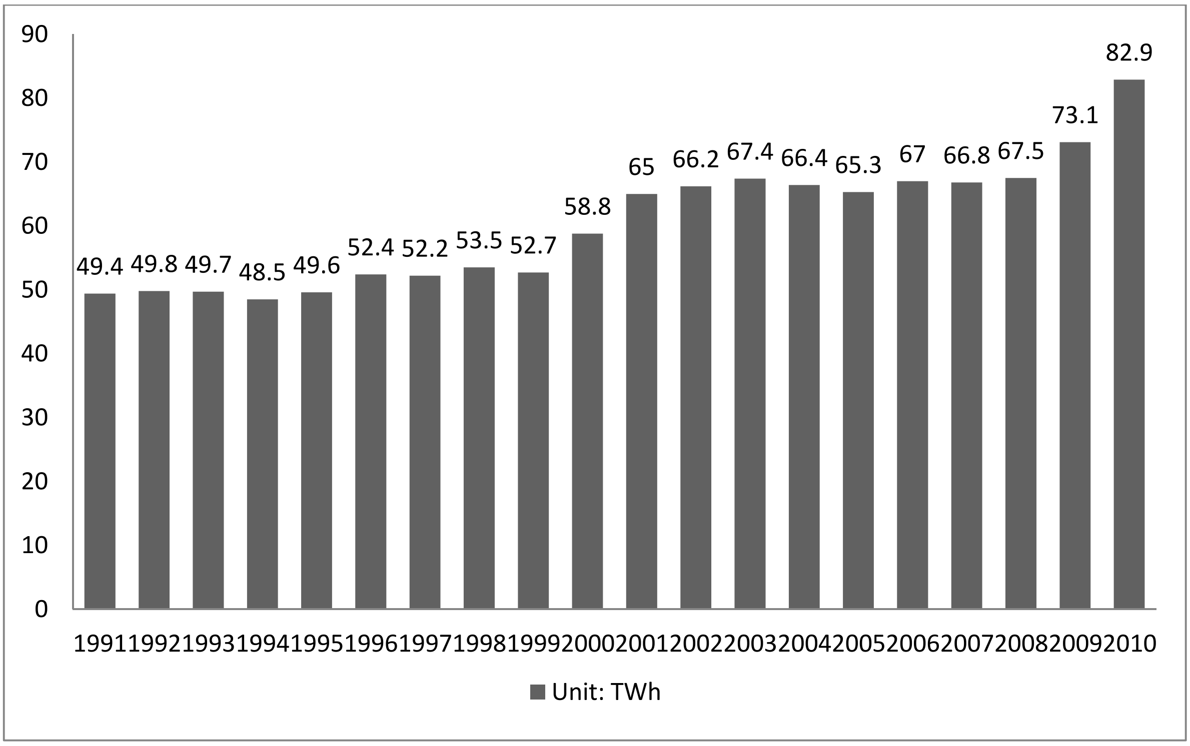


Figure 3-10 Energy Consumption of Space Heating in Finland

The heating of Finland is mainly supplied by DH and electric heating. Figure 3-11 shows the market share of Finnish space heating in 2010 [20]. DH is the most important heating supply in Finland with nearly half of the total space heating market share. Electric heating including direct electric heating and HP, accounting for 28.4% of total mark share, is the second largest heating supply in Finland.

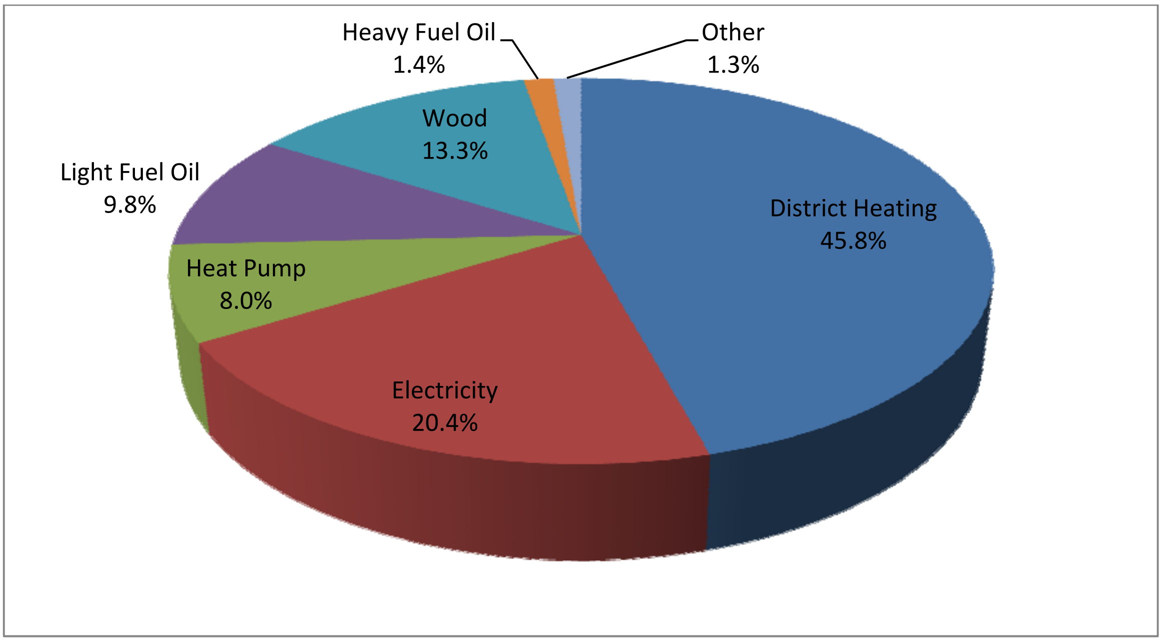


Figure 3-11 Market Share of Space Heating in Finland 2010

The overall distribution of heating supply for Finnish dewellings stayed rather the same during the decade from 1995 to 2005. DH together with electric heating supplied over half of the heating energy. However, it is worth pointing out that the heating supply by HP raised steadily from 2510 TJ in 1995 to 6520 TJ in 2005. Figure 3-12 shows the energy sources for heating residential, commercial and public buildings in this period [21].

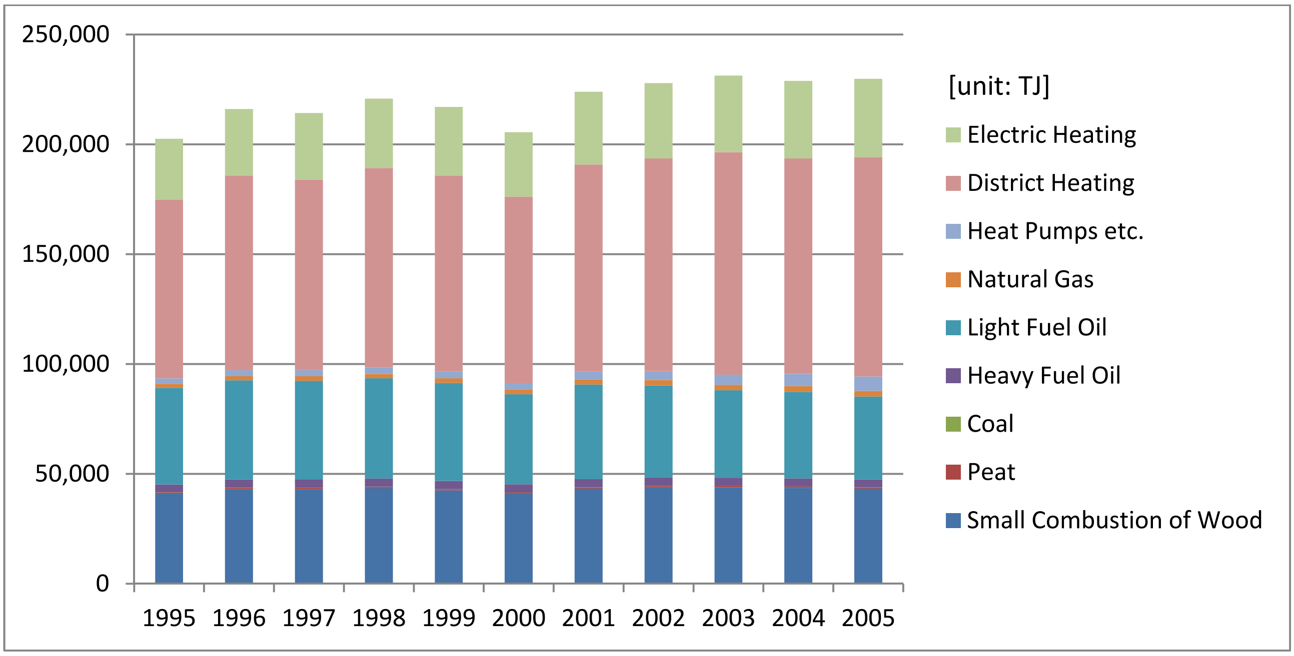


Figure 3-12 Energy Sources for Heating Residential, Commercial and Public Buildings in Finland

Table 3-8 Energy Sources for Space Heating by Types of Buildings in Finland 2006

Energy Sources for Space Heating by Types of Buildings in 2006 [GWh]								
	Small Combustion of Wood	Peat	Coal	Fuel Oil	Natural Gas	Heat Pumps	District Heating	Electirc Heating
Total	14190,0	419,5	3,6	17081,9	1208,4	2400,0	31600,0	13760,0
Residential Buildings	11456,5	130,6	3,6	7820,1	402,8	-	16980,0	8650,0
- Detached Houses	9884,1	119,5	-	6044,9	94,5	-	1370,0	7060,0
- Attached Houses	33,3	2,8	-	1030,6	152,8	-	2490,0	1080,0
- Residential Blocks of Flats	11,1	8,3	-	708,4	147,2	-	13120,0	150,0
- Residential Recreational Buildings	1527,9	-	3,6	36,1	8,3	-	-	360,0
Commercial and Public Buildings	772,3	22,2	-	3728,1	336,1	-	11440,0	1640,0
Industrial Buildings	555,6	113,9	-	3969,8	444,5	-	3050,0	2700,0
Agricultural buildings	1405,7	152,8	-	1564,0	25,0	-	130,0	770,0

* Data for HPs in 2006 has been retrieved from [22].

Table 3-8 shows the energy sources for the space heating of different types of buildings in Finland in the year 2006 [23]. It is indicated that the majority of the heating is supplied for residential buildings. In the total heating supply, the proportion of fussil fuel including peat, coal, fuel oil and natural gas is 23.2%, which is 18713 GWh.

In 2010, the total DH production in Finland was 38460 GWh, about 71.3% of which came through steam or gas turbines or diesel units. Besides, CHP plants produced electricity 16510 GWh. The total fuel use was 65060 GWh in production of DH and CHP production. Figure 3-13 shows the number of customers and total length of DH networks in Finland since 1970. Figure 3-14 shows the total heating capacity feeding the district heat networks and the connected heat load of customers since 1970. It is shown that DH development in Finland was fast in this period. The connected heat load was 17960MW at the end of 2010 and the heat delivered to costumers was 35900 GWh for the whole year [24].

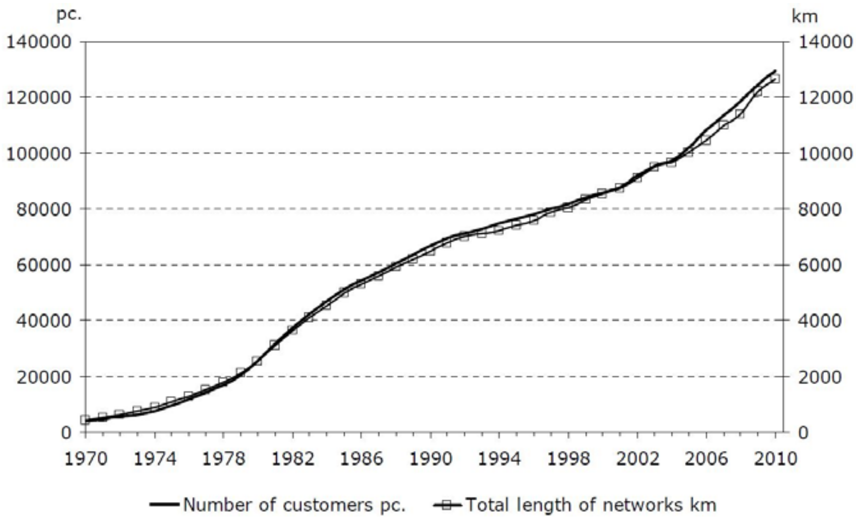


Figure 3-13 Number of Customers and Length of DH Network in Finland

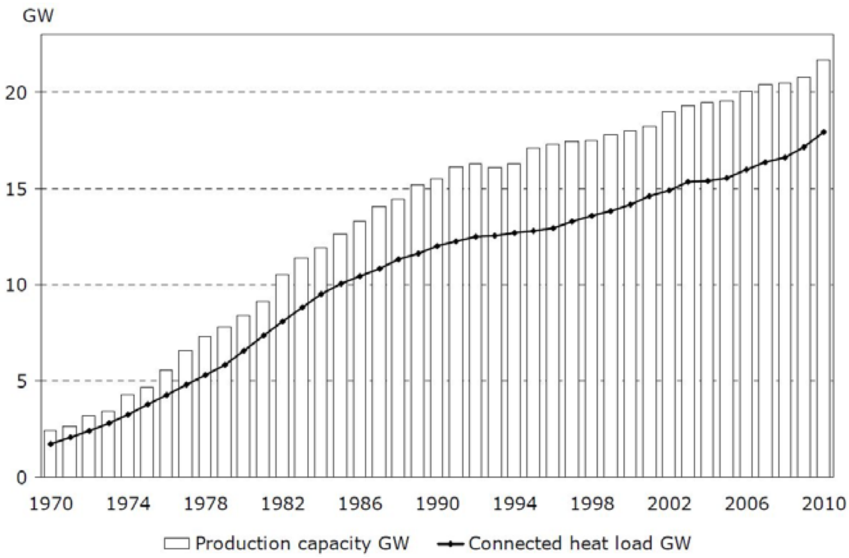


Figure 3-14 Total Heating Capacity and Connected Heat Load of DH in Finland

The total energy consumed in the production of DH and CHP was 65060GWh in Finland in 2010. Table 3-9 shows the distribution of fuels for DH and CHP in Finland for the year 2009 and 2010. In 2010, the proportion of the fossil fuel including natural gas, coal, peat and fuel oil was up to 79.5%, which was 51723GWh.

