

## Country-specific factors for the development of household smart grid solutions

*Comparison of the electricity systems, energy policies and smart grid R&D and demonstration projects in Spain, Norway and Denmark*

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# Country-specific factors for the development of household smart grid solutions

Comparison of the electricity systems, energy policies and smart grid R&D and demonstration projects in Spain, Norway and Denmark

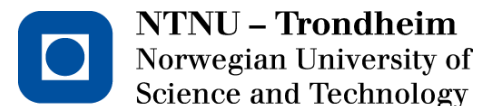
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July 2013

Report from the ERA-Net SmartGrids project “Integrating households in the smart grid” (IHSMAG) – [www.ihsmag.eu](http://www.ihsmag.eu)





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# 1. Introduction

This report is an outcome of the project *Integrating Households in the Smart Grid* (IHSMAG), which involves partners from Norway, Denmark and the Basque Country (Spain). The aim of IHSMAG is to contribute with knowledge of how to develop comprehensive designs of smart grid solutions that involve households in the smart grid. On the basis of experiences and results from a number of demonstration projects in Norway, Denmark and the Basque Country, the project explores how household smart grid solutions depend on household technologies, everyday practices and the overall electricity system and regulation. The IHSMAG project runs from January 2012 to December 2014 and is supported by the 2<sup>nd</sup> ERA-Net Smart Grid Joint Call.<sup>1</sup>

The aim of this report is to provide an overview of relevant country-specific factors in relation to understanding the context of the development of smart grid solutions in each of the three participating countries (e.g. main characteristics of the energy system) and to give an overview of the current status of activities in relation to smart grid solutions in households. In this way, the survey also serves as a common ground for the later synthesis of the country-specific results of the IHSMAG project (especially in relation to the development of design criteria for household smart grid solutions and policy recommendations). Understanding the differences and similarities between the three countries is important when evaluating whether the country-specific results and insights are “transferable” between the countries. The report is based on contributions from the Danish Building Research Institute (Aalborg University), Tecnalia in the Basque Country and Department of Interdisciplinary Studies of Culture (Norwegian University of Science and Technology).

Section 2 presents the main characteristics of the existing energy systems of the three countries (with a primary focus on the electricity system). This includes information about the share of renewable energy, the temporal pattern of electricity consumption and the roll-out of an advanced metering infrastructure (“smart meters”). Section 3 gives an overview of the national policies and regulation in relation to the electricity system and smart grid. Finally, section 4 presents a brief survey of the national smart grid research & development (R&D) and demonstration activities related to households in the three countries.

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<sup>1</sup> For more information about the IHSMAG project, see the website: [www.ihsmag.eu](http://www.ihsmag.eu)

## 2. The energy system – with particular focus on the electricity system

This section presents a number of characteristics of the energy systems – and particularly the electricity systems – of Denmark, Norway and Spain<sup>2</sup>. The presentation focuses mainly on statistics on the overall energy system, residential final electricity consumption, load profiles and electricity prices.

### 2.1 General overview and development within last 20 years

#### Overall energy system

Table 1 shows key figures on population, Gross Domestic Product, supply and consumption of energy and CO<sub>2</sub> emissions for 1990 and 2009 for Spain, Norway and Denmark.

**Table 1:** Key figures on population, GDP, energy supply & consumption and CO<sub>2</sub> emission for 1990 and 2009.

	Spain		Norway		Denmark	
	1990	2009	1990	2009	1990	2009
Population (millions)	39.0	45.9	4.2	4.8	5.1	5.5
Gross Domestic Product (billion 2000 USD)	441	713	117	196	124	168
Total primary energy supply TPES <sup>1</sup> (TWh)	1048	1471	244	328	202	216
TPES/population (kWh/capita)	26,865	31,983	57,569	68,036	39,309	39,193
Electricity generated <sup>2</sup> (TWh)	151.2	291.0	121.6	132.0	26.1	36.4
Net electricity import <sup>3</sup> (TWh)	-0.5	-8.1	-15.9	-9.0	7.1	0.4
Total final consumption TFC <sup>4</sup> (TWh) of energy	706	1073	203	231	153	165
Total final consumption (TFC) of electricity (TWh)	125.8	255.4	96.8	105.3	28.4	31.6
Electricity share of total final consumption – per cent	18%	24%	48%	46%	19%	19%
TFC electr./population (kWh/capita)	3,226	5,562	22,835	21,827	5,520	5,721
CO <sub>2</sub> emissions total <sup>5</sup> (Mt CO <sub>2</sub> )	205.8	283.4	28.3	37.3	50.4	46.8
CO <sub>2</sub> emission/population (tons/capita) <sup>5</sup>	5.3	6.2	6.7	7.7	9.8	8.5
CO <sub>2</sub> emission/kWh, electr. and heat generation (g/kWh) <sup>6</sup>	427	299	3	17	477	303

<sup>1</sup> Total primary energy supply (TPES) is made up of the sum of domestic energy production and energy imports minus energy exports and international marine/aviation bunkers (the figure is also corrected for changes in stock of energy, e.g. oil). Notice that primary energy is the energy input *before* conversion/transformation to other energy forms (e.g. the input of embodied energy in coal used in power plants).

<sup>2</sup> Electricity generated is the gross production of electricity, excluding the amount of electricity produced in pumped storage plants

<sup>3</sup> Net electricity import is the total import of electricity minus total export. Negative figures represent net export of electricity (i.e. a situation with larger annual electricity export than annual import)

<sup>4</sup> Total final consumption (TFC) is the sum of consumption by the different end-use sectors.

<sup>5</sup> CO<sub>2</sub> emissions from fuel combustion (all sectors, including transport, industry etc.)

<sup>6</sup> The CO<sub>2</sub> emissions per kWh for electricity and heat generation

Sources: IEA 2011a: p. IV.250-IV.251 (Denmark), p. IV.538-539 (Norway) and p. IV.628-629 (Spain). On CO<sub>2</sub> emissions (total emissions and emissions/capita): IEA 2011b: xix, II.55, II.67.

Table 1 shows that the **total primary energy supply (TPES)** has increased over the period 1990-2009 for all countries. The increase has been most significant for Spain (40%) and Norway (34%) and least for Denmark (7%). If

<sup>2</sup> As the Spanish electricity system is an integrated system, we do not focus specifically on the Basque Country.

**related to the size of the population** (TPES/population), Table 1 shows that for all countries, part of the increase can be explained by an increase in the population size. Thus, the increase in total primary energy supply *pr. capita* is 19% for Spain and 18% for Norway, i.e. about half of the increase in TPES. For these two countries, about half of the increase in TPES can be explained by the increased population. For Denmark, the per capita total primary energy supply has been more or less stable, which means that the (relative small) increase in the Danish TPES mainly can be ascribed to an increase in the population size. Furthermore, the increase in TPES might also relate to general increases in the level of consumption (including energy consumption) and production, which is reflected in the overall increase in the countries' **Gross Domestic Product** (GDP) over the period. Spain and Norway have had remarkable high GDP growth rates (62% and 68%, respectively), while the Danish GDP has shown a modest growth rate (35%).

There are also a number of other reasons why the Danish TPES has shown a less significant growth rate than the Norwegian and Spanish: First of all, there has been a general shift from electricity production based on traditional condensing power plants to combined heat and power (CHP) plants, which has increased the overall efficiency of the energy system due to the utilization of heat for district heating. Secondly, the share of electricity production based on wind power has increased markedly, which also contributes to lower primary energy supply (as the primary energy input equals the output of electricity for wind power). Other explanations include higher energy efficiency, lower energy consumption for industry and manufacturing etc. (Danish Energy Agency 2011)

The TPES/population figures furthermore show some interesting differences between the countries with regard to the **size of total primary energy supply pr. capita**: In 2009, the TPES per capita in Norway was twice the size of the TPES per capita for Spain (68 MWh versus 32 MWh) and also significant larger than the Danish TPES per capita (39 MWh). In relation to this, it is interesting to notice that even though the TPES/population is much lower in Spain than in Norway, the 1990-2009 increase in TPES/population of the two countries are nearly the same. Starting from a much higher level, one might have expected a lower increase for Norway than for Spain. However, as mentioned before, a significant share of the TPES/population increase in the two countries might be correlated with the remarkable high growth rates (compared to Denmark) in the Gross Domestic Product (GDP) over the period.

The **electricity generation** has been increasing in all countries. However, the increase has been most marked in Spain, where the electricity generation has almost doubled (92%), while the increase in Denmark has been 40% and in Norway only 9%. The increase in electricity generation in Spain has mainly been covered by increasing the natural gas-based electricity generation and, to a less extent, wind power generation. Also, the **total final consumption (TFC) of energy** has increased in all countries; most in Spain (52%) and least in Norway (14%) and Denmark (8%). Similarly, the **total final consumption (TFC) of electricity** has been increasing in all countries; again most markedly in Spain (103%) and with lower growth rates in Norway and Denmark (9% and 11%, respectively). However, worth of notice, the increase in the Spanish TFC of electricity actually peaked in 2007 and 2008 (reaching about 260 TWh/year), and the 2009-figure therefore represents a decline compared to 2007/2008. More details on the development in the countries' electricity consumption follow later in this section.

The **electricity share of the total final consumption (TFC) of energy** is significant higher in Norway (46% in 2009) as compared with Spain (24%) and Denmark (19%). This relates to the high availability of hydropower in Norway and, therefore, the historical focus on electricity as a primary energy source for households (e.g., electric heating is widespread in Norway). In 2009, nearly 96% of the electricity generated in Norway came from hydropower (see Table 3). The widespread use of electric heating is also an important part of the explanation why the **electricity consumption per capita** in Norway is almost four times that in Spain and Denmark.

Furthermore, the hydropower-based electricity production of Norway explains the very low **CO<sub>2</sub> emission per kWh** for Norway as compared with Spain and Denmark. However, it is interesting to notice that if including *all* CO<sub>2</sub> emissions from fuel combustion (including transport, industry etc.), the Norwegian **CO<sub>2</sub> emission per capita** is actually not much different from the figures of Spain and Denmark (25% higher than in Spain and 9% lower than in Denmark). This is mainly due to a relative high emission related to energy industries (see Table 2), which represent about one quarter of the total Norwegian CO<sub>2</sub> emissions (Konkraft 2009).

While the CO<sub>2</sub> emission per capita has been increasing in both Spain and Norway (17% and 16%, respectively), it has decreased by 14% in Denmark from 1990 to 2009. This is mainly due to an increased share of wind power (from 2% in 1990 to 18% in 2009), which has replaced generation based on fossil fuels.

**Table 2:** CO<sub>2</sub> emission from fuel combustion by sectors in 2009 (Mt CO<sub>2</sub>)

	Spain	Norway	Denmark
Total CO <sub>2</sub> emission from fuel combustion	283.4	37.3	46.8
- electricity and heat production	87.0 (31%)	2.4 (6%)	22.0 (47%)
- other energy industry own use <sup>1</sup>	17.5 (6%)	11.4 (31%)	2.4 (5%)
- manufacturing industries and construction	47.3 (17%)	6.6 (18%)	3.8 (8%)
- transport	100.5 (35%)	13.5 (36%)	13.1 (28%)
- other sectors	31.2 (11%)	3.4 (9%)	5.5 (12%)

<sup>1</sup> Includes emissions from fuel combustion in oil refineries, for the manufacture of solid fuels, coal mining, oil and gas extraction and other energy-producing industries

Source: IEA 2011b: p. II.25.

Table 2 shows great differences between the three countries with regard to the distribution of CO<sub>2</sub> emissions from fuel combustion by sectors. While the production of heat and electricity accounts for almost half of the total Danish CO<sub>2</sub> emissions, this accounts for only 6% in Norway and 31% in Spain. On the other hand, the share of CO<sub>2</sub> emissions from “other energy industry” is five times higher in Norway compared with Spain and Denmark (due to the extensive oil production in Norway). Furthermore, both transport and manufacturing industries/construction account for a smaller share in Denmark than in Spain and Norway.

These figures show that the three countries face different challenges in relation to reducing CO<sub>2</sub> emissions. While electricity/heat production and transport represent the major contributors to the Spanish and Danish CO<sub>2</sub> emissions, the major sources of CO<sub>2</sub> emissions in Norway are related to transport (as well) and other energy industry (oil production).

### Energy sources for electricity generation

The countries differ much with regard to the sources of energy for electricity production, as shown by the following table and figure (Table 3 and Figure 1).

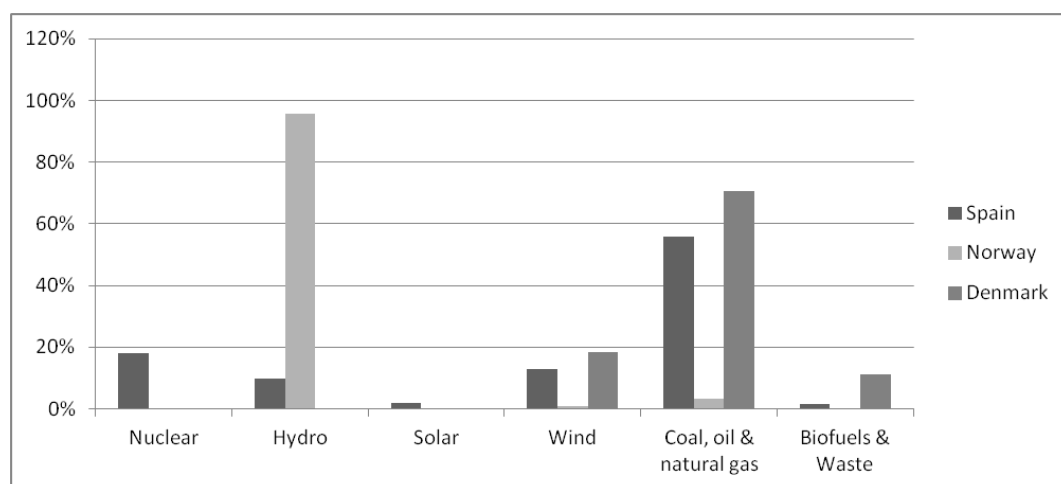


**Table 3:** Gross electricity production by source of primary energy (TWh).

	Spain			Norway			Denmark		
	1990	2000	2009	1990	2000	2009	1990	2000	2009
<b>Gross production (TWh)</b>	<b>151.9</b>	<b>224.5</b>	<b>293.8</b>	<b>121.8</b>	<b>140.1</b>	<b>132.8</b>	<b>26.0</b>	<b>36.1</b>	<b>36.4</b>
- nuclear	54.3	62.2	52.8	-	-	-	-	-	-
- hydro	26.2	31.8	29.2	121.4	139.4	127.1	0.0	0.0	0.0
- geothermal	-	-	-	-	-	-	-	-	-
- solar	0.0	0.0	6.0	-	-	-	-	-	-
- tide, wave , ocean	-	-	-	-	-	-	-	-	-
- wind	0.0	4.7	37.8	-	0.0	1.0	0.6	4.2	6.7
- combustible fuels	71.4	125.7	167.8	0.3	0.6	4.7	25.3	31.7	29.6
<i>coal</i>	60.7	80.9	37.2	0.1	0.1	0.1	23.6	16.7	17.7
<i>oil</i>	8.6	22.6	19.0	0.0	0.0	0.0	0.9	4.4	1.2
<i>natural gas</i>	1.5	20.2	107.4	-	0.2	4.2	0.7	8.8	6.7
<i>biofuels &amp; waste</i>	0.7	2.1	4.2	0.2	0.3	0.3	0.2	1.9	4.0
- other (e.g. fuel cells)	-	-	0.3	0.1 e	0.1 e	0.1	-	0.0	-

Note: Gross electricity production is measured at the alternator terminals, and thus includes losses and own use of power in power stations and in transformers.