Table 3-9 Fuel Share of DH and CHP in Finland in 2009 and 2010

Fuel	2010	2009
Natural gas	35,1 %	34,1 %
Coal	21,6 %	24,2 %
Peat	17,8 %	16,4 %
Forest wood	9,3 %	8,5 %
Industrial wood residues	5,9 %	5,0 %
Other bio fuels	1,1 %	1,5 %
Mixed fuels	1,6 %	1,4 %
Industrial reaction heat	1,2 %	1,5 %
Heavy fuel oil	4,7 %	4,8 %
Light fuel oil	0,3 %	0,4 %
Others	1,3 %	2,2 %
Total	100,0%	100,0%

3.2 Algorithm for Calculating HPs' Electrical Power Demand and Annual Electricity Consumption

The HP installation around Nordic countries is growing rapidly in recent years. Generally, the demand profiles of the increasing HP market are considered in two divisions: the supply share of HPs in the individual space heating supply, the HPs in DH. For the target of limiting the CO_2 emission and achieving carbon neutralization in 2050, the fossil fuels in the heating sectors of Nordic countries should see a replacement by HPs or other carbon neutral technology such as the usage of biomass. Besides, the electric direct heating shall also see such replacement by HPs for higher heating efficiencies. For the DH, five scenarios from the Nordic Energy Technology Perspectives (NETP) project are adopted and analyzed regarding the heating supplies to DH by HPs around the Nordic area. In the NETP project, forecasts on the heat generation by CHP and heat plants are provided for the five scenarios, including:

- 4DS (scenario representing an objective of limit the temperature rise to 4°C by 2050);
- 2DS (scenario representing an objective of limit the temperature rise to 2°C by 2050);
- 2DS85% (scenario representing an objective of limiting the temperature rise to 2°C and CO_2 emissions falling by 85% by 2050);
- 2DS85%BignBio (scenario representing an objective of limiting the temperature rise to 2°C and CO_2 emissions falling by 85% by 2050 with a stronger emphasis on Bio-Energy);
- 2DS85%FlexFlow (scenario representing an objective of limiting the temperature rise to 2°C and CO_2 emissions falling by 85% by 2050 with a stronger emphasis on electrification) [25].

For the efficiency and electricity consumption of HPs under a specific heat demand profile, the European Standard EN 14825 provides a detailed calculation method [26]. Generally, the method divides a heating season into a series of numbers of hours with different temperatures, which are called bins. A detailed heating demand profile for HPs is then determined to meet the heating requirement under each set of temperatures. Furthermore, the corresponding electrical capacity and electricity consumption of HPs are calculated. The method in EN 14825 is generally for the electricity consumption and seasonal coefficient of performance (SCOP) calculation of a HP. The calculation method is adopted here and the capacity of HPs is scaled up to describe the accumulated capacity of all HPs in the Nordic countries. The calculated electrical capacity and electricity consumption are therefore the total electrical capacity and electricity consumption of all HPs. The symbols in the calculation are listed in Table 3-10.

Table 3-10 Symbols in the Energy Consumption Calculation of HP

Symbol	**Unit**	**Definition**
Q_{demand}	GWh	Total heating demand in a heating season
P_h	GW	Heating demand with different temperatures
H	hour	Number of hours with different temperatures
CR	-	Capacity ratio
P_{DC}	GW	Declared capacity of HPs
$COP_{part\ load}$	-	Coefficient of performance of HPs on part load
COP_{DC}	-	Declared coefficient of performance of HPs
C_C	-	Degradation coefficient of HPs
P_{hp}	GW	Heating capacity of HPs
P_{sup}	GW	Heating capacity of supplemental heating
P_{el}	GW	Electricity capacity for heating
ρ	-	Ratio of electric direct heating in supplemental heating
Q_{el}	GWh	Total electricity consumption for heating

According to EN 14825, the calculation method involves bins which are the numbers of hours with different temperatures in the heating season. As the climate varies across Europe, EN 14825 provides three typical climate profiles for SCOP calculation, including average profile corresponding to Strasbourg, colder profile corresponding to Helsinki and warmer profile corresponding to Athens as shown in Figure 3-15.

Among the three climate profiles, the average profile is designed on the basis of the temperature distribution corresponding Strasbourg. Since temperature distribution in Denmark is very similar to that of Strasbourg, the average temperature profile will therefore be representative of Danish conditions [27]. The colder temperature profile will be adopted for Swedish, Norwegian and Finnish scenarios.

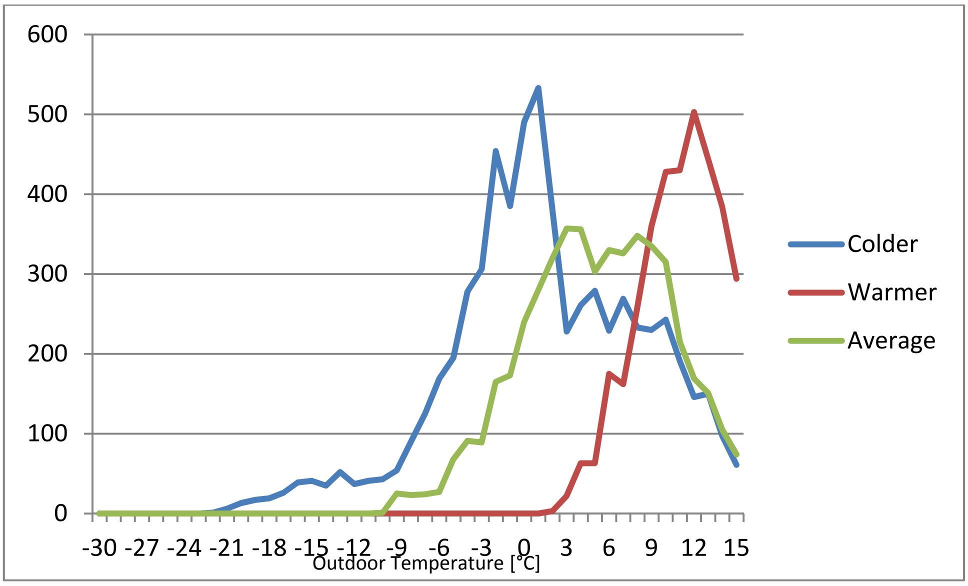


Figure 3-15 Numbers of Hours by Temperatures for Average, Colder and Warmer Climate Profiles

The heating demand for HPs varies along with the outdoor temperature. Figure 3-16 shows the heating demand curve and capacity curve for HPs [27]. The heating demand curve is a straight line which runs through the determined heating demand at the design temperature and a heating demand of 0 kW at 16 °C. The balance point locates where the HP capacity is equal to the heating demand. For temperatures below balance point $T_{bivalent}$, supplemental heating will be needed to fulfill the heating demand. This backup heating can be supplied by any type of heating, for example electric direct heating or ovens with biomass.

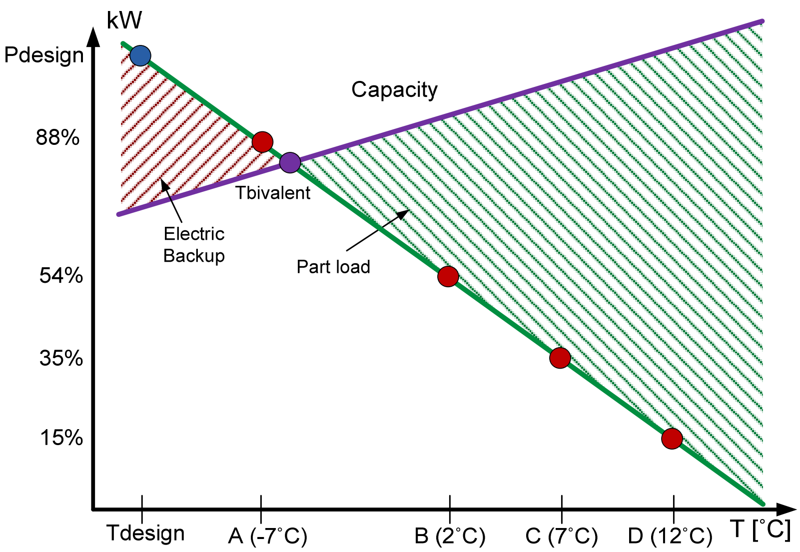


Figure 3-16 Heating Demand Curve and Capacity Curve for HPs

The annual heating demand Q_{demand} is accumulated by the heating demand at different temperatures, as shown in equation (1). As the heating demands P_h have a linear relation with the temperatures as shown in Figure 3-16, once Q_{demand} is fixed each P_h with different temperature is determined according to equation (1). *CR* is the capacity ratio which equals the heating demand divided by the declared capacity of HPs at the same temperature as shown in equation (2). With capacity ratio, the efficiency of HPs with the same proportion of part load can be calculated according to equation (3). C_C in equation (3) is the degradation coefficient, which shall be set 0.9 by default if it is not determined by test. The heating demand is fulfilled by HPs together with supplemental heating for the temperatures lower than the balance point. The total electric capacity can be calculated according to equation (5). Coefficient ρ in the proportion of electric direct heating in the supplemental heating with an efficiency COP of 1. For the temperature over the balance point, ρ equals to 0. The electricity demands under different temperatures are summed up to calculate the total electricity consumption as shown in equation (6).

$$Q_{demand} = \sum_{i=T_{design}}^{16^\circ C} P_{hi} H_i \tag{1}$$

$$CR = \frac{P_h}{P_{DC}} \tag{2}$$

$$COP_{part\ load} = COP_{DC} \cdot \frac{CR}{C_C \cdot CR + (1 - C_C)} \tag{3}$$

$$P_h = P_{hp} + P_{sup} \tag{4}$$

$$P_{el} = \frac{P_{hp}}{COP_{part\ load}} + P_{sup} \cdot \rho \tag{5}$$

$$Q_{el} = \sum_{i=T_{design}}^{16^\circ C} P_{eli} H_i \tag{6}$$

With the uncertainties on the capacity and COP of HPs with different temperatures regarding the types, sizes, installations and efficiency of the HPs, two approximations are adopted in this estimation. The balance point of HPs is set at -6 °C and the HP capacity is scale up to the heating requirement in accordance with the HP capacity in the calculation sample in EN 14825 [26]. The typical COP with different temperatures in the calculation sample in EN 14825 is also adopted for the average COP in the estimation. For the points that are not tested in the calculation sample in EN 14825, interpolated or extrapolated values are adopted.

The impacts of these two approximations lie in the total electric capacity and consumption. With a higher balance point of HPs, the HP capacity shrinks and the supplemental heating rises accordingly, which lead to higher peak load and electricity consumption under low temperatures if the backup heating is supplied by electric direct heating. Along with the improvement of the design, manufacture as well as installation of HPs, the efficiency of HP is on an increase. With a higher COP, both of the electric capacity requirement and electricity consumption shall decline accordingly.

3.3 Demand Profile of HPs in Denmark

Along with the growing importance of HPs in Danish energy policy, the stock of HPs in Denmark is accelerating in the recent years. Today there are around 40000 HPs installed in Denmark, which are either of the air source or ground source types [28]. A survey focusing on the ground-to-water and air-to-water HPs was carried out by COWI for the Danish Energy Agency. Table 3-11 from this survey shows the numbers of installations, average seasonal coefficient of performance (SCOP), heat produced, electricity consumed and load for all ground-to-water and air-to-water HPs used for heating in permanent housing in Denmark 2011 [29].