Source: IEA 2011a: p. IV.251 (Denmark), p. IV.539 (Norway) and p. IV.629 (Spain)

**Figure 1:** Distribution of 2009 electricity production by source of energy (based on data in Table 3)

The Norwegian electricity production is almost entirely based on hydropower (96%) and only a little share of wind power and fossil fuels. Compared to Norway, the electricity production is far more diversified in Denmark and (particularly) Spain. Thus, the Spanish electricity production includes all six categories of energy sources in Figure 1. A little more than half (56%) of the Spanish electricity production is based on coal, oil & natural gas, while nuclear power represents 18%, wind 13%, hydropower 10%, solar power 2% and biofuels/waste 1%. In Denmark, almost three quarters (71%) of the electricity is generated on the basis of coal, oil & natural gas. Wind power represents about 18% and biofuels & waste 11%.

With regard to how the electricity is produced, it should be noticed that in Denmark and Spain, a considerable part of the electricity production is based on either condensing power/combined heat and power plants or combined-cycle gas turbine plants (approx. 75% in Spain and approx. 82% in Denmark, while only approx. 3% in Norway). Electricity production based on condensing power/CHP plants is in general relatively inflexible for short-term changes (particularly for larger plants). Thus, the Spanish and particularly the Danish electricity systems are less flexible for short-term changes in electricity production from intermittent renewable energy

resources compared with the Norwegian system, which has a high share of flexible hydropower production

However, as a considerable part of the Spanish electricity production is based on relatively flexible natural gas-fired combined-cycle plants, and to some degree also flexible hydropower, these can work as a backup source for intermittent renewable energy. In 2010, combined-cycle gas turbines represented 26% of the installed power capacity compared with 18% installed hydropower capacity (REE 2010). In general, the stop and start-up costs related to regulation of hydropower (and wind power) are lower compared to nuclear power and natural gas plants.

The Danish combination of a high share of electricity production based on relatively inflexible condensing/CHP plants and a high share of intermittent wind power production is one of the major reasons for the particular focus on load management in the Danish smart grid discussion and R&D projects (as showed later). Today, the Nordic electricity market Nord Pool Spot (which includes Denmark, Norway, Sweden, Finland, Estonia, Latvia and Lithuania) provides much of the regulating power needed to balance the consumption and generation side of the Danish electricity system (especially the exchange with Norway is important). However, with an increasing share of wind power, other supplementary solutions will be needed.

### Final energy consumption by sectors

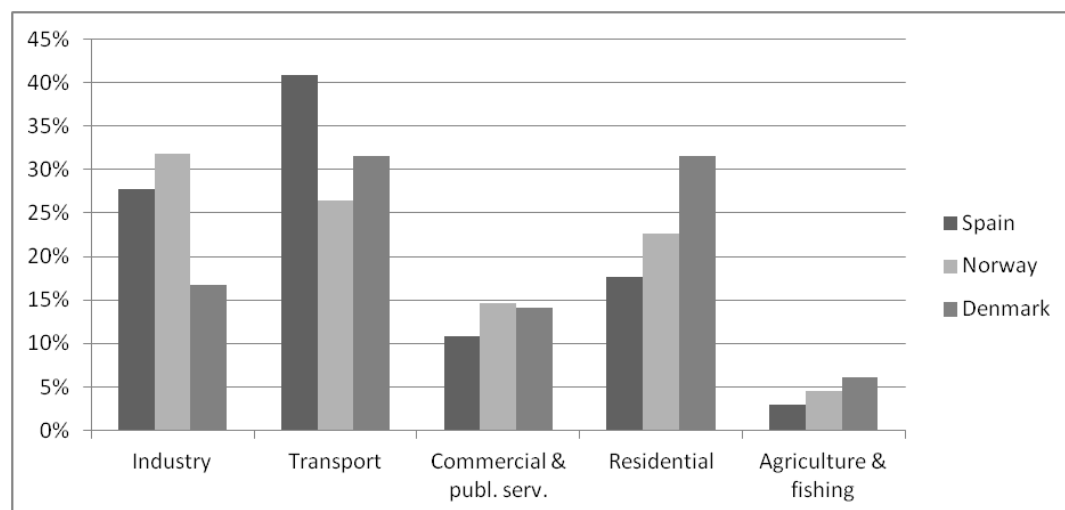
Table 4 and Figure 2 show the total final consumption (TFC) of energy by sectors.

**Table 4:** Total Final Consumption (TFC) of energy by sectors (Mtoe = Mega ton of oil equivalents)

	Spain			Norway			Denmark		
	1990	2000	2009	1990	2000	2009	1990	2000	2009
TFC (Mtoe)	60.74	85.48	92.29	17.44	19.80	19.85	13.17	14.23	14.22
- industry	19.39	24.72	23.35	6.03	6.94	5.59	2.69	2.94	2.33
- transport	21.28	30.21	34.44	3.41	4.06	4.65	3.45	4.03	4.41
- commercial & publ. serv.	3.41	6.70	9.11	2.04	2.12	2.57	1.72	1.83	1.97
- residential	9.15	11.88	14.89	3.60	3.82	3.99	4.00	4.16	4.40
- agriculture & fishing	1.66	2.56	2.54	0.51	0.77	0.79	0.99	0.96	0.85
- other	-	0.00	0.81	-	-	0.08	0.01	0.01	0.01
- non-energy use	5.84	9.40	7.15	1.84	2.08	2.17	0.30	0.30	0.25

1 Mtoe = 11.63 TWh = 41,868 TJ

Source: IEA 2011a: p. IV.259-260 (Denmark), IV.548 (Norway) and IV.636-637 (Spain).



**Figure 2:** Distribution of 2009 Total Final Consumption (TFC) of energy by sectors (based on Table 4)  
Note: "Other" and "Non-energy use" not included.

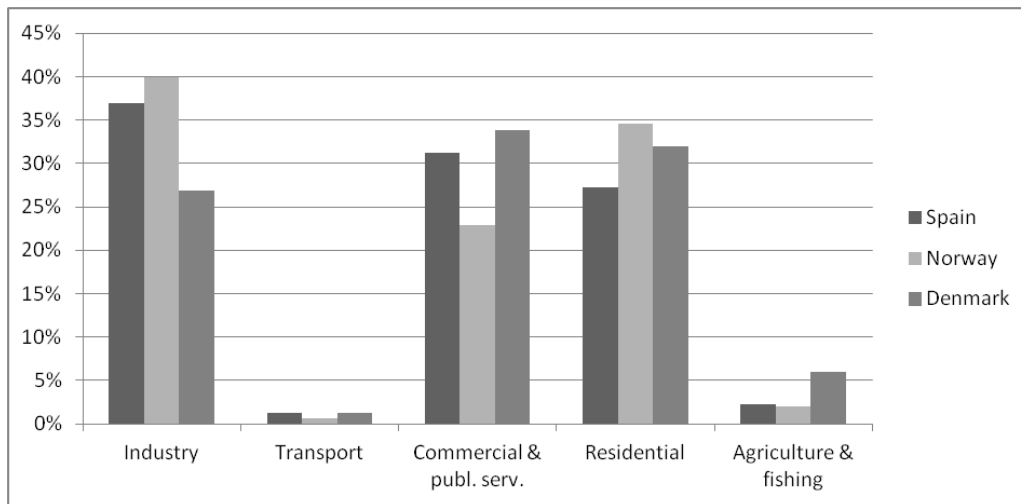
The distribution by sectors varies between the three countries, particularly with relation to industry, transport and the residential sector (notice that transport by households is included in "Transport" and not in "Residential", which primarily includes electricity consumption and heating). The residential sector accounts for 32% of TFC in Denmark and only 18% in Spain (23% in Norway). More than 40% of TFC in Spain is related to transport, whereas the figure for Norway is only 26% (32% in Denmark). Finally, the industry sector accounts for 28-32% of TFC in Spain and Norway and only 17% in Denmark. The high share of energy consumption within the industry sector is among the reasons for a particular focus in Norway on implementing load management within the industry sector.

Turning focus to electricity consumption only, the following Table 5 and Figure 3 show the distribution of the total final electricity consumption by sectors.

**Table 5:** Total final electricity consumption by sectors (TWh)

	Spain			Norway			Denmark		
	1990	2000	2009	1990	2000	2009	1990	2000	2009
Total final electricity consumption (TWh)	125.8	188.5	255.4	96.8	109.5	105.3	28.4	32.5	31.6
Industry	63.3	85.6	94.3	45.8	51.6	42.1	8.4	10.0	8.5
Transport	3.7	4.2	3.1	0.7	0.6	0.7	0.2	0.3	0.4
Commercial & publ. serv.	25.1	50.0	79.9	19.4	20.6	24.1	8.3	9.9	10.7
Residential	30.2	43.6	69.5	30.3	34.6	36.4	9.7	10.2	10.1
Agriculture & fishing	3.5	5.0	5.7	0.7	2.1	2.1	1.7	1.9	1.9
Sector non specified	-	-	2.9	-	-	-	-	-	-

Source: IEA 2011a: p. IV.251 (Denmark), IV.539 (Norway) and IV.629 (Spain).



**Figure 3:** Distribution of 2009 total final electricity consumption by sectors (based on Table 5)

In Denmark, the industry sector accounts for only 27% of the final electricity consumption compared with 40% in Norway and 37% in Spain (2009-figures, cf. Figure 3). This probably reflects that industry and manufacturing have a less prominent role in the Danish economy than in Spain and Norway. For comparison, the commercial & public sector represents a higher share of the final electricity consumption in Denmark (34%) than in Spain (31%) and particularly Norway (23%). The same goes for agriculture & fishing.

With regard to the residential sector, this sector accounts for between 27% in Spain and 35% in Norway, with Denmark placed in the middle (32%).

As pointed out previously, the increase in the total final consumption of electricity for the period 1990-2009 has been particularly marked for Spain compared to Norway and Denmark. As shown in Table 5, the Spanish increase has been particularly marked within the commercial & public service sector (218% increase) and the residential sector (130% increase).

On the basis of the figures of the total final electricity consumption for the residential sector (Table 5), the total final consumption of electricity per capita can be calculated. Thus, in 2009, the average residential electricity consumption was 1,514 kWh/capita in Spain, 1,836 kWh/capita in Denmark and 7,583 kWh/capita in Norway. Interestingly, Spain and Denmark have more or less the same level of residential electricity consumption per capita, whereas the Norwegian consumption is about 4-5 times the Danish and Spanish consumption level. The primary reason for the high residential electricity consumption in Norway is the widespread use of electric heating in buildings and a high heating demand (see also next section).

### **Residential electricity consumption by final use**

Table 6 shows the distribution of the residential final electricity consumption by final use categories for the three countries.

**Table 6:** Distribution of final residential electricity consumption by final use for Denmark, Norway and Spain.

	Denmark (2006)	Norway (2007)	Spain (2007)
Light	11%	9%	18%
Heating and power	59%	86%	64%
Cooking	8%	2%	15%
Heating (space and water)	18%	76%	18%
Fridge/freezer	18%	5%	18%
Laundry	15%	3%	10%
Air-conditioning	-	-	1%
Dishwasher	-	-	2%
Miscellaneous	30%	5%	18%
TV, video, stereo	12%	-	10%
PC	8%	2%	7%
Total	100%	100%	100%

Note (Danish figures): "Laundry" includes dishwashers, washing machines and tumble dryers. Sources: Røpke et al. 2010 (Denmark) and Shandurkova 2011 based on results from the REMODECE project (Norway). Spanish data from "Practical guide: efficient energy consumption", published by the Institute for Energy Savings and Diversification (IDAE), Ministry of Industry, Energy and Tourism.

As shown in Table 6, Norway has by far the highest percentage of residential final electricity consumption related to heating of space and water, which represents three quarters of the total electricity consumption. This is due to electric heating being the dominant heating form in Norwegian buildings. In comparison, the share of electricity used for heating is only 18% in Spain and Denmark.

When comparing the Norwegian percentages with the Danish and Spanish, it is important to bear in mind that the Norwegian final electricity consumption *per capita* is about four times higher than the Danish and five times higher than the Spanish. The difference is mainly due to the dominance of electric heating and the high heating demand due to the climatic conditions in Norway. Denmark has also a relatively high heating demand, but only 6% of Danish dwellings are heated by electricity (Statistics Denmark 2013). If heating is excluded from the Norwegian figures, the per capita electricity consumption is only about 1,800 kWh/capita, i.e. more or less the same level as in Denmark. But due to the differences in the per capita consumption, the Norwegian percentages for all other final uses (except heating) are relatively smaller than the Danish and Spanish figures.

The percentage of electricity related to lighting varies considerably between the countries, and if heating is excluded, the variations become even much higher: 13% for Denmark, 22% for Spain and 38% for Norway. This is interesting, as lighting is less suitable for load management compared with other final uses like heating or cooling.

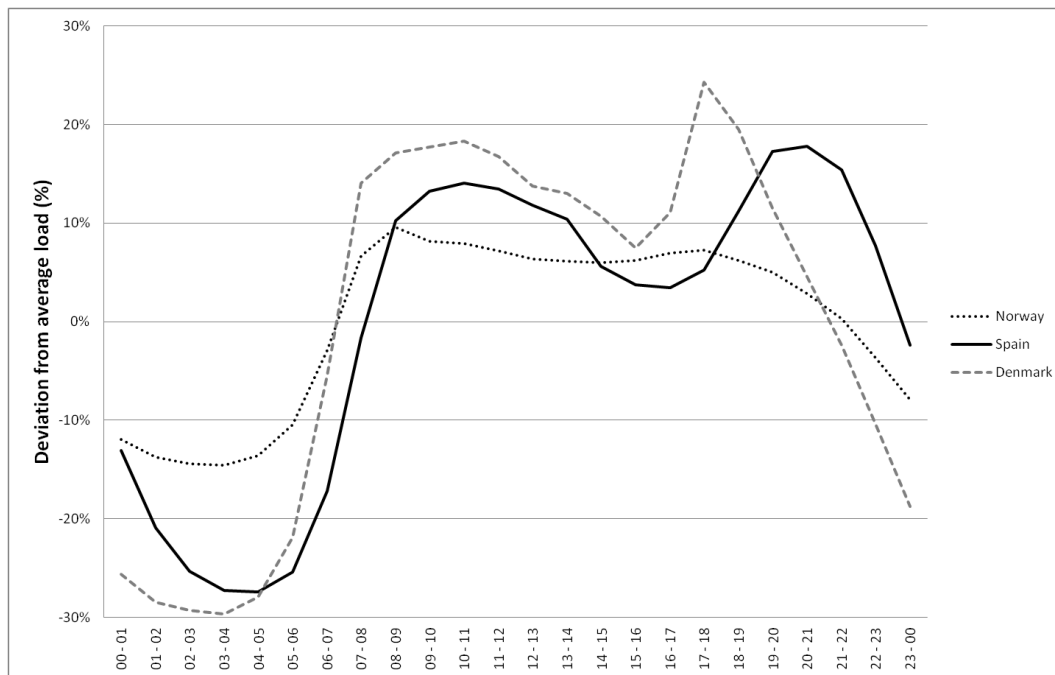
Recognizing that some uses of electricity are more likely to be subject to load management than others, Table 6 can give an indication of the different potentials for load management in the three countries. By adding up the percentages of the final uses that might *potentially* be subject to time-shifting (in Table 6, this could be heating, cooling (fridge/freezer), laundering, air conditioning and dishwashing), the share of residential electricity consumption that could (ideally) be subject to some extent of load management would be: 51% for Denmark, 84% for Norway and 49% for Spain. Thus, Norway seems to have a higher potential for load management compared with Spain and Denmark, primarily due to the widespread use of electric heating. This also partly explains why, in Denmark, the smart grid debate with regard to load management focuses particularly on promoting

the electrification of heating and transportation through households' increased use of heat pumps and electric vehicles. The aim of this is to increase the potential for load management.

Air conditioning represents a specific challenge in the case of Spain: Even though the electricity consumption for air conditioning is relatively low at the national level, the consumption in the southern regions is high and increasing. In regions with high penetration, it can represent 30% of the consumption during the summer peaks, which creates peak-capacity problems for the grid during warm periods. (Izquierdo et al. 2011)

## Load profiles

Figure 4 shows a comparison of the electricity load profiles (all sectors) for Norway, Spain and Denmark on winter weekdays (Monday to Friday).