Table 3-11 Total Number of Ground-to-Water and Air-to-Water HPs in Denmark 2011

Total number of ground-to-water and air-to-water heat pumps 2011						
Geographical Region	**House Type**	**Number**	**Av. SCOP**	**Heat Production MWh**	**Electrictiy Consumption MWh**	**Network Load kW**
Capital Region		**3 919**	**2,85**	**54 516**	**19 141**	**8 666**
	Single-family Houses	3 023	2,86	41 711	14 565	6 623
	Terrace Houses	473	2,59	4 946	1 911	959
	Farm Houses	424	2,95	7 859	2 664	1 085
Central Denmark Region		**7 505**	**3,02**	**107 669**	**35 662**	**16 821**
	Single-family Houses	5 085	2,97	68 978	23 222	11 175
	Terrace Houses	177	2,54	1 905	750	371
	Farm Houses	2 242	3,15	36 786	11 690	5 276
North Denmark Region		**4 393**	**3,09**	**67 289**	**21 753**	**10 271**
	Single-family Houses	2 871	3,08	42 236	13 723	6 610
	Terrace Houses	60	2,46	697	283	136
	Farm Houses	1 462	3,14	24 356	7 746	3 525
Zealand Region		**4 568**	**2,85**	**65 951**	**23 123**	**10 505**
	Single-family Houses	3 441	2,80	47 814	17 088	7 759
	Terrace Houses	210	2,67	2	798	410
	Farm Houses	917	3,06	16 009	5 237	2 336
South Denmark Region		**6 967**	**3,01**	**104 205**	**34 649**	**15 760**
	Single-family Houses	5 030	2,95	69 437	23 540	11 066
	Terrace Houses	147	2,74	2 168	790	341
	Farm Houses	1 790	3,16	32 600	10 319	4 353
Total		**27 352**	**2,98**	**399 630**	**134 327**	**62 024**

It is shown from the table that the central and southern region of Denmark has the most ground-to-water and air-to-water HPs. However, the capital region has the least share, which may result from the domination of DH in the heating market of this area. The average SCOP is 2.98 and the total heat production is around 400 GWh with an electricity consumption of 134 GWh per year. The average SCOP is over the EU efficiency criterion that SCOP should be over 2.63. This number will possibly keep rising along with proper installations of new HPs with higher efficiency.

Up to 2010, the space heating demand in Denmark supplied by fossil fuels and electricity amounted to 19569 GWh/year. In order to cover 100% this part of heating demand by HPs, the energy efficiency, consumption and capacity need to be estimated generally. Table 3-12 indicates the case when HPs cover a total of 19569 GWh/year heating with electric direct heating as 100% of the supplemental heating. The numbers of hours with different temperatures in an average temperature profile, heating demand, HP capacity, electric backup heating capacity along with the temperature are shown in Table 3-12. The total electricity consumption and average SCOP is calculated. In order to cover a total heating demand of 19569 GWh/year in Denmark by HPs, the electricity consumption amounts to 5463 GWh/year, implying a SCOP of 3.58. To be noticed, the maximum electricity capacity requirement is 5.51 GWh/h when the temperature reaches the lowest point. Table 3-13 indicates the case with electric direct heating as 50% of the supplemental heating. The other 50% of supplemental heating shall be supplied by a non-electrical way, for example ovens with biomass. It is shown in Table 3-13 that the annual electricity consumption is 5410 GWh, which is 99% of the amount in the 100% electric-supplemental-heating case. However, the maximum electricity capacity requirement is reduced to 3.99 GWh/h during the hours of lowest temperature. Regarding a more extreme situation for comparison, the case with 0% electric-supplemental-heating is shown in Table 3-14. The annual electricity consumption decreases slightly to 5357 GWh while the maximum electricity capacity requirement during the coldest hours drops sharply to 2.48 GWh/h. With a non-electrical supplemental heating besides the HPs, the majority of heating demand throughout the year is still supplied by electricity. However, the maximum electricity capacity requirement during low temperatures would be reduced significantly, which would release the tension in power grid capacity to some extent.

Table 3-12 HP Electricity Consumption Calculation with 100% Electric-Supplemental-Heating in Denmark

Bins, Heating Pump Capacity, COP, Electricity Consumption For SCOP Calculation									
T	***H***	***Ph***	***Php***	***Psup***	***ρ***		***Pel***	***Qdemand***	***Qel***
Temperature [°C]	**Bins**	**Heating Demand [GW]**	**Heat Pump Capacity [GW]**	**Backup Heating [GW]**	**Electric Ratio of Backup Heating**	***COP part load***	**Total electricity consumption per hour [GWh/h]**	**Total Heating Demand [GWh]**	**Total Electricity Consumption [GWh]**
-10	1	9,47	6,45	3,03	1	2,60	5,51	9,47	5,51
-9	25	9,11	6,84	2,27	1	2,82	4,69	227,73	117,33
-8	23	8,74	7,23	1,51	1	3,04	3,89	201,13	89,53
-7	24	8,38	7,89	0,49	1	3,26	2,91	201,13	69,82
-6	27	8,02	8,02	0,00	-	3,30	2,43	216,44	65,59
-5	68	7,65	7,65	0,00	-	3,35	2,28	520,32	155,32
-4	91	7,29	7,29	0,00	-	3,39	2,15	663,15	195,62
-3	89	6,92	6,92	0,00	-	3,44	2,01	616,15	179,11
-2	165	6,56	6,56	0,00	-	3,49	1,88	1082,18	310,08
-1	173	6,19	6,19	0,00	-	3,53	1,75	1071,61	303,57
0	240	5,83	5,83	0,00	-	3,58	1,63	1399,18	390,83
1	280	5,47	5,47	0,00	-	3,62	1,51	1530,35	422,75
2	320	5,10	5,10	0,00	-	3,67	1,39	1632,37	444,79
3	357	4,74	4,74	0,00	-	3,74	1,27	1691,04	452,15
4	356	4,37	4,37	0,00	-	3,81	1,15	1556,59	408,55
5	303	4,01	4,01	0,00	-	3,89	1,03	1214,44	312,20
6	330	3,64	3,64	0,00	-	3,96	0,92	1202,42	303,64
7	326	3,28	3,28	0,00	-	4,03	0,81	1069,06	265,28
8	348	2,91	2,91	0,00	-	3,87	0,75	1014,40	262,12
9	335	2,55	2,55	0,00	-	3,70	0,69	854,45	230,93
10	315	2,19	2,19	0,00	-	3,54	0,62	688,66	194,54
11	215	1,82	1,82	0,00	-	3,37	0,54	391,70	116,23
12	169	1,46	1,46	0,00	-	3,21	0,45	246,31	76,73
13	151	1,09	1,09	0,00	-	3,05	0,36	165,06	54,12
14	105	0,73	0,73	0,00	-	2,88	0,25	76,52	26,57
15	74	0,36	0,36	0,00	-	2,72	0,13	26,96	9,91
								19 569	5 463

Table 3-13 HP Electricity Consumption Calculation with 50% Electric-Supplemental-Heating in Denmark

Bins, Heating Pump Capacity, COP , Electricity Consumption For SCOP Calculation									
T	*H*	*Ph*	*Php*	*Psup*	*ρ*		*Pel*	*Qdemand*	*Qel*
Temperature [°C]	**Bins**	**Heating Demand [GW]**	**Heat Pump Capacity [GW]**	**Backup Heating [GW]**	**Electric Ratio of Backup Heating**	***COP part load***	**Total electricity consumption per hour [GWh/h]**	**Total Heating Demand [GWh]**	**Total Electricity Consumption [GWh]**
-10	1	9,47	6,45	3,03	0,5	2,60	3,99	9,47	3,99
-9	25	9,11	6,84	2,27	0,5	2,82	3,56	227,73	88,99
-8	23	8,74	7,23	1,51	0,5	3,04	3,14	201,13	72,12
-7	24	8,38	7,89	0,49	0,5	3,26	2,67	201,13	63,96
-6	27	8,02	8,02	0,00	-	3,30	2,43	216,44	65,59
-5	68	7,65	7,65	0,00	-	3,35	2,28	520,32	155,32
-4	91	7,29	7,29	0,00	-	3,39	2,15	663,15	195,62
-3	89	6,92	6,92	0,00	-	3,44	2,01	616,15	179,11
-2	165	6,56	6,56	0,00	-	3,49	1,88	1082,18	310,08
-1	173	6,19	6,19	0,00	-	3,53	1,75	1071,61	303,57
0	240	5,83	5,83	0,00	-	3,58	1,63	1399,18	390,83
1	280	5,47	5,47	0,00	-	3,62	1,51	1530,35	422,75
2	320	5,10	5,10	0,00	-	3,67	1,39	1632,37	444,79
3	357	4,74	4,74	0,00	-	3,74	1,27	1691,04	452,15
4	356	4,37	4,37	0,00	-	3,81	1,15	1556,59	408,55
5	303	4,01	4,01	0,00	-	3,89	1,03	1214,44	312,20
6	330	3,64	3,64	0,00	-	3,96	0,92	1202,42	303,64
7	326	3,28	3,28	0,00	-	4,03	0,81	1069,06	265,28
8	348	2,91	2,91	0,00	-	3,87	0,75	1014,40	262,12
9	335	2,55	2,55	0,00	-	3,70	0,69	854,45	230,93
10	315	2,19	2,19	0,00	-	3,54	0,62	688,66	194,54
11	215	1,82	1,82	0,00	-	3,37	0,54	391,70	116,23
12	169	1,46	1,46	0,00	-	3,21	0,45	246,31	76,73
13	151	1,09	1,09	0,00	-	3,05	0,36	165,06	54,12
14	105	0,73	0,73	0,00	-	2,88	0,25	76,52	26,57
15	74	0,36	0,36	0,00	-	2,72	0,13	26,96	9,91
								19 569	5 410

Table 3-14 HP Electricity Consumption Calculation with 0% Electric-Supplemental-Heating in Denmark

Bins, Heating Pump Capacity, COP , Electricity Consumption For SCOP Calculation									
T	*H*	*Ph*	*Php*	*Psup*	*ρ*		*Pel*	*Qdemand*	*Qel*
Temperature [°C]	Bins	Heating Demand [GW]	Heat Pump Capacity [GW]	Backup Heating [GW]	Electric Ratio of Backup Heating	*COP part load*	Total electricity consumption per hour [GWh/h]	Total Heating Demand [GWh]	Total Electricity Consumption [GWh]
-10	1	9,47	6,45	3,03	0	2,60	2,48	9,47	2,48
-9	25	9,11	6,84	2,27	0	2,82	2,43	227,73	60,66
-8	23	8,74	7,23	1,51	0	3,04	2,38	201,13	54,71
-7	24	8,38	7,89	0,49	0	3,26	2,42	201,13	58,10
-6	27	8,02	8,02	0,00	-	3,30	2,43	216,44	65,59
-5	68	7,65	7,65	0,00	-	3,35	2,28	520,32	155,32
-4	91	7,29	7,29	0,00	-	3,39	2,15	663,15	195,62
-3	89	6,92	6,92	0,00	-	3,44	2,01	616,15	179,11
-2	165	6,56	6,56	0,00	-	3,49	1,88	1082,18	310,08
-1	173	6,19	6,19	0,00	-	3,53	1,75	1071,61	303,57
0	240	5,83	5,83	0,00	-	3,58	1,63	1399,18	390,83
1	280	5,47	5,47	0,00	-	3,62	1,51	1530,35	422,75
2	320	5,10	5,10	0,00	-	3,67	1,39	1632,37	444,79
3	357	4,74	4,74	0,00	-	3,74	1,27	1691,04	452,15
4	356	4,37	4,37	0,00	-	3,81	1,15	1556,59	408,55
5	303	4,01	4,01	0,00	-	3,89	1,03	1214,44	312,20
6	330	3,64	3,64	0,00	-	3,96	0,92	1202,42	303,64
7	326	3,28	3,28	0,00	-	4,03	0,81	1069,06	265,28
8	348	2,91	2,91	0,00	-	3,87	0,75	1014,40	262,12
9	335	2,55	2,55	0,00	-	3,70	0,69	854,45	230,93
10	315	2,19	2,19	0,00	-	3,54	0,62	688,66	194,54
11	215	1,82	1,82	0,00	-	3,37	0,54	391,70	116,23
12	169	1,46	1,46	0,00	-	3,21	0,45	246,31	76,73
13	151	1,09	1,09	0,00	-	3,05	0,36	165,06	54,12
14	105	0,73	0,73	0,00	-	2,88	0,25	76,52	26,57
15	74	0,36	0,36	0,00	-	2,72	0,13	26,96	9,91
								19 569	5 357

If only half of the 19569 GWh heating demand supplied by fossil fuels and electricity, which is 9785 GWh, is to be supplied by HPs, the annual electricity consumption will change accordingly to 2732 GWh, and the maximum electrical requirement will be 2.76 GWh/h during the lowest temperature.

If only 25% of the 19569 GWh heating demand supplied by fossil fuels and electricity, which is 4892 GWh, is to be supplied by HPs, the annual electricity consumption will decline to 1366 GWh, and the maximum electrical requirement will reduce to 1.38 GWh/h.

For the DH division, the five scenarios in NETP are analyzed. Table 3-15 shows the heating generation forecast of the HPs in heat plants in the five scenarios for Denmark.