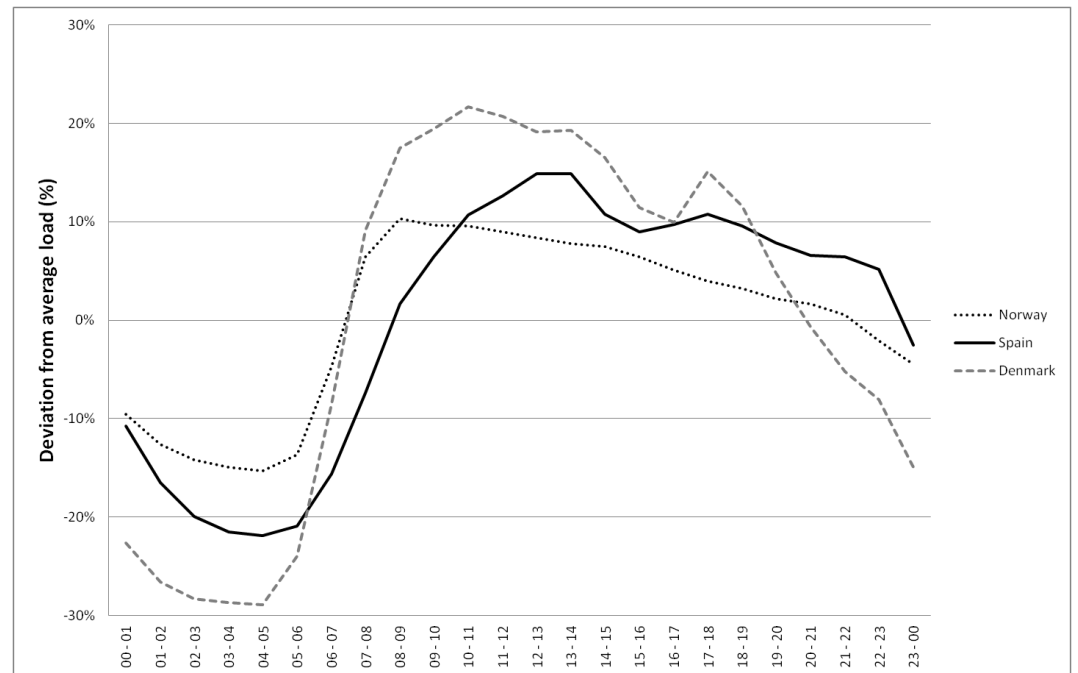


**Figure 4:** Comparison of load profiles for Norway, Spain and Denmark for weekdays in January 2012.

Note: For each country, the figure shows the hourly deviation (in per cent) of the electricity consumption (all sectors) from the average consumption per hour during five weekdays in January (Monday 23 January to Friday 27 January 2012). The average consumption per hour (MWh/hour) is 19,227 (Norway), 32,970 (Spain) and 4,641 (Denmark). Source: NordPool 2013 (Denmark and Norway) and REE 2013 (Spain).

Figure 4 shows a high degree of similarity between the Spanish and the Danish load profiles: Both follow a “two-peak pattern” during daytime and in both countries the difference between the peaks during daytime and the “dip” during the night is substantial. Thus, the maximum/minimum ratio of the energy consumption in Figure 4 is 1.62 for Spain and 1.77 for Denmark. In contrast, the Norwegian load profile is much more level and with less significant peaks during daytime; consequently, the difference between maximum and minimum is lower than for Spain and Denmark (the Norwegian maximum/minimum ratio is 1.28). This is mainly a result of about three quarters of the Norwegian electricity consumption being related to heating, which does not change as much in accordance with the daily practices of the households as in the case of electricity consumption related to other activities like cooking or laundering.

For comparison, Figure 5 shows the load profiles for summer weekdays (in June, a week before the summer holidays).



**Figure 5:** Comparison of load profiles for Norway, Spain and Denmark for weekdays in June 2012.

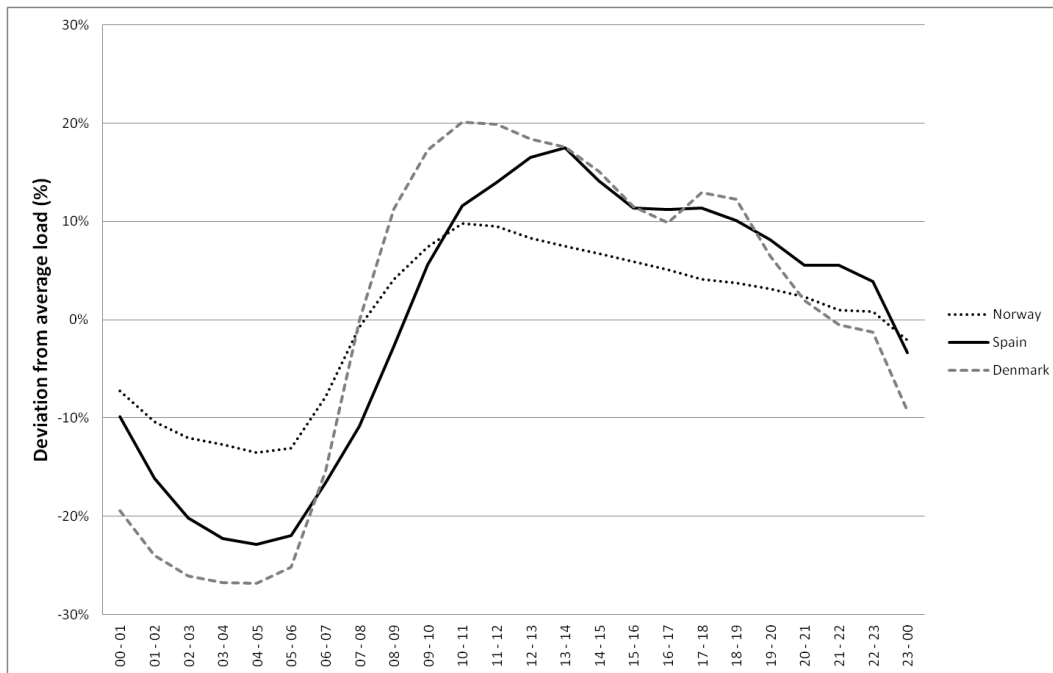
Note: The figure shows the hourly deviation for each country (in per cent) of the electricity consumption (all sectors) from the average consumption per hour during five weekdays in June (Monday 11 June to Friday 15 June 2012). The average consumption per hour (MWh/hour) is 12,082 (Norway), 29,351 (Spain) and 3,663 (Denmark).

Source: NordPool 2013 (Denmark and Norway) and REE 2013 (Spain).

Figure 4 and 5 show that the Danish and Spanish load profiles are more “smooth” during summer time compared to winter time. The Danish summer load profile still displays the two-peak pattern, but the late-afternoon peak is much less prominent in the summer load profile. In the case of Spain, the two-peak pattern is almost missing in the summer load profile. There is still a morning peak (which peaks a little later than during winter time), but the peak in the evening is much less significant. Also the Norwegian winter and summer profiles show some differences, but much less than in the case of Denmark and Spain.

While the average consumption per hour is only slightly lower during the summer for Denmark and Spain (21% lower for Denmark and 11% lower for Spain), the Norwegian summer average consumption per hour is more than one third lower than in the winter (37% lower). The great difference reflects the widespread use of electricity for heating during the winter.

In addition to Figure 4 and 5, Figure 6 shows the load profiles for weekdays during the *summer holidays*.



**Figure 6:** Comparison of load profiles for Norway, Spain and Denmark for weekdays in July 2012 (summer holidays)

Note: The figure shows the hourly deviation for each country (in per cent) of the electricity consumption (all sectors) from the average consumption per hour during five weekdays in July (Monday 23 July to Friday 27 July 2012). The average consumption per hour (MWh/hour) is 10,840 (Norway), 30,636 (Spain) and 3,175 (Denmark). Source: NordPool 2013 (Denmark and Norway) and REE 2013 (Spain).

Figure 6 shows that during the summer holidays, the Danish and Spanish two-peak pattern is even less marked compared to ordinary summer weekdays (Figure 5); while there is still a peak in the morning (Denmark) or early afternoon (Spain), only the Danish profile shows a weak second peak in the late afternoon. But except from this, the differences between Figure 5 and 6 are not as marked as in the case of the differences between the winter and summer load profiles (Figure 4 and 5).

On a more general level, the above figures show the differences in relation to the challenges of load management, which appear to be greater for Denmark and Spain than for Norway. This is because a higher share of electricity consumption in Denmark and Spain is related to daily practices of morning or lunch activities or (in the case of the afternoon/evening peak) cooking practices and other activities related to coming home from work or educational activities. Thus, it seems difficult to change the timing of this consumption in Denmark and Spain as this would to a higher degree imply changes in the timing of daily routines than in the case of Norway, where a majority of the electricity consumption is related to heating, which has larger potentials for load management due to the thermal capacity of buildings. For the same reason, the Norwegian debate of load management in households mainly focuses on the potential for managing the heat demand, even though there is also some interest in possible future applications of load management that would arise from electrifying personal transport.

## Electricity prices

Table 7 compares the retail (end-user) electricity prices for households. The prices include taxes and are from 2010 (2009 for Spain).



**Table 7:** End-user electricity prices for households in Spain, Norway and Denmark

	Spain	Norway	Denmark
Price (euro/kWh)	0.15	0.13	0.27
- of which tax	0.03	0.04	0.15

Source: IEA 2011a: IV.643 (Spain), IV.554 (Norway) and IV.266 (Denmark).

The table shows that Spain and Norway have almost the same price of electricity, while the electricity price in Denmark is about double. The main reason for this difference in price is the different taxation; taxes represent 56% of the electricity price in Denmark, but only 20% in Spain and 31% in Norway.

None of the three countries have a general roll-out of dynamic pricing schemes. In Denmark, it has for many years only been large customers (with an annual electricity consumption above 100,000 kWh) who have had the possibility of joining a dynamic pricing scheme. However, a smaller electricity supplier (SE) has recently started to offer their customers a dynamic pricing scheme based on the hourly electricity spot prices on the Nordpool market. Similarly, Spanish residential customers do not participate in the wholesale market, and – like in Denmark – the contracts between the residential customers and the suppliers are based on fixed tariffs.

In Norway, customers can in principle demand to be charged by spot prices, but not according to variations in consumption or load shifting, as billed consumption is based on average weekly consumption. Until 2009, it was possible to get somewhat cheaper net-tariffs if the customer agreed to let the electricity company curtail the customer's electricity load for heating. However, this required that the customers had supplementary heating forms (e.g. like a combined electricity/oil boiler). This scheme is now closed.

## 2.2 Status of advanced metering infrastructure (smart meter roll-out)

The rollout of so-called “smart meters” is regarded as pivotal for the development of an advanced metering infrastructure that is expected to be the infrastructural backbone of the future smart grid. Smart meters are electrical meters that enable two-way communication between the meter and the supplier and recording electricity consumption in intervals of an hour or less. Smart meters are typically a technological prerequisite for feedback to customers about their electricity consumption and for load management. Furthermore, the remote reporting feature of smart meters is regarded by many Distribution System Operators as a more cost-effective alternative to the traditional meters that included considerable administrative costs in relation to the reading of the meters. In fact, this might hitherto have been a main driver for the investments in smart meters in Europe (Renner et al. 2011).

For the countries studied here, a specific driver for the smart meter roll-out is the need for finding solutions to increasing shares of intermittent electricity generation through load management. This applies particularly to Denmark, which faces the greatest challenges in this regard due to the goal of 50% wind power by 2020. Furthermore, load management is also promoted as a more cost-efficient way of solving present or future capacity problems of the electricity grid through peak-shaving. In Norway, this argument has been put forward by the Norwegian regulator in relation to capacity problems of the regional electricity grid (NVE 2011). In Denmark, on the other hand the main focus seems to be on future capacity problems of the local distribution

network due to expectations of significant increases in households' use of heat pumps and EVs.

Finally, the legal framework of EU also works as a driver for the roll-out of smart meters; particularly the Directive on Internal Markets from 2009, which is part of the Third Energy Package. In order to promote energy efficiency, this directive demands member states or regulatory authorities to work for an optimisation of the use of electricity, e.g. through introducing intelligent metering systems. Before September 2012, all member states had to carry out a cost-benefit assessment for the rollout of smart metering. This assessment should also include a plan for the implementation of smart meters within the following maximum 10 years. The directive demands that in case the outcome of this cost-benefit assessment is positive, at least 80% of the national customers shall be equipped with intelligent metering systems by 2020. (Renner et al. 2011).

The present situation with regard to the roll-out of smart meters in Spain, Norway and Denmark is described briefly below.

### **Spain**

According to the Spanish Energy Law, smart meters have to be installed for all consumers under 15 kW (i.e. most households) before the end of 2018. Minimum functional requirements include electronic meters with remote control, hourly metering and option for hourly tariff selection. Remote control should include possibilities for remote energy management. The overall aim of the Spanish meter substitution plan is to support remote energy management systems (Renner et al. 2011).

By 2011, about 2 million smart meters have been installed (Renner et al. 2011), which represents app. 8% of the 26 million electricity customers in Spain.

### **Norway**

In Norway, focus has primarily been on smart meters as a way to improve the efficiency of the electricity market (e.g. making it easier to change electricity supplier) and for better management of the electricity system. Hourly metering of electricity consumption is only obligatory for customers with an annual consumption larger than 100,000 kWh. As a result, only about 4% of the 2.5 million meters in Norway have hourly metering. Some DSO's have already replaced their customers' meters with smart meters, but these are mainly smaller DSOs (Renner et al. 2011).

In 2011, the Norwegian Water Resources and Energy Directorate decreed that all meters (app. 2.7 million) are to be replaced by advanced metering infrastructure (smart meters) within 2017. In conjunction with this, a regulatory guideline, created in concert with the directorate and all interested parties (mostly Norwegian DSOs), was issued. With respect to functionality, an extended debate ensued, resulting in Norwegian meter specifications looking much like other state-of-the art smart meters developed elsewhere and in the EU. The AMI must 1) measure in intervals of max-min 60-15 minutes, 2) use standardized UI based on open standards which may communicate with external units, 3) allow connectivity and communication with other types of meters, 4) boast data storage immune to power outage, 5) have kill-switch for remote curtailment included, 6) ability to send/receive price and tariff information in addition to service notifications in case of for instance earth faults, 7) include ample data and control security measurements, and 8) maintain registration of active and reactive power flow in both directions (NVE, 2011). However, due to the pressure from the Norwegian industries, the smart meter roll-out deadline was in the beginning

of 2013 postponed to 2019 (Norwegian Ministry of Petroleum and Energy 2013a).

At this point each Norwegian DSOs have more or less started the process of procuring and rolling out new meters to the new specifications. Several demonstration and pilot projects have appeared, dealing first and foremost with communication infrastructures and meter data management issues. Later phases will include comprehensive tests of various display solutions for communicating with the end user, however this may need to include third party developers and market actors largely absent from the scene as of yet. The DSOs are all also working in concert with the Water Resources and Energy Directorate and Statnett, the Norwegian TSO, in creating a common ICT architecture for meter data management (Throndsen, 2013).

### **Denmark**

The roll-out of smart meters to small customers (households) is not yet mandatory in Denmark. However, despite the lack of mandatory framework, many DSOs have already installed or plan to install smart meters in households. It is estimated that by 2011, about 50% of the app. 3 million customers had smart meters and remote reading installed (Renner et al. 2011). Thus, the DSOs represent in themselves the main actor behind the actual rollout of smart meters in Denmark. The rollout has particularly taken place in Jutland, on Funen and south-western Zealand (but not in Copenhagen and north Zealand, as the largest DSO, DONG Energy, has not yet decided a smart meter rollout among their about 1 million customers).

In April 2013, The Danish Government presented their proposal to a Smart Grid Strategy for Denmark. The strategy suggests a final roll-out of smart meters to all customers in Denmark by 2020. In relation to households, the smart meter roll-out is seen as an important prerequisite for ensuring energy savings (through more detailed data and feedback to households about their electricity consumption) and for the realization of the vision about flexible electricity consumption (load management) in households. The strategy also suggests that the smart meter roll-out is going to be combined with the introduction of flexible electricity pricing schemes on the retailer market (offered all customers, whether large or small) and the setting up of a central data hub for collecting and processing data from the smart meters. (Danish Government 2013)

### 3. National energy and smart grid policies

The following review of the national energy and smart grid policies of Spain, Norway and Denmark is primarily based on the country reviews of the International Energy Agency (IEA) supplemented with other sources.