As shown in Table 3-15, the heat generation by HPs will increase to 4244 GWh, 4331 GWh, 4331 GWh, 2902 GWh and 8423 GWh for DH respectively by 2050 in the five scenarios. According to the calculation method mentioned above, the corresponding electrical peak load and electricity consumption are shown in Table 3-16. The corresponding electricity consumption in heating season would be 1185 GWh, 1209 GWh, 1209 GWh, 810 GWh, and 2351 GWh. Again it is shown in the table that with non-electric supplemental heating for HPs, the majority energy carrier will stay to be electricity, but the electrical capacity requirement will drop considerably.

Table 3-15 Heating Generation of HPs in Heat Plants of Denmark in NETP Scenarios

Heat Generation by Electricity in Heat Plants [GWh]									
	2010	2015	2020	2025	2030	2035	2040	2045	2050
4GS Scenario									
Electricity (heat pump)	21	325	677	1 085	1 557	2 105	2 741	3 477	4 244
2GS Scenario									
Electricity (heat pump)	21	325	677	1 085	1 557	2 105	2 741	3 477	4 331
2GS85% Scenario									
Electricity (heat pump)	21	325	677	1 085	1 557	2 105	2 741	3 477	4 331
2GS85%BignBio Scenario									
Electricity (heat pump)	21	319	635	967	1 317	1 684	2 070	2 475	2 902
2GS85%Flexflow Scenario									
Electricity (heat pump)	21	565	1 255	2 055	2 982	4 057	5 303	6 748	8 423

Table 3-16 Electrical Peak Load and Electricity Consumption for HPs in Heat Plants of Denmark in 2050

Electrical Peak Load and Electricity Consumption for Heat Pump in Heat Plants in 2050							
		100% Electric Supplemental Heating		50% Electric Supplemental Heating		0% Electric Supplemental Heating	
Scenario	Heat Demand [GWh]	Electrical Peak Load [GWh/h]	Electricity Consumption [GWh]	Electrical Peak Load [GWh/h]	Electricity Consumption [GWh]	Electrical Peak Load [GWh/h]	Electricity Consumption [GWh]
4GS	4 244	1,19	1 185	0,87	1 173	0,54	1 162
2GS	4 331	1,22	1 209	0,88	1 197	0,55	1 185
2GS85%	4 331	1,22	1 209	0,88	1 197	0,55	1 185
2GS85%BignBio	2 902	0,82	810	0,59	802	0,37	794
2GS85%Flexflow	8 423	2,37	2 351	1,72	2 328	1,07	2 306

3.4 Demand Profile of HPs in Sweden

The installation of HPs in Sweden is on a continous increase. In 2010, the number of HPs in dwellings and non-residential premises was estimated to be 841000. The majority of these, 805000 HPs or 95 percent, can be found in one- and two-dwelling buildings. Geothermal and lake water HPs were the most common types of HPs [13]. The market of HPs in Sweden is relatively mature offering about 8% of the total space heating to the public.

Up to year 2010 the space heating demand in Sweden supplied by fossil fuels and electricity amounted to 22700 GWh/year. Table 3-17 indicates the case if HPs were used to cover the 22700 GWh/year heating with electric direct heating as 100% of the supplemental heating. The numbers of hours with different temperatures in a colder temperature profile, heating demand, HP capacity, electric backup heating capacity along with the temperature are shown in Table 3-17. The total electricity consumption and average SCOP is calculated. In order to cover a total heating demand of 22700 GWh/year in Sweden by HPs, the electricity consumption amounts to 7782 GWh/year, which means a SCOP of 2.88. To be noticed, the maximum electricity capacity requirement is 8.96 GWh/h when the temperature reaches the lowest point. Table 3-18 indicates the case with electric direct heating 50% of as the supplemental heating. The other 50% of supplemental heating shall be supplied by a non-electrical way. It is shown in Table 3-18 that the annual electricity consumption is 7014 GWh, which is 89% of the amount in the 100% electric-supplemental-heating case. However, the maximum electricity capacity requirement is reduced to 4.93 GWh/h during the hours of lowest temperature. Regarding a more extreme situation for comparison, the case with 0% electric-supplemental-heating is shown in Table 3-19. The annual electricity consumption decreases to 6146 GWh while the maximum electricity capacity requirement during the coldest hours drops sharply to 0.90 GWh/h. The highest electrical capacity requirement is 1.65 GWh/h.

Table 3-17 HP Electricity Consumption Calculation with 100% Electric-Supplemental-Heating in Sweden

Bins, Heating Pump Capacity, COP , Electricity Consumption For SCOP Calculation									
T	*H*	*Ph*	*Php*	*Psup*	*ρ*		*Pel*	*Qdemand*	*Qel*
Temperature [°C]	Bins	Heating Demand [GW]	Heat Pump Capacity [GW]	Backup Heating [GW]	Electric Ratio of Backup Heating	*COP part load*	Total electricity consumption per hour [GWh/h]	Total Heating Demand [GWh]	Total Electricity Consumption [GWh]
-22	1	9,21	1,15	8,06	1	1,28	8,96	9,21	8,96
-21	6	8,97	1,42	7,55	1	1,39	8,57	53,81	51,42
-20	13	8,73	1,68	7,05	1	1,50	8,17	113,43	106,16
-19	17	8,48	1,94	6,55	1	1,61	7,75	144,21	131,73
-18	19	8,24	2,20	6,04	1	1,72	7,32	156,57	139,08
-17	26	8,00	2,46	5,54	1	1,83	6,88	207,95	178,94
-16	39	7,76	2,72	5,03	1	1,94	6,44	302,48	251,06
-15	41	7,51	2,98	4,53	1	2,05	5,99	308,05	245,43
-14	35	7,27	3,24	4,03	1	2,16	5,53	254,49	193,53
-13	52	7,03	3,50	3,52	1	2,27	5,07	365,49	263,54
-12	37	6,79	3,77	3,02	1	2,38	4,60	251,09	170,31
-11	41	6,54	4,03	2,52	1	2,49	4,13	268,30	169,51
-10	43	6,30	4,29	2,01	1	2,60	3,66	270,97	157,51
-9	54	6,06	4,55	1,51	1	2,82	3,12	327,20	168,57
-8	90	5,82	4,81	1,01	1	3,04	2,59	523,52	233,02
-7	125	5,57	5,25	0,32	1	3,26	1,94	696,81	241,89
-6	169	5,33	5,33	0,00	-	3,30	1,62	901,13	273,07
-5	195	5,09	5,09	0,00	-	3,35	1,52	992,50	296,27
-4	278	4,85	4,85	0,00	-	3,39	1,43	1347,57	397,51
-3	306	4,61	4,61	0,00	-	3,44	1,34	1409,13	409,63
-2	454	4,36	4,36	0,00	-	3,49	1,25	1980,63	567,52
-1	385	4,12	4,12	0,00	-	3,53	1,17	1586,30	449,38
0	490	3,88	3,88	0,00	-	3,58	1,08	1900,17	530,77
1	533	3,64	3,64	0,00	-	3,62	1,00	1937,74	535,29
2	380	3,39	3,39	0,00	-	3,67	0,92	1289,40	351,34
3	228	3,15	3,15	0,00	-	3,74	0,84	718,38	192,08
4	261	2,91	2,91	0,00	-	3,81	0,76	759,10	199,24
5	279	2,67	2,67	0,00	-	3,89	0,69	743,83	191,22
6	229	2,42	2,42	0,00	-	3,96	0,61	555,02	140,16
7	269	2,18	2,18	0,00	-	4,03	0,54	586,77	145,60
8	233	1,94	1,94	0,00	-	3,87	0,50	451,77	116,74
9	230	1,70	1,70	0,00	-	3,70	0,46	390,21	105,46
10	243	1,45	1,45	0,00	-	3,54	0,41	353,37	99,82
11	191	1,21	1,21	0,00	-	3,37	0,36	231,46	68,68
12	146	0,97	0,97	0,00	-	3,21	0,30	141,54	44,09
13	150	0,73	0,73	0,00	-	3,05	0,24	109,07	35,76
14	97	0,48	0,48	0,00	-	2,88	0,17	47,02	16,33
15	61	0,24	0,24	0,00	-	2,72	0,09	14,78	5,44
								22 700	7 882

Table 3-18 HP Electricity Consumption Calculation with 50% Electric-Supplemental-Heating in Sweden

Bins, Heating Pump Capacity, COP , Electricity Consumption For SCOP Calculation									
T	*H*	*Ph*	*Php*	*Psup*	*ρ*		*Pel*	*Qdemand*	*Qel*
Temperature [°C]	Bins	Heating Demand [GW]	Heat Pump Capacity [GW]	Backup Heating [GW]	Electric Ratio of Backup Heating	*COP part load*	Total electricity consumption per hour [GWh/h]	Total Heating Demand [GWh]	Total Electricity Consumption [GWh]
-22	1	9,21	1,15	8,06	0,5	1,28	4,93	9,21	4,93
-21	6	8,97	1,42	7,55	0,5	1,39	4,79	53,81	28,77
-20	13	8,73	1,68	7,05	0,5	1,50	4,64	113,43	60,35
-19	17	8,48	1,94	6,55	0,5	1,61	4,48	144,21	76,09
-18	19	8,24	2,20	6,04	0,5	1,72	4,30	156,57	81,69
-17	26	8,00	2,46	5,54	0,5	1,83	4,11	207,95	106,95
-16	39	7,76	2,72	5,03	0,5	1,94	3,92	302,48	152,88
-15	41	7,51	2,98	4,53	0,5	2,05	3,72	308,05	152,53
-14	35	7,27	3,24	4,03	0,5	2,16	3,52	254,49	123,04
-13	52	7,03	3,50	3,52	0,5	2,27	3,31	365,49	171,91
-12	37	6,79	3,77	3,02	0,5	2,38	3,09	251,09	114,42
-11	41	6,54	4,03	2,52	0,5	2,49	2,88	268,30	117,91
-10	43	6,30	4,29	2,01	0,5	2,60	2,66	270,97	114,21
-9	54	6,06	4,55	1,51	0,5	2,82	2,37	327,20	127,86
-8	90	5,82	4,81	1,01	0,5	3,04	2,09	523,52	187,71
-7	125	5,57	5,25	0,32	0,5	3,26	1,77	696,81	221,59
-6	169	5,33	5,33	0,00	-	3,30	1,62	901,13	273,07
-5	195	5,09	5,09	0,00	-	3,35	1,52	992,50	296,27
-4	278	4,85	4,85	0,00	-	3,39	1,43	1347,57	397,51
-3	306	4,61	4,61	0,00	-	3,44	1,34	1409,13	409,63
-2	454	4,36	4,36	0,00	-	3,49	1,25	1980,63	567,52
-1	385	4,12	4,12	0,00	-	3,53	1,17	1586,30	449,38
0	490	3,88	3,88	0,00	-	3,58	1,08	1900,17	530,77
1	533	3,64	3,64	0,00	-	3,62	1,00	1937,74	535,29
2	380	3,39	3,39	0,00	-	3,67	0,92	1289,40	351,34
3	228	3,15	3,15	0,00	-	3,74	0,84	718,38	192,08
4	261	2,91	2,91	0,00	-	3,81	0,76	759,10	199,24
5	279	2,67	2,67	0,00	-	3,89	0,69	743,83	191,22
6	229	2,42	2,42	0,00	-	3,96	0,61	555,02	140,16
7	269	2,18	2,18	0,00	-	4,03	0,54	586,77	145,60
8	233	1,94	1,94	0,00	-	3,87	0,50	451,77	116,74
9	230	1,70	1,70	0,00	-	3,70	0,46	390,21	105,46
10	243	1,45	1,45	0,00	-	3,54	0,41	353,37	99,82
11	191	1,21	1,21	0,00	-	3,37	0,36	231,46	68,68
12	146	0,97	0,97	0,00	-	3,21	0,30	141,54	44,09
13	150	0,73	0,73	0,00	-	3,05	0,24	109,07	35,76
14	97	0,48	0,48	0,00	-	2,88	0,17	47,02	16,33
15	61	0,24	0,24	0,00	-	2,72	0,09	14,78	5,44
								22 700	7 014

Table 3-19 HP Electricity Consumption Calculation with 0% Electric-Supplemental-Heating in Sweden