#### 3.1 Spain

Within recent years, the growth in electricity production has mainly been based on expanding the natural gas power production and (to a much less extent) extending wind power. From 2000 to 2007, gas-fired electricity generation increased with 101 TWh and represented 37% of the total electricity generation in 2009. According to the IEA 2009 country review of Spain (IEA 2009), the increase in electricity from combined-cycle gas turbines was in the beginning driven by a need for fast capacity extension (due to higher electricity consumption), but later also by the CO<sub>2</sub> reduction obligations related to the EU Emission Trading System (with gas replacing more carbon-intensive fossil fuels like coal and oil) and the need for backup power capacity for the growing wind power production. According to government projections, both gas-fired generation and wind-power generation are expected to increase from 2008-2016, while coal and oil-fired generation are expected to decrease further. (IEA 2009: 103-104)

All other electricity sources (except solar power and waste/biomass) have been in decline since 2000. With regard to nuclear power, the long-term goal is a phase out of nuclear energy. In 2008, fossil fuels represented 60% of the electricity consumption, while nuclear and renewable sources covered 20% each. (IEA 2009)

The overall aim of the Spanish energy policy is to “support sustainable development and ensure energy supply that allows for economic growth and competitiveness, while reducing the impact on the environment of energy production, transformation and end use” (IEA 2009: 18). According to the 2009 IEA country review of Spain (IEA 2009), policies in relation to supporting renewable energy are partly motivated by concerns related to security of supply (Spain imports about 80% of its energy supply):

“The national government and the autonomous regions see renewable energy as both bringing environmental and energy security benefits, and enhancing local economic development and employment. Renewable energy technology development, especially wind and solar, is a focus area of Spain’s industrial policy.” (IEA 2009: 95)

Renewable energy development is generally supported through premiums and feed-in tariffs for power generation, investments subsidies (mostly for heat generation) and tax incentives for biofuels in transport (IEA 2009: 19).

Like in the other two countries, the Spanish energy policy is strongly influenced by the EU regulation, e.g. in relation to electricity and natural gas markets and with regard to energy efficiency in appliances and buildings such as the EU Energy Performance of Buildings Directive (IEA 2009). Another important EU regulation is the EU Climate and Energy package, which sets the so-called 20/20/20 targets for EU for 2020 (reduction in

greenhouse gas emissions by at least 20% below 1990-level, 20% of energy consumption to come from renewable resources and 20% reduction in primary energy use compared with projected levels for 2020). The specific CO<sub>2</sub> reduction targets for Spain is 10% reduction in 2020 compared to 2005-level (EU 2009a) and the specific target in relation to renewable energy is to increase the share of energy from renewable sources in gross final consumption of energy to 20% in 2020 compared to 8.7% in 2005 (EU 2009b). At the time of writing, proposals for the Energy Efficiency Directive, which is going to set specific targets for each member state, is still being negotiated at EU level and by the EU leaders. In addition to the obligations in relation to the EU 20/20/20 targets, Spain – like other EU member states – has a binding target of covering 10% of the demand for transport fuel by renewable energy in 2020 (IEA 2009).

In relation to the Kyoto protocol, Spain's target (according to the EU Burden-Sharing Agreement) is to limit the greenhouse gas emissions to an average of 15% above the 1990 level for the period 2008-12. However, in 2007 emissions were 53% higher than in 1990. Thus, Spain will probably have to rely strongly on the Kyoto flexible mechanisms in order to fulfill its Kyoto targets (IEA 2009).

As previously mentioned, the wind power generation of Spain has increased fast in recent years. The larger share of intermittent wind power generation, combined with relatively low possibilities for cross-border electricity exchange with other countries, means that the variations in wind power generation to a large extent have to be dealt with within the Spanish electricity system. However, "Spain has successfully focused on developing a well-integrated system to balance these variations" (IEA 2009: 19), with natural gas being the most common backup option for wind power. In situations with high wind power production and low demand, it has also been necessary to cut wind turbines off in order to ensure system balance. The Spanish government, industry and the transmission system operator Red Eléctrica de España (REE) work on developing solutions that can handle an increased share of wind power in the future, including possible solutions like improved interconnections with France, using pumped storage for the surplus of wind power and charging electric vehicle batteries (IEA 2009: 108). The Spanish electricity system has relations to the electricity markets in Portugal (in particular) and France and (North) Africa. However, the Spanish electricity system (together with the Portuguese) in many respects works as an island system (the Iberian Peninsula).

In relation to handling intermittent renewable electricity production, the IEA 2009 country review points at a particular problem related to coincidences of high power demand and low wind power production that needs to be handled:

"Power demand peaks at times of high use of air-conditioners or electric heaters, i.e. when temperatures rise or drop to their extremes. Normally, this is during high pressure and, therefore, when there is little wind. As a result, Spain needs expensive backup capacity, typically gas-fired, to make up for this unavailability of renewable energy. Peak demand could be reduced by more efficient heating and cooling appliances, by better insulating buildings and using light colours for roofs and pavements, as well as natural shading, to reduce the need for these appliances." (IEA 2009: 9)

## 3.2 Norway

The overall target of the Norwegian energy and climate policy is to reduce greenhouse gas emissions by 30% (compared with 1990) by 2020 and to be carbon-neutral in 2050 (taking into account the country's contribution to emission reductions abroad). The electricity supply and energy use in buildings are already more or less carbon neutral due to a high share of hydropower and as energy consumption in buildings is 70-80% based on electricity (Norwegian Ministry of the Environment, 2012). Thus, reductions in greenhouse gas emissions have largely to take place within other sectors than electricity and housing. For instance, the three largest contributors to the Norwegian CO<sub>2</sub> emissions were the transport sector, industry and petroleum industry, representing 69% of the total emissions in 2010 (Norwegian Ministry of the Environment, 2012). Through negotiations with the EU, Norway has pledged that 67.5% of its energy consumption will come from renewable energy by 2020 (compared with 62% in 2010). Even though Norway is not an EU member state, the country participates in the EU Emission Trading System (EU ETS). It is believed that Norway may play an important role in reducing emissions abroad by exporting renewable energy, but also by offering reductions from carbon capture solutions as they mature sufficiently (NOU, 2012).

The Norwegian electricity system is an integrated part of the Nordic wholesale market (Nord Pool Spot) and there is a high degree of exchange of electricity with Sweden, Denmark and Finland. As pointed out by the IEA 2011 country report (IEA 2011c), Norway has an important strategic role due to its high hydropower reservoir capacity, which can work as a backup (and storage) capacity for intermittent renewable electricity production in other countries. A large reservoir capacity provides flexibility, but it is still vulnerable to dry years (especially so in combination with cold weather and high heating demands).

Already today, the exchange of electricity between Norway and its neighboring countries (including the Netherlands) is significant (e.g., Denmark exports electricity to Norway at times with high wind power production and imports electricity from Norway at times with low wind). The Norwegian transmission system operator (Statnett) plans to build several new cross-border interconnections in order to strengthen the integration between the Norwegian electricity system (and thereby the Nordic electricity market) and the rest of Europe. This includes possible connections to Germany, UK and the Netherlands (IEA 2011c) as well as between its own regions (NOU, 2012).

In relation to electricity production based on fossil fuels, the Government does not allow the construction of any new gas-fired plants without carbon capture and storage (CCS) technology: "This effectively rules out the gas option until CCS becomes more competitive" (IEA 2011c: 8). However, 46 TWh of gas power was used in the offshore industry in 2010, and in 2012 there was 1,096 MW of thermal power installed on-shore, commissioned before the relatively new CCS-demands. Production rate in these plants is always dependent on the relation between high energy prices (a seldom occurring event) and cost of production (gas prices), and this often makes these plants a last resort. The last four years have seen on-shore thermal energy production in the range of 1-6 TWh (NOU, 2012), and the production facilities themselves are also sites for CCS-research. Technology Centre Mongstad, a CCS research facility dedicated to providing the decision basis for further realization no later than 2016, opens May 2012 (NOU, 2012).