Bins, Heating Pump Capacity, COP, Electricity Consumption For SCOP Calculation									
T	*H*	*Ph*	*Php*	*Psup*	*ρ*		*Pel*	*Qdemand*	*Qel*
Temperature [°C]	**Bins**	**Heating Demand [GW]**	**Heat Pump Capacity [GW]**	**Backup Heating [GW]**	**Electric Ratio of Backup Heating**	***COP part load***	**Total electricity consumption per hour [GWh/h]**	**Total Heating Demand [GWh]**	**Total Electricity Consumption [GWh]**
-22	1	9,21	1,15	8,06	0	1,28	0,90	9,21	0,90
-21	6	8,97	1,42	7,55	0	1,39	1,02	53,81	6,11
-20	13	8,73	1,68	7,05	0	1,50	1,12	113,43	14,53
-19	17	8,48	1,94	6,55	0	1,61	1,20	144,21	20,46
-18	19	8,24	2,20	6,04	0	1,72	1,28	156,57	24,29
-17	26	8,00	2,46	5,54	0	1,83	1,34	207,95	34,95
-16	39	7,76	2,72	5,03	0	1,94	1,40	302,48	54,70
-15	41	7,51	2,98	4,53	0	2,05	1,45	308,05	59,64
-14	35	7,27	3,24	4,03	0	2,16	1,50	254,49	52,55
-13	52	7,03	3,50	3,52	0	2,27	1,54	365,49	80,28
-12	37	6,79	3,77	3,02	0	2,38	1,58	251,09	58,54
-11	41	6,54	4,03	2,52	0	2,49	1,62	268,30	66,30
-10	43	6,30	4,29	2,01	0	2,60	1,65	270,97	70,91
-9	54	6,06	4,55	1,51	0	2,82	1,61	327,20	87,16
-8	90	5,82	4,81	1,01	0	3,04	1,58	523,52	142,40
-7	125	5,57	5,25	0,32	0	3,26	1,61	696,81	201,29
-6	169	5,33	5,33	0,00	-	3,30	1,62	901,13	273,07
-5	195	5,09	5,09	0,00	-	3,35	1,52	992,50	296,27
-4	278	4,85	4,85	0,00	-	3,39	1,43	1347,57	397,51
-3	306	4,61	4,61	0,00	-	3,44	1,34	1409,13	409,63
-2	454	4,36	4,36	0,00	-	3,49	1,25	1980,63	567,52
-1	385	4,12	4,12	0,00	-	3,53	1,17	1586,30	449,38
0	490	3,88	3,88	0,00	-	3,58	1,08	1900,17	530,77
1	533	3,64	3,64	0,00	-	3,62	1,00	1937,74	535,29
2	380	3,39	3,39	0,00	-	3,67	0,92	1289,40	351,34
3	228	3,15	3,15	0,00	-	3,74	0,84	718,38	192,08
4	261	2,91	2,91	0,00	-	3,81	0,76	759,10	199,24
5	279	2,67	2,67	0,00	-	3,89	0,69	743,83	191,22
6	229	2,42	2,42	0,00	-	3,96	0,61	555,02	140,16
7	269	2,18	2,18	0,00	-	4,03	0,54	586,77	145,60
8	233	1,94	1,94	0,00	-	3,87	0,50	451,77	116,74
9	230	1,70	1,70	0,00	-	3,70	0,46	390,21	105,46
10	243	1,45	1,45	0,00	-	3,54	0,41	353,37	99,82
11	191	1,21	1,21	0,00	-	3,37	0,36	231,46	68,68
12	146	0,97	0,97	0,00	-	3,21	0,30	141,54	44,09
13	150	0,73	0,73	0,00	-	3,05	0,24	109,07	35,76
14	97	0,48	0,48	0,00	-	2,88	0,17	47,02	16,33
15	61	0,24	0,24	0,00	-	2,72	0,09	14,78	5,44
								22 700	6 146

If only half of the 22700 GWh heating demand supplied by fossil fuels and electricity, which is 11350 GWh, is to be supplied by HPs, the annual electricity consumption will change accordingly to 3941 GWh, and the maximum electrical requirement will be 4.48 GWh/h during the lowest temperature.

If only 25% of the 22700 GWh heating demand supplied by fossil fuels and electricity, which is 5675 GWh, is to be supplied by HPs, the annual electricity consumption will decline to 1971 GWh, and the maximum electrical requirement will reduce to 2.24 GWh/h.

For the DH division, the five scenarios in NETP are analyzed. Table 3-20 shows the heating generation forecast of the HPs in heat plants of the five scenarios for Sweden in the NETP project. As shown in Table

3-20, the heating generation by HP will rise to 21167 GWh, 14574 GWh, 14213 GWh, 10738 GWh and 14406 GWh respectively by 2050 in the five scenarios. The corresponding electrical peak load and electricity consumption are shown in Table 3-21. As shown in Table 3-21 electricity consumption in heating season would be 7350 GWh, 5060 GWh, 4935 GWh, 3728 GWh, and 5001 GWh. Further, it is shown in the table that with non-electric supplemental heating for HPs, the majority energy carrier will stay to be electricity, but the electrical capacity requirement will drop considerably.

Table 3-20 Heating Generation of HPs in Heat Plants of Sweden in NETP Scenarios

Heat Generation by Electricity in Heat Plants [GWh]									
	2010	2015	2020	2025	2030	2035	2040	2045	2050
4GS Scenario									
Electricity (heat pump)	7 769	6 308	7 613	9 126	10 879	12 912	15 268	18 000	21 167
2GS Scenario									
Electricity (heat pump)	7 769	6 308	7 613	9 126	10 879	12 912	15 268	15 321	14 574
2GS85% Scenario									
Electricity (heat pump)	7 769	6 308	7 613	9 126	10 879	12 912	15 268	14 790	14 213
2GS85%BignBio Scenario									
Electricity (heat pump)	7 769	5 851	6 449	7 078	7 739	8 434	9 164	9 931	10 738
2GS85%Flexflow Scenario									
Electricity (heat pump)	7 769	6 548	8 191	10 096	12 304	14 864	15 196	16 883	14 406

Table 3-21 Electrical Peak Load and Electricity Consumption for HPs of Sweden in Heat Plants in 2050

Electrical Peak Load and Electricity Consumption for Heat Pump in Heat Plants in 2050							
		100% Electric Supplemental Heating		50% Electric Supplemental Heating		0% Electric Supplemental Heating	
Scenario	Heat Demand [GWh]	Electrical Peak Load [GWh/h]	Electricity Consumption [GWh]	Electrical Peak Load [GWh/h]	Electricity Consumption [GWh]	Electrical Peak Load [GWh/h]	Electricity Consumption [GWh]
4GS	21 167	8,35	7 350	4,60	6 541	1,54	5 731
2GS	14 574	5,75	5 060	3,16	4 503	1,06	3 946
2GS85%	14 213	5,61	4 935	3,09	4 392	1,03	3 848
2GS85%BignBio	10 738	4,23	3 728	2,33	3 318	0,78	2 907
2GS85%Flexflow	14 406	5,68	5 001	3,13	4 451	1,05	3 901

3.5 Demand Profile of HPs in Norway

HP market in Norway is on a rapid increase since the late 1990s. Up to year 2009, 18.5% of all households had a HP in Norway while this share was only 8% in 2006. For detached dwellings this share was 33% [16]. Approximately 15000 ground source heat pumps (GSHPs) were estimated to be operating in Norway in 2007. In 2008 air-to-water HPs appeared to make a significant breakthrough into the market, judged by the continued increase in applications for government grants. Most HPs in Norway installed in houses are air-to-air, and the residential sector is the main market for these. They are dominant because water-based central heating is relatively rare and air-to-air HPs are easier and less expensive to install than GSHPs. In the commercial and public sectors of Norway, 50% of the energy used for heating is provided via central heating. 3% of the buildings with central heating systems have HPs [30].

The heating demand for buildings in Norway is about 45 TWh, the majority of which is supplied by electric space heating. With a deduction of the DH consumption for about 3.8 TWh in Norway, the heating demand amounts to 41.2 TWh. About 95% of the buildings hold electric space heaters or electric floor heating around Norway. However, electric direct heating has lower energy efficiency than HPs. An estimation of the case that all 41.2 TWh heating demand is supplied by HPs is shown in Table 3-22. Table 3-22 indicates the case when HPs cover a total of 41200 GWh/year heating with electric direct heating as 100% of the supplemental heating. The numbers of hours with different temperatures in a colder temperature profile, heating demand, HP capacity, electric backup heating capacity along with the temperature are shown in Table 3-22. In order to cover a total heating demand of 41200 GWh/year in Norway by HPs, the electricity consumption amounts to 14305 GWh/year. To be noticed, the maximum electricity capacity requirement is 16.26 GWh/h when the temperature reaches the lowest point. Table 3-23 indicates the case with electric direct heating as 50% of the supplemental heating. The other 50% of supplemental heating shall be supplied by a non-electrical way. It is shown in Table 3-23 that the annual electricity consumption is 12730 GWh. However, the maximum electricity capacity requirement is reduced to 8.95 GWh/h during the hours of lowest temperature. Regarding a more extreme situation for comparison, the case with 0% electric-supplemental-heating is shown in Table 3-24. The annual electricity consumption decreases to 11155 GWh while the electricity capacity requirement during the coldest hours drops sharply to 1.64 GWh/h and the maximum electricity capacity requirement becomes 2.99 GWh/h.

If only half of the 41200 GWh heating demand supplied by fossil fuels and electricity, which is 20600 GWh, is to be supplied by HPs, the annual electricity consumption will change accordingly to 7153 GWh, and the maximum electrical requirement will be 8.13 GWh/h during the lowest temperature.

If only 25% of the 41200 GWh heating demand supplied by fossil fuels and electricity, which is 10300 GWh, is to be supplied by HPs, the annual electricity consumption will decline to 3576 GWh, and the maximum electrical requirement will reduce to 4.07 GWh/h.

For the DH division, the five scenarios in NETP are analyzed. Table 3-25 shows the heating generation forecast of the HPs in heat plants of the five scenarios for Norway in the NETP project. As shown in Table 3-25, the heating generation by HP will increase to 4726 GWh, 2808 GWh, 3765 GWh, 2733 GWh and 3529 GWh respectively by 2050 in the five scenarios. The corresponding electrical peak load and electricity consumption are shown in Table 3-26. As shown in Table 3-26, the electricity consumption are 1641 GWh, 975 GWh, 1307 GWh, 949 GWh and 1225 GWh respectively. Again it is shown in the table that with non-electric supplemental heating for HPs, the majority energy carrier will stay to be electricity, but the electrical capacity requirement will drop considerably.

Table 3-22 HP Electricity Consumption Calculation with 100% Electric-Supplemental-Heating in Norway

Bins, Heating Pump Capacity, COP , Electricity Consumption For SCOP Calculation									
T	*H*	*Ph*	*Php*	*Psup*	*ρ*		*Pel*	*Qdemand*	*Qel*
Temperature [°C]	Bins	Heating Demand [GW]	Heat Pump Capacity [GW]	Backup Heating [GW]	Electric Ratio of Backup Heating	*COP part load*	Total electricity consumption per hour [GWh/h]	Total Heating Demand [GWh]	Total Electricity Consumption [GWh]
-22	1	16,72	2,10	14,62	1	1,28	16,26	16,72	16,26
-21	6	16,28	2,57	13,71	1	1,39	15,55	97,65	93,33
-20	13	15,84	3,04	12,79	1	1,50	14,82	205,86	192,68
-19	17	15,40	3,52	11,88	1	1,61	14,06	261,73	239,08
-18	19	14,96	3,99	10,97	1	1,72	13,29	284,16	252,42
-17	26	14,52	4,46	10,05	1	1,83	12,49	377,42	324,77
-16	39	14,08	4,94	9,14	1	1,94	11,68	548,97	455,65
-15	41	13,64	5,41	8,22	1	2,05	10,86	559,09	445,43
-14	35	13,20	5,89	7,31	1	2,16	10,04	461,88	351,24
-13	52	12,76	6,36	6,40	1	2,27	9,20	663,34	478,31
-12	37	12,32	6,83	5,48	1	2,38	8,35	455,72	309,10
-11	41	11,88	7,31	4,57	1	2,49	7,50	486,95	307,66
-10	43	11,44	7,78	3,66	1	2,60	6,65	491,79	285,87
-9	54	11,00	8,26	2,74	1	2,82	5,67	593,84	305,95
-8	90	10,56	8,73	1,83	1	3,04	4,70	950,14	422,92
-7	125	10,12	9,53	0,59	1	3,26	3,51	1264,66	439,02
-6	169	9,68	9,68	0,00	-	3,30	2,93	1635,48	495,60
-5	195	9,24	9,24	0,00	-	3,35	2,76	1801,32	537,71
-4	278	8,80	8,80	0,00	-	3,39	2,60	2445,74	721,46
-3	306	8,36	8,36	0,00	-	3,44	2,43	2557,47	743,45
-2	454	7,92	7,92	0,00	-	3,49	2,27	3594,71	1030,00
-1	385	7,48	7,48	0,00	-	3,53	2,12	2879,02	815,59
0	490	7,04	7,04	0,00	-	3,58	1,97	3448,67	963,32
1	533	6,60	6,60	0,00	-	3,62	1,82	3516,85	971,51
2	380	6,16	6,16	0,00	-	3,67	1,68	2340,17	637,65
3	228	5,72	5,72	0,00	-	3,74	1,53	1303,81	348,61
4	261	5,28	5,28	0,00	-	3,81	1,39	1377,71	361,60
5	279	4,84	4,84	0,00	-	3,89	1,24	1350,00	347,04
6	229	4,40	4,40	0,00	-	3,96	1,11	1007,33	254,38
7	269	3,96	3,96	0,00	-	4,03	0,98	1064,95	264,26
8	233	3,52	3,52	0,00	-	3,87	0,91	819,94	211,87
9	230	3,08	3,08	0,00	-	3,70	0,83	708,21	191,41
10	243	2,64	2,64	0,00	-	3,54	0,75	641,35	181,17
11	191	2,20	2,20	0,00	-	3,37	0,65	420,09	124,65
12	146	1,76	1,76	0,00	-	3,21	0,55	256,89	80,03
13	150	1,32	1,32	0,00	-	3,05	0,43	197,95	64,90
14	97	0,88	0,88	0,00	-	2,88	0,31	85,34	29,63
15	61	0,44	0,44	0,00	-	2,72	0,16	26,83	9,86
								41 200	14 305

Table 3-23 HP Electricity Consumption Calculation with 50% Electric-Supplemental-Heating in Norway

Bins, Heating Pump Capacity, COP , Electricity Consumption For SCOP Calculation									
T	*H*	*Ph*	*Php*	*Psup*	*ρ*		*Pel*	*Qdemand*	*Qel*
Temperature [°C]	**Bins**	**Heating Demand [GW]**	**Heat Pump Capacity [GW]**	**Backup Heating [GW]**	**Electric Ratio of Backup Heating**	***COP part load***	**Total electricity consumption per hour [GWh/h]**	**Total Heating Demand [GWh]**	**Total Electricity Consumption [GWh]**
-22	1	16,72	2,10	14,62	0,5	1,28	8,95	16,72	8,95
-21	6	16,28	2,57	13,71	0,5	1,39	8,70	97,65	52,21
-20	13	15,84	3,04	12,79	0,5	1,50	8,43	205,86	109,53
-19	17	15,40	3,52	11,88	0,5	1,61	8,12	261,73	138,11
-18	19	14,96	3,99	10,97	0,5	1,72	7,80	284,16	148,25
-17	26	14,52	4,46	10,05	0,5	1,83	7,47	377,42	194,10
-16	39	14,08	4,94	9,14	0,5	1,94	7,11	548,97	277,46
-15	41	13,64	5,41	8,22	0,5	2,05	6,75	559,09	276,84
-14	35	13,20	5,89	7,31	0,5	2,16	6,38	461,88	223,31
-13	52	12,76	6,36	6,40	0,5	2,27	6,00	663,34	312,00
-12	37	12,32	6,83	5,48	0,5	2,38	5,61	455,72	207,67
-11	41	11,88	7,31	4,57	0,5	2,49	5,22	486,95	213,99
-10	43	11,44	7,78	3,66	0,5	2,60	4,82	491,79	207,28
-9	54	11,00	8,26	2,74	0,5	2,82	4,30	593,84	232,06
-8	90	10,56	8,73	1,83	0,5	3,04	3,79	950,14	340,68
-7	125	10,12	9,53	0,59	0,5	3,26	3,22	1264,66	402,17
-6	169	9,68	9,68	0,00	-	3,30	2,93	1635,48	495,60
-5	195	9,24	9,24	0,00	-	3,35	2,76	1801,32	537,71
-4	278	8,80	8,80	0,00	-	3,39	2,60	2445,74	721,46
-3	306	8,36	8,36	0,00	-	3,44	2,43	2557,47	743,45
-2	454	7,92	7,92	0,00	-	3,49	2,27	3594,71	1030,00
-1	385	7,48	7,48	0,00	-	3,53	2,12	2879,02	815,59
0	490	7,04	7,04	0,00	-	3,58	1,97	3448,67	963,32
1	533	6,60	6,60	0,00	-	3,62	1,82	3516,85	971,51
2	380	6,16	6,16	0,00	-	3,67	1,68	2340,17	637,65
3	228	5,72	5,72	0,00	-	3,74	1,53	1303,81	348,61
4	261	5,28	5,28	0,00	-	3,81	1,39	1377,71	361,60
5	279	4,84	4,84	0,00	-	3,89	1,24	1350,00	347,04
6	229	4,40	4,40	0,00	-	3,96	1,11	1007,33	254,38
7	269	3,96	3,96	0,00	-	4,03	0,98	1064,95	264,26
8	233	3,52	3,52	0,00	-	3,87	0,91	819,94	211,87
9	230	3,08	3,08	0,00	-	3,70	0,83	708,21	191,41
10	243	2,64	2,64	0,00	-	3,54	0,75	641,35	181,17
11	191	2,20	2,20	0,00	-	3,37	0,65	420,09	124,65
12	146	1,76	1,76	0,00	-	3,21	0,55	256,89	80,03
13	150	1,32	1,32	0,00	-	3,05	0,43	197,95	64,90
14	97	0,88	0,88	0,00	-	2,88	0,31	85,34	29,63
15	61	0,44	0,44	0,00	-	2,72	0,16	26,83	9,86
								41 200	12 730

Table 3-24 HP Electricity Consumption Calculation with 0% Electric-Supplemental-Heating in Norway

Bins, Heating Pump Capacity, COP, Electricity Consumption For SCOP Calculation									
T	*H*	*Ph*	*Php*	*Psup*	*ρ*		*Pel*	*Qdemand*	*Qel*
Temperature [°C]	Bins	Heating Demand [GW]	Heat Pump Capacity [GW]	Backup Heating [GW]	Electric Ratio of Backup Heating	*COP part load*	Total electricity consumption per hour [GWh/h]	Total Heating Demand [GWh]	Total Electricity Consumption [GWh]
-22	1	16,72	2,10	14,62	0	1,28	1,64	16,72	1,64
-21	6	16,28	2,57	13,71	0	1,39	1,85	97,65	11,09
-20	13	15,84	3,04	12,79	0	1,50	2,03	205,86	26,37
-19	17	15,40	3,52	11,88	0	1,61	2,18	261,73	37,13
-18	19	14,96	3,99	10,97	0	1,72	2,32	284,16	44,08
-17	26	14,52	4,46	10,05	0	1,83	2,44	377,42	63,43
-16	39	14,08	4,94	9,14	0	1,94	2,55	548,97	99,28
-15	41	13,64	5,41	8,22	0	2,05	2,64	559,09	108,25
-14	35	13,20	5,89	7,31	0	2,16	2,73	461,88	95,38
-13	52	12,76	6,36	6,40	0	2,27	2,80	663,34	145,69
-12	37	12,32	6,83	5,48	0	2,38	2,87	455,72	106,24
-11	41	11,88	7,31	4,57	0	2,49	2,93	486,95	120,33
-10	43	11,44	7,78	3,66	0	2,60	2,99	491,79	128,70
-9	54	11,00	8,26	2,74	0	2,82	2,93	593,84	158,18
-8	90	10,56	8,73	1,83	0	3,04	2,87	950,14	258,44
-7	125	10,12	9,53	0,59	0	3,26	2,92	1264,66	365,33
-6	169	9,68	9,68	0,00	-	3,30	2,93	1635,48	495,60
-5	195	9,24	9,24	0,00	-	3,35	2,76	1801,32	537,71
-4	278	8,80	8,80	0,00	-	3,39	2,60	2445,74	721,46
-3	306	8,36	8,36	0,00	-	3,44	2,43	2557,47	743,45
-2	454	7,92	7,92	0,00	-	3,49	2,27	3594,71	1030,00
-1	385	7,48	7,48	0,00	-	3,53	2,12	2879,02	815,59
0	490	7,04	7,04	0,00	-	3,58	1,97	3448,67	963,32
1	533	6,60	6,60	0,00	-	3,62	1,82	3516,85	971,51
2	380	6,16	6,16	0,00	-	3,67	1,68	2340,17	637,65
3	228	5,72	5,72	0,00	-	3,74	1,53	1303,81	348,61
4	261	5,28	5,28	0,00	-	3,81	1,39	1377,71	361,60
5	279	4,84	4,84	0,00	-	3,89	1,24	1350,00	347,04
6	229	4,40	4,40	0,00	-	3,96	1,11	1007,33	254,38
7	269	3,96	3,96	0,00	-	4,03	0,98	1064,95	264,26
8	233	3,52	3,52	0,00	-	3,87	0,91	819,94	211,87
9	230	3,08	3,08	0,00	-	3,70	0,83	708,21	191,41
10	243	2,64	2,64	0,00	-	3,54	0,75	641,35	181,17
11	191	2,20	2,20	0,00	-	3,37	0,65	420,09	124,65
12	146	1,76	1,76	0,00	-	3,21	0,55	256,89	80,03
13	150	1,32	1,32	0,00	-	3,05	0,43	197,95	64,90
14	97	0,88	0,88	0,00	-	2,88	0,31	85,34	29,63
15	61	0,44	0,44	0,00	-	2,72	0,16	26,83	9,86
								41 200	11 155

Table 3-25 Heating Generation of HPs of Norway in Heat Plants in NETP Scenarios

Heat Generation by Electricity in Heat Plants [GWh]	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
4GS Scenario									
Electricity (heat pump)	1 071	960	1 413	1 938	2 547	3 253	3 851	4 106	4 726
2GS Scenario									
Electricity (heat pump)	1 071	960	1 413	1 939	2 547	3 253	3 235	2 989	2 808
2GS85% Scenario									
Electricity (heat pump)	1 071	960	1 413	1 939	2 547	3 253	3 237	2 989	3 765
2GS85%BignBio Scenario									
Electricity (heat pump)	1 071	906	1 252	1 616	1 999	2 401	2 337	2 315	2 733
2GS85%Flexflow Scenario									
Electricity (heat pump)	1 071	1 200	1 992	2 909	3 062	3 260	3 185	3 068	3 529

Table 3-26 Electrical Peak Load and Electricity Consumption for HPs of Norway in Heat Plants in 2050

Electrical Peak Load and Electricity Consumption for Heat Pump in Heat Plants in 2050							
		100% Electric Supplemental Heating		**50% Electric Supplemental Heating**		**0% Electric Supplemental Heating**	
Scenario	**Heat Demand [GWh]**	**Electrical Peak Load [GWh/h]**	**Electricity Consumption [GWh]**	**Electrical Peak Load [GWh/h]**	**Electricity Consumption [GWh]**	**Electrical Peak Load [GWh/h]**	**Electricity Consumption [GWh]**
4GS	4 726	1,86	1 641	1,03	1 460	0,34	1 280
2GS	2 808	1,11	975	0,61	868	0,20	760
2GS85%	3 765	1,49	1 307	0,82	1 163	0,27	1 019
2GS85%BignBio	2 733	1,08	949	0,59	845	0,20	740
2GS85%Flexflow	3 529	1,39	1 225	0,77	1 090	0,26	956

3.6 Demand Profile of HPs in Finland

The growth speed of HP market in Finland was very fast in the past ten to twenty years. Table 3-27 shows the penetration of HPs in Finland [31]. The total capacity of HP in Finland rose dramaticly from 164 MW to 1362 MW in 12 years. Further, the heat generated per year rose from 611 GWh to 2664 GWh in 2009.

Table 3-27 Penetration of HPs in Finnish Heating Market

	Air Source Heat Pumps*			Ground Source Heat Pumps		
Year	Amount	Heating Capacity [MW]	Generated Heat [GWh]	Amount	Heating Capacity [MW]	Generated Heat [GWh]
1997	4427	17	26	15592	147	585
1998	5228	20	30	16324	153	612
1999	5725	22	31	17264	162	621
2000	6525	26	32	16835	158	536
2001	7566	31	41	16376	154	601
2002	9696	41	51	15708	148	584
2003	15560	67	80	15696	148	581
2004	24710	109	124	16953	159	608
2005	43170	194	211	20073	189	691
2006	75272	348	380	24551	231	849
2007	104818	489	535	29698	279	1004
2008	156721	750	851	37336	351	1202
2009	198235	958	1132	42996	404	1532

* Air source heat pumps include air/air, air/water and exhaust air heat pumps.

Up to year 2006 the space heating demand in Finland supplied by fossil fuels and electricity amounted to 34873 GWh/year. In order to cover 100% this part of heating demand by HPs, the energy efficiency, consumption and capacity need to be estimated generally. Table 3-28 indicates the case when HPs cover a total of 34873 GWh/year heating with electric direct heating as 100% of the supplemental heating. The numbers of hours with different temperatures in a colder temperature profile, heating demand, HP capacity, electric backup heating capacity along with the temperature are shown in Table 3-28. The total electricity consumption is calculated. In order to cover a total heating demand of 34873 GWh/year in Finland by HPs, the electricity consumption amounts to 12109 GWh/year. To be noticed, the maximum electricity capacity requirement is 13.76 GWh/h when the temperature reaches the lowest point. Table 3-29 indicates the case with electric direct heating as 50% of the supplemental heating. The other 50% of supplemental heating shall be supplied by a non-electrical way. It is shown in Table 3-29 that the annual electricity consumption is 10776 GWh. However, the maximum electricity capacity requirement is reduced to 7.57 GWh/h during the hours of lowest temperature. Regarding a more extreme situation for comparison, the case with 0% electric-supplemental-heating is shown in Table 3-30. The annual electricity consumption decreases to 9442 GWh while the maximum electricity capacity requirement drops to 2.53 GWh/h.

Table 3-28 HP Electricity Consumption Calculation with 100% Electric-Supplemental-Heating in Finland

Bins, Heating Pump Capacity, COP , Electricity Consumption For SCOP Calculation									
T	*H*	*Ph*	*Php*	*Psup*	*ρ*		*Pel*	*Qdemand*	*Qel*
Temperature [°C]	Bins	Heating Demand [GW]	Heat Pump Capacity [GW]	Backup Heating [GW]	Electric Ratio of Backup Heating	*COP part load*	Total electricity consumption per hour [GWh/h]	Total Heating Demand [GWh]	Total Electricity Consumption [GWh]
-22	1	14,15	1,77	12,38	1	1,28	13,76	14,15	13,76
-21	6	13,78	2,17	11,60	1	1,39	13,17	82,66	79,00
-20	13	13,40	2,58	10,83	1	1,50	12,55	174,25	163,09
-19	17	13,03	2,98	10,06	1	1,61	11,90	221,54	202,37
-18	19	12,66	3,38	9,28	1	1,72	11,25	240,53	213,66
-17	26	12,29	3,78	8,51	1	1,83	10,57	319,47	274,90
-16	39	11,91	4,18	7,73	1	1,94	9,89	464,68	385,68
-15	41	11,54	4,58	6,96	1	2,05	9,20	473,24	377,03
-14	35	11,17	4,98	6,19	1	2,16	8,49	390,95	297,30
-13	52	10,80	5,38	5,41	1	2,27	7,79	561,48	404,86
-12	37	10,43	5,78	4,64	1	2,38	7,07	385,74	261,64
-11	41	10,05	6,19	3,87	1	2,49	6,35	412,18	260,41
-10	43	9,68	6,59	3,09	1	2,60	5,63	416,27	241,97
-9	54	9,31	6,99	2,32	1	2,82	4,80	502,65	258,97
-8	90	8,94	7,39	1,55	1	3,04	3,98	804,25	357,98
-7	125	8,56	8,06	0,50	1	3,26	2,97	1070,47	371,61
-6	169	8,19	8,19	0,00	-	3,30	2,48	1384,35	419,50
-5	195	7,82	7,82	0,00	-	3,35	2,33	1524,72	455,14
-4	278	7,45	7,45	0,00	-	3,39	2,20	2070,19	610,68
-3	306	7,07	7,07	0,00	-	3,44	2,06	2164,77	629,29
-2	454	6,70	6,70	0,00	-	3,49	1,92	3042,74	871,84
-1	385	6,33	6,33	0,00	-	3,53	1,79	2436,94	690,35
0	490	5,96	5,96	0,00	-	3,58	1,66	2919,12	815,40
1	533	5,59	5,59	0,00	-	3,62	1,54	2976,83	822,33
2	380	5,21	5,21	0,00	-	3,67	1,42	1980,83	539,74
3	228	4,84	4,84	0,00	-	3,74	1,29	1103,61	295,08
4	261	4,47	4,47	0,00	-	3,81	1,17	1166,16	306,08
5	279	4,10	4,10	0,00	-	3,89	1,05	1142,70	293,75
6	229	3,72	3,72	0,00	-	3,96	0,94	852,65	215,32
7	269	3,35	3,35	0,00	-	4,03	0,83	901,43	223,68
8	233	2,98	2,98	0,00	-	3,87	0,77	694,04	179,34
9	230	2,61	2,61	0,00	-	3,70	0,70	599,46	162,02
10	243	2,23	2,23	0,00	-	3,54	0,63	542,87	153,35
11	191	1,86	1,86	0,00	-	3,37	0,55	355,58	105,51
12	146	1,49	1,49	0,00	-	3,21	0,46	217,44	67,74
13	150	1,12	1,12	0,00	-	3,05	0,37	167,55	54,93
14	97	0,74	0,74	0,00	-	2,88	0,26	72,23	25,08
15	61	0,37	0,37	0,00	-	2,72	0,14	22,71	8,35
								34 873	12 109

Table 3-29 HP Electricity Consumption Calculation with 50% Electric-Supplemental-Heating in Finland

Bins, Heating Pump Capacity, COP , Electricity Consumption For SCOP Calculation									
T	*H*	*Ph*	*Php*	*Psup*	*ρ*		*Pel*	*Qdemand*	*Qel*
Temperature [°C]	Bins	Heating Demand [GW]	Heat Pump Capacity [GW]	Backup Heating [GW]	Electric Ratio of Backup Heating	*COP part load*	Total electricity consumption per hour [GWh/h]	Total Heating Demand [GWh]	Total Electricity Consumption [GWh]
-22	1	14,15	1,77	12,38	0,5	1,28	7,57	14,15	7,57
-21	6	13,78	2,17	11,60	0,5	1,39	7,37	82,66	44,19
-20	13	13,40	2,58	10,83	0,5	1,50	7,13	174,25	92,71
-19	17	13,03	2,98	10,06	0,5	1,61	6,88	221,54	116,90
-18	19	12,66	3,38	9,28	0,5	1,72	6,60	240,53	125,49
-17	26	12,29	3,78	8,51	0,5	1,83	6,32	319,47	164,30
-16	39	11,91	4,18	7,73	0,5	1,94	6,02	464,68	234,86
-15	41	11,54	4,58	6,96	0,5	2,05	5,72	473,24	234,33
-14	35	11,17	4,98	6,19	0,5	2,16	5,40	390,95	189,02
-13	52	10,80	5,38	5,41	0,5	2,27	5,08	561,48	264,09
-12	37	10,43	5,78	4,64	0,5	2,38	4,75	385,74	175,78
-11	41	10,05	6,19	3,87	0,5	2,49	4,42	412,18	181,13
-10	43	9,68	6,59	3,09	0,5	2,60	4,08	416,27	175,46
-9	54	9,31	6,99	2,32	0,5	2,82	3,64	502,65	196,43
-8	90	8,94	7,39	1,55	0,5	3,04	3,20	804,25	288,37
-7	125	8,56	8,06	0,50	0,5	3,26	2,72	1070,47	340,42
-6	169	8,19	8,19	0,00	-	3,30	2,48	1384,35	419,50
-5	195	7,82	7,82	0,00	-	3,35	2,33	1524,72	455,14
-4	278	7,45	7,45	0,00	-	3,39	2,20	2070,19	610,68
-3	306	7,07	7,07	0,00	-	3,44	2,06	2164,77	629,29
-2	454	6,70	6,70	0,00	-	3,49	1,92	3042,74	871,84
-1	385	6,33	6,33	0,00	-	3,53	1,79	2436,94	690,35
0	490	5,96	5,96	0,00	-	3,58	1,66	2919,12	815,40
1	533	5,59	5,59	0,00	-	3,62	1,54	2976,83	822,33
2	380	5,21	5,21	0,00	-	3,67	1,42	1980,83	539,74
3	228	4,84	4,84	0,00	-	3,74	1,29	1103,61	295,08
4	261	4,47	4,47	0,00	-	3,81	1,17	1166,16	306,08
5	279	4,10	4,10	0,00	-	3,89	1,05	1142,70	293,75
6	229	3,72	3,72	0,00	-	3,96	0,94	852,65	215,32
7	269	3,35	3,35	0,00	-	4,03	0,83	901,43	223,68
8	233	2,98	2,98	0,00	-	3,87	0,77	694,04	179,34
9	230	2,61	2,61	0,00	-	3,70	0,70	599,46	162,02
10	243	2,23	2,23	0,00	-	3,54	0,63	542,87	153,35
11	191	1,86	1,86	0,00	-	3,37	0,55	355,58	105,51
12	146	1,49	1,49	0,00	-	3,21	0,46	217,44	67,74
13	150	1,12	1,12	0,00	-	3,05	0,37	167,55	54,93
14	97	0,74	0,74	0,00	-	2,88	0,26	72,23	25,08
15	61	0,37	0,37	0,00	-	2,72	0,14	22,71	8,35
								34 873	10 776

Table 3-30 HP Electricity Consumption Calculation with 0% Electric-Supplemental-Heating in Finland

Bins, Heating Pump Capacity, COP , Electricity Consumption For SCOP Calculation									
T	*H*	*Ph*	*Php*	*Psup*	*ρ*		*Pel*	*Qdemand*	*Qel*
Temperature [°C]	Bins	Heating Demand [GW]	Heat Pump Capacity [GW]	Backup Heating [GW]	Electric Ratio of Backup Heating	*COP part load*	Total electricity consumption per hour [GWh/h]	Total Heating Demand [GWh]	Total Electricity Consumption [GWh]
-22	1	14,15	1,77	12,38	0	1,28	1,39	14,15	1,39
-21	6	13,78	2,17	11,60	0	1,39	1,56	82,66	9,39
-20	13	13,40	2,58	10,83	0	1,50	1,72	174,25	22,32
-19	17	13,03	2,98	10,06	0	1,61	1,85	221,54	31,43
-18	19	12,66	3,38	9,28	0	1,72	1,96	240,53	37,31
-17	26	12,29	3,78	8,51	0	1,83	2,07	319,47	53,69
-16	39	11,91	4,18	7,73	0	1,94	2,15	464,68	84,03
-15	41	11,54	4,58	6,96	0	2,05	2,23	473,24	91,63
-14	35	11,17	4,98	6,19	0	2,16	2,31	390,95	80,73
-13	52	10,80	5,38	5,41	0	2,27	2,37	561,48	123,32
-12	37	10,43	5,78	4,64	0	2,38	2,43	385,74	89,93
-11	41	10,05	6,19	3,87	0	2,49	2,48	412,18	101,85
-10	43	9,68	6,59	3,09	0	2,60	2,53	416,27	108,94
-9	54	9,31	6,99	2,32	0	2,82	2,48	502,65	133,89
-8	90	8,94	7,39	1,55	0	3,04	2,43	804,25	218,76
-7	125	8,56	8,06	0,50	0	3,26	2,47	1070,47	309,23
-6	169	8,19	8,19	0,00	-	3,30	2,48	1384,35	419,50
-5	195	7,82	7,82	0,00	-	3,35	2,33	1524,72	455,14
-4	278	7,45	7,45	0,00	-	3,39	2,20	2070,19	610,68
-3	306	7,07	7,07	0,00	-	3,44	2,06	2164,77	629,29
-2	454	6,70	6,70	0,00	-	3,49	1,92	3042,74	871,84
-1	385	6,33	6,33	0,00	-	3,53	1,79	2436,94	690,35
0	490	5,96	5,96	0,00	-	3,58	1,66	2919,12	815,40
1	533	5,59	5,59	0,00	-	3,62	1,54	2976,83	822,33
2	380	5,21	5,21	0,00	-	3,67	1,42	1980,83	539,74
3	228	4,84	4,84	0,00	-	3,74	1,29	1103,61	295,08
4	261	4,47	4,47	0,00	-	3,81	1,17	1166,16	306,08
5	279	4,10	4,10	0,00	-	3,89	1,05	1142,70	293,75
6	229	3,72	3,72	0,00	-	3,96	0,94	852,65	215,32
7	269	3,35	3,35	0,00	-	4,03	0,83	901,43	223,68
8	233	2,98	2,98	0,00	-	3,87	0,77	694,04	179,34
9	230	2,61	2,61	0,00	-	3,70	0,70	599,46	162,02
10	243	2,23	2,23	0,00	-	3,54	0,63	542,87	153,35
11	191	1,86	1,86	0,00	-	3,37	0,55	355,58	105,51
12	146	1,49	1,49	0,00	-	3,21	0,46	217,44	67,74
13	150	1,12	1,12	0,00	-	3,05	0,37	167,55	54,93
14	97	0,74	0,74	0,00	-	2,88	0,26	72,23	25,08
15	61	0,37	0,37	0,00	-	2,72	0,14	22,71	8,35
								34 873	9 442

If only half of the 34873 GWh heating demand supplied by fossil fuels and electricity, which is 17437 GWh, is to be supplied by HPs, the annual electricity consumption will change accordingly to 6055 GWh, and the maximum electrical requirement will be 6.88 GWh/h during the lowest temperature.

If only 25% of the 34873 GWh heating demand supplied by fossil fuels and electricity, which is 8718 GWh, is to be supplied by HPs, the annual electricity consumption will decline to 3027 GWh, and the maximum electrical requirement will reduce to 3.44 GWh/h.

For the DH division, the five scenarios in NETP are analyzed. Table 3-31 shows the heating generation forecast of the HPs in heat plants of the five scenarios for Finland in the NETP project. As shown in Table 3-31, the heating generation by HP increase to 6485 GWh, 6485 GWh, 6485 GWh, 3904 GWh and 10577 GWh respectively by 2050 in the five scenarios. The corresponding electrical peak load and annual electricity consumption are shown in Table 3-32. As shown in Table 3-32, the electricity consumption are 2252 GWh, 2252 GWh, 2252 GWh, 1355 GWh and 3672 GWh respectively.

Table 3-31 Heating Generation of HPs of Finland in Heat Plants in NETP Scenarios

Heat Generation by Electricity in Heat Plants [GWh]									
	2010	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
4GS Scenario									
Electricity (heat pump)	1 392	1 090	1 564	2 113	2 750	3 488	4 343	5 335	6 485
2GS Scenario									
Electricity (heat pump)	1 392	1 090	1 564	2 113	2 750	3 488	4 343	5 335	6 485
2GS85% Scenario									
Electricity (heat pump)	1 392	1 090	1 564	2 113	2 750	3 488	4 343	5 335	6 485
2GS85%BignBio Scenario									
Electricity (heat pump)	1 392	1 026	1 379	1 749	2 138	2 547	2 977	3 429	3 904
2GS85%Flexflow Scenario									
Electricity (heat pump)	1 392	1 330	2 142	3 084	4 175	5 440	6 906	8 606	10 577

Table 3-32 Electrical Peak Load and Electricity Consumption for HPs of Finland in Heat Plants in 2050

Electrical Peak Load and Electricity Consumption for Heat Pump in Heat Plants in 2050							
		100% Electric Supplemental Heating		**50% Electric Supplemental Heating**		**0% Electric Supplemental Heating**	
Scenario	**Heat Demand [GWh]**	**Electrical Peak Load [GWh/h]**	**Electricity Consumption [GWh]**	**Electrical Peak Load [GWh/h]**	**Electricity Consumption [GWh]**	**Electrical Peak Load [GWh/h]**	**Electricity Consumption [GWh]**
4GS	6 485	2,56	2 252	1,41	2 010	0,55	1 767
2GS	6 485	2,56	2 252	1,41	2 010	0,55	1 767
2GS85%	6 485	2,56	2 252	1,41	2 010	0,55	1 767
2GS85%BignBio	3 094	1,54	1 355	0,85	1 210	0,33	1 064
2GS85%Flexflow	10 577	4,17	3 672	2,30	3 278	0,90	2 883

3.7 Summary

This chapter studies the demand profiles with high HP penetration of the four Nordic countries. A calculation method of HP efficiency and electricity consumption in the European Standard EN 14825 is introduced here and used to obtain the HP demand profiles. For the four Nordic countries, the HP demand profiles of the individual space heating and DH sectors are studied respectively.

The 2GS85% and 2GS85%Flexflow scenarios give the images of the Nordic region with the objectives of limiting the average global temperature increase to 2°C and CO_2 emissions falling by 85% by 2050. The 2GS85%Flexflow scenario refers to a scenario of achieving the goals above with a stronger emphasis on electrification. Table 3-33 shows the annual heat demand, electrical peak load and corresponding electricity consumption of HPs for the individual space heating with 100% substitution to the fossil fuels and electric direct heating by HPs and DH with the 2GS85%Flexflow scenario in the four Nordic countries. Table 3-34 shows the annual heat demand, electrical peak load and corresponding electricity consumption of HPs for the individual space heating with 100% substitution to the fossil fuels and electric direct heating by HPs and DH with the 2GS85% scenario in the four Nordic countries.

Table 3-33 Peak Load and Energy Consumption of HPs for Individual Heating with 2GS85%Flexflow Scenario for DH in the Nordic Countries in 2050

Power Load and Energy Consumption of Heat Pump for Individual Heating and 2GS85%Flexflow in 2050							
		100% Electric Supplemental Heating		50% Electric Supplemental Heating		0% Electric Supplemental Heating	
Country	Heat Demand [GWh]	Electrical Peak Load [GWh/h]	Electricity Consumption [GWh]	Electrical Peak Load [GWh/h]	Electricity Consumption [GWh]	Electrical Peak Load [GWh/h]	Electricity Consumption [GWh]
Denmark	27 992	7,88	7 814	5,71	7 738	3,55	7 663
Sweden	37 106	14,64	12 883	8,06	11 465	2,70	10 047
Norway	44 729	17,65	15 530	9,72	13 820	3,25	12 111
Finland	45 450	17,93	15 781	9,87	14 054	3,43	12 325

Table 3-34 Peak Load and Energy Consumption of HPs for Individual Heating with 2GS85% Scenario for DH in the Nordic Countries in 2050

Power Load and Energy Consumption of Heat Pump for Individual Heating and 2GS85% in 2050							
		100% Electric Supplemental Heating		50% Electric Supplemental Heating		0% Electric Supplemental Heating	
Country	Heat Demand [GWh]	Electrical Peak Load [GWh/h]	Electricity Consumption [GWh]	Electrical Peak Load [GWh/h]	Electricity Consumption [GWh]	Electrical Peak Load [GWh/h]	Electricity Consumption [GWh]
Denmark	23 900	6,73	6 672	4,87	6 607	3,03	6 542
Sweden	36 913	14,57	12 817	8,02	11 406	2,68	9 994
Norway	44 965	17,75	15 612	9,77	13 893	3,26	12 174
Finland	41 358	16,32	14 361	8,98	12 786	3,08	11 209

With continuous decreasing level of fossil fuels and low level of electrical space heating in the heating sector, the heating demand of HP in Sweden shows to be the lowest among the four Nordic countries. Besides, the relatively warmer temperature in Denmark offers higher efficiency of HPs, which is critical during low temperatures. The demands of HPs in Finland and Norway are considerably higher than those of Sweden and Denmark. The relatively high levels of electric direct heating and fossil fuels in both individual heating and DH sectors of Finland result in the high substitute demand of HPs in the Finnish study case. With a wide usage of electric space heating currently, the impact of the deployment of HPs over the electrical power grid in Norway needs further research. Moreover, it is shown in the study of this chapter that the selection of backup heating for HPs is of great importance to the peak electrical power load. With non-electrical supplemental heating, HPs have much lower electrical power load during low temperatures while the majority of heating is supplied by electricity within the whole year.

4 Conclusions

This working report is focusing on the electrical demand profile of the large deployment of EVs and HPs in the Nordic countries including Denmark, Sweden, Norway and Finland. With the studies utilizing statistic data, an estimate of the demand profiles of EVs and HPs is obtained.

High penetartion level of EVs will bring considerable electrical power load to the electrical power systems. The peak loads are on GWh/h level around the Nordic countries for the 100% EV penetration cases with 1 phase 10 A timed charging. The Swedish case sees the highest power demand with the largest amount of passenger cars in the four mentioned Nordic countries. For the annual energy consumption, Finland sees a top amount of about 7.6 TWh/year as its average driving disctance is about 47km/day, which is the highest among all the four Nordic countries.

The estimation of the HP demand profiles shows high electricity consumption as well as high electrical capacity requirement under the aggressive scenario in the heating sector of all the four Nordic countries. The peak electricity demand for HPs is steep for the low-temperature-period. It should be also noted that the selection of supplemental heating for HPs is of great significance to the peak electricity load during the low temperatures. The capacity and efficiency of HPs decline along with the decrease of temperature. Electric direct heating, usually serving as the backup heating of HPs, causes the peak electricity load below the balance temperature. Applying non-electrical supplemental heating would release the electrical capacity requirement while the majority of heating is supplied by electricity through HPs throughout the heating season.

References

All references from internet were downloaded in the period October 2012 – January 2013 unless specified in the reference description.

[1] Qiuwei. Wu, Arne. H. Nielsen, Jacob. Østergaard, "*Potential Analysis For Electric Vehicle (EV) Grid Integration*, 2011" Technical University, CET, 2011.

[2] Danmarks Statisk, Available: http://www.dst.dk/en

[3] N. S. A. (SCB), "*FORDON_2011_v2*," National Statistics Authority (SCB), 2011.

[4] Statistics Norway, 2012, "*Registered vehicles*, 2011" Available: http://www.ssb.no/bilreg_en/

[5] Statistics Norway, 2012, "*Distances covered by main type of vehicle and the owner's county of residence*, 2011" Available: http://www.ssb.no/emner/10/12/20/klreg/tab-2012-05-04-06.html

[6] L. Vågane, I. Brechan and R. Hjorthol, 2011 "*2009 Norwegian National Travel Survey - key reports*," Transportøkonomisk Institutt, Oslo, 2011

[7] Finnish, Transport and Agency, 2011"*The National Travel Survey,2011*" Available: http://portal.liikennevirasto.fi/sivu/www/e/fta/research_development/national_travel_survey

[8] Statistics Finland, 2012, "*Vehicle stock grew by 3,9 per cent in 2011*" Available: http://www.stat.fi/til/mkan/2011/mkan_2011_2012-02-24_tie_001_en.html

[9] Danish Energy Agency, 2012, *"Large and small scale district heating plants,"* Available: http://www.ens.dk/EN-US/SUPPLY/HEAT/DISTRICT_HEATING_PLANTS/Sider/Forside.aspx

[10] Danish Energy Agency, 2012, *"Energy Statistic 2010,"* Available: http://www.ens.dk/EN-US/INFO/FACTSANDFIGURES/ENERGY_STATISTICS_AND_INDICATORS/ANNUAL%20STATISTICS/Sider/Forside.aspx

[11] Danish Energy Agency, 2012, *"Annual Energy Statistic, Tables 2010,"* Available: http://www.ens.dk/EN-US/INFO/FACTSANDFIGURES/ENERGY_STATISTICS_AND_INDICATORS/ANNUAL%20STATISTICS/Sider/Forside.aspx

[12] Swedish Energy Agency, 2012, *"Energy in Sweden 2011"* Available: http://webbshop.cm.se/System/TemplateView.aspx?p=Energimyndigheten&view=default&id=3928fa664fb74c2f9b6c2e214c274698

[13] Swedish Energy Agency, 2012, *"Energistatistik för småhus, flerbostadshus och lokaler, 2010,"* Available: http://webbshop.cm.se/System/TemplateView.aspx?p=Energimyndigheten&view=default&id=6e711c6cc2764bc49e88545185815663

[14] Statistics Norway, 2012, *"Record high energy consumption in 2010,"* Available: http://www.ssb.no/english/subjects/01/03/10/energiregn_en/arkiv/art-2011-12-12-01-en.html

[15] ENOVA, 2012, *"7.3 TWh of renewable heat Enova Systems by end of 2011"* Available: http://www.enova.no/innsikt/rapporter/varmerapport-2011/fornybare-varmeresultater/441/0

[16] Statistics Norway, 2012, *"Major increase in the use of heat pumps, 2009,"* Available: http://www.ssb.no/english/subjects/01/03/10/husenergi_en/

[17] Statistics Norway, 2012, *"Increased consumption of district heating, 2010,"* Available: http://www.ssb.no/fjernvarme_en/arkiv/

[18] Statistics Norway, 2012, *"Consumption of fuel used for gross production of district heating, 2010,"* Available: http://www.ssb.no/english/subjects/10/08/10/fjernvarme_en/tab-2011-12-05-03-en.html

[19] Statistics Finland, 2012, *"Final energy consumption by sector, 2010,"* Available: http://pxweb2.stat.fi/Dialog/varval.asp?ma=080_ehk_tau_108_en&ti=Final+energy+consumption+by+sector&path=../Database/StatFin/ene/ehk/&lang=1&multilang=en

[20] Finnish Energy Industries, 2012, *"Energy Year 2011 – District Heat, 2011,"* Available: http://energia.fi/en/slides/energy-year-2011-district-heat-0

[21] Statistics Finland, 2012, *"Energy sources for heating residential, commercial and public buildings, 1970-2006,"* Available: http://pxweb2.stat.fi/sahkoiset_julkaisut/vuosikirja2007/html/engl0005.htm

[22] Finnish Government 2008, *"Klimat- och energistrategi på lång sikt,"* Available: http://www.tem.fi/files/20586/Dnr_1382_klimat-_och_energistrategi_3.11.2008.pdf

[23] Statistics Finland, 2012, *"Energy sources for space heating by type of buildings, 2006,"* Available: http://pxweb2.stat.fi/sahkoiset_julkaisut/vuosikirja2007/html/engl0005.htm

[24] Finnish Energy Industries, 2012, *"District Heating in Finland, 2010,"* Available: http://energia.fi/en/ajankohtaista/lehdistotiedotteet/district-heating-year-2010

[25] Nordic Energy Research Project, *"Nordic Energy Technology Perspectives"*

[26] British Standard Institution, 2012, *"Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling – Testing and rating at part load conditions and calculation of seasonal performance, 2012,"*

[27] Danish Energy Agency, 2011, *"Calculation of SCOP for heat pumps according to EN 14825, 2011,"* Available: http://www.eceee.org/Eco_design/products/boilers/App%20B%20teknical%20SCOP%20NEF%20%20En14825%20heatpumpsEN.docx

[28] BUILD UP, 2012, *"Heat pumps get a warm welcome in Denmark, 2010,"* Available: http://www.buildup.eu/news/10985

[29] Danish Energy Agency, 2012, *"Stock of heat pumps for heating in all-year residences in Denmark, 2011,"* Available: http://www.ens.dk/da-DK/ForbrugOgBesparelser/IndsatsIBygninger/Varmepumper/fagligerapporter/Documents/1%20-Stock%20of%20Heat%20Pumps%20111104%20-FINAL.pdf

[30] ProHeatPump, 2009, *"Heat Pumps in Norway, 2009,"* Available: http://www.geos.ed.ac.uk/homes/nmarkuss/HPNorway.pdf

[31] Samuli Honkapuro, LUT, 2011, *"Heat pumps and other DER technologies in Finland, 2010,"* Available: http://www.ieadsm.org/Files/Tasks/Task%20XVII%20-%20Integration%20of%20Demand%20Side%20Management,%20Energy%20Efficiency,%20Distributed%20Generation%20and%20Renewable%20Energy%20Sources/Sophia%20Antipolis%20public%20workshop/Samuli-Goran.pdf