Even though the domestic electricity production is almost entirely based on carbon-neutral hydropower, it is worth noticing that Norway import electricity from coal-fired plants (particularly in Denmark) and nuclear power (from Sweden and Finland) in situations of low hydropower availability in the Nordic market area and/or sudden and extreme peaks in domestic demand.

With regard to meeting the greenhouse gas targets for 2020 and 2050, measures employed in relation to reducing greenhouse gas emissions include: Increased public investments in research, development and deployment of clean energy technologies (including CCS and development of offshore wind turbines), tightening the energy requirements for new buildings (with the passive house standard as the target level for the building codes by 2020), refurbishing old buildings at a rate of 3% per year, transitioning from fossil fuels in the transport sector to more electricity, bio and hydrogen fuel (including exemptions for EVs from toll road charges and other taxes, free public parking and infrastructure development funding) and plans for increasing use of rail in freight transport (IEA 2011c: 9-10). Norway has also adopted a strategy for development of offshore wind power and is planning to expand hydropower production by utilizing previously untapped hydropower potentials (IEA 2011c) and by refurbishing some older hydropower installations for increased effect. For instance, a new treaty with Sweden on green certificates aims at subsidizing 26.4 TWh of renewable production between the two countries (Norwegian Ministry of Petroleum and Energy 2013b). Furthermore, as around a quarter of Norwegian emissions stems from thermal energy production in the off-shore sector, it is estimated that a great deal of Norwegian emissions may be reduced by connecting the oil and gas production facilities with the mainland electricity grid (NOU 2012). This is, however, a complicated structural and political process, as creating large portions of demand off-shore must be seen in relation to the supply situation on the mainland.

There are, of course, many challenges in relation to exploiting the extensive renewable energy resources in Norway. Main obstacles include public acceptance issues and investment inertia due to immature technology and (relatively) low energy prices. A large focus is therefore also placed on efficiency improvements and load management solutions to preserve the flexibility of the system. It is thought that a smarter grid will allow for Europe as a whole to exploit the variations in the many distributed and intermittent resources better (NOU 2012). Thus, the idea of Norway as “the green battery of Europe” is prominent in the Norwegian debate. Because of this, and also to exploit its own flexibility potential better, the country's energy authorities (the Water Resources and Energy Directorate and the government-owned TSO) have demanded that all DSOs introduce AMS by 2017 (later postponed to 2019), and are now working in concert with the sector to create a robust and nation-wide smarter grid. However, the focus now, and at least for some time to come, is mainly on the transmission, distribution and metering side of the system; the market and consumer-oriented portion of smart grid developments are still in their infancy.

### 3.3 Denmark

As show previously, fossil fuels (mainly coal and natural gas) dominate the Danish electricity production as primary energy sources. Expanding the wind power production in order to mitigate climate change and improve energy sovereignty has been a main target of the Danish energy plans since the 1990s. In March 2012, all parties in the Danish parliament (except for one smaller party) agreed on a new Energy Plan with the overall aim of reducing

the Danish CO<sub>2</sub> emissions by at least 34% in 2020 (compared to emissions in 1990). According to the plan, this will be achieved by reducing the total final energy consumption (transport not included) by 7% in 2020 (compared with 2010) and by increasing the share of renewable energy in the total energy system to 35% in 2020. With regard to the latter, this goal will be achieved first and foremost by doubling the wind power production to 49.5% of the Danish electricity production in 2020. Other major initiatives include increasing the use of biomass in combined heat and power production and increasing the production of biogas based on manure from farming and other biomass resources. Even though the measures of the Energy Plan only cover the period 2012-2020, the long-term goal is to build an energy system based on 100% renewable energy by 2050. (Energy Plan 2012)

Wind power being the main vehicle for achieving the renewable energy goals, the Energy Plan emphasises the importance of developing an “intelligent electricity system” (smart grid). However, the Energy Plan do not include specific measures in relation to the development of the smart grid, except that it prescribes the development of an overall smart grid strategy (a proposal for the smart grid strategy was presented by the Danish Government in April 2013) and making efforts for achieving a *voluntary* agreement with the Danish electricity distribution companies about the roll-out of smart meters. Also, the Energy Plan prescribes that a detailed analysis of the regulation of the Danish electricity system has to be carried out before 2015. The aim of this analysis is to ensure incentives for a “green transition”, cost-effectiveness, market competitiveness and consumer protection. Part of the analysis may focus on the taxation of electricity, including the discussion of a more dynamic taxation. (Energy Plan 2012)

The increasing share of fluctuating wind power in the electricity system results in new challenges in relation to balancing the input and output of the electricity grid. Already today, the wind power production exceeds the domestic electricity consumption at times with high wind speeds and low domestic consumption. These situations are partly handled through exchange of electricity with Norway, Sweden and Germany. In this way, Denmark has been able to take “advantage of hydropower resources in the rest of the Nordic market to balance its electricity system at short notice” (IEA 2011d: 32). However, as noted in the IEA country review (2011), the extent to which Norway also in the future can provide hydropower based balancing resources for the (increased) Danish wind power production will be dependent on the need for balancing resources in Norway itself as well as the Nordic market in general.

The growing challenges of balancing input and output and the visions of a dramatic increase in wind power production within the next decade have given rise to an interest among Danish Distribution System Operators (DSOs), the Danish Transmission System Operator (TSO) Energinet.dk and the Danish energy authorities in developing solutions to manage the consumption side through load management. Hitherto, the focus has particularly been on load management combined with electric vehicles and electric heating of buildings. However, most activities are still at a R&D or demonstration level, and a national strategy for the development of the smart grid has not yet been adopted.



## 4. Survey of national household smart grid activities

This section presents a survey of national household smart grid activities in Spain, Norway and Denmark. The survey is based on a study by the Joint Research Centre (2011) and our own review of existing projects or recently finished projects. Results of the survey have also been reported in Christensen et al. (2013a, 2013b).

A 2011 survey of European smart grid projects by the Joint Research Center (2011) shows that most of the EU smart grid R&D and demonstration projects are concentrated in a few countries. Denmark, Spain, Germany and the UK account for about half of the total number of projects (Denmark alone accounts for 22%). Thus, both Spain and Denmark have a high activity level with regard to development of the smart grid, but also Norway has a number of smart grid projects.

As the focus of the IHSMAG project is on smart grid solution related to *households*, only projects which include technologies or solutions related to households have been included in this survey. As part of the survey, each of the identified household smart grid projects was categorized according to the *type of smart grid activity* and the *household consumption area* that the project focused on. The following typologies were used for the categorization according to these two dimensions:

### Type of smart grid activity

- Electricity saving: Projects with the aim of achieving electricity savings in households through the use of smart grid solutions (e.g. smart meter-enabled feedback to household members about their electricity consumption)
- Load management: Projects with a focus on load management in households (e.g. through test of dynamic pricing schemes, automated control of electricity consuming appliances such as heat pumps or the charging of EVs etc.).
- Micro-generation: Projects with a focus on household-based generation of electricity from renewable energy sources (e.g. solar power or small wind turbines).
- Other activities: Household smart grid projects with another activity focus than the above mentioned.

### Type of household consumption area in focus

- Heating (space and/or water) and air conditioning (e.g. heat pumps)
- Cooling (freezers and refrigerators)
- Laundering (washing machines and tumble dryers)
- Cooking (e.g. electric cookers, dishwashers etc.)
- Lighting & other electric appliances (including consumer electronics)
- Transport (only if electricity is included, e.g. EV's)
- Electricity consumption in general (no specific area in focus).
- Other

Appendix 1 shows the distribution of the identified projects by type of smart grid activity and type of consumption area in focus. As it can be seen from Appendix 1, many of the R&D and demonstration projects address more

than one type of smart grid activity and/or type of household consumption area.

In total, 18 household smart grid projects have been identified in Denmark, 5 in Spain and 3 in Norway. With regard to the distribution by type of smart grid activity in focus, Appendix 1 shows that most projects address load management or (to a less extent) electricity saving, while micro-generation seems to play a minor role in relation to household smart grid projects in the three countries. With regard to the household consumption area in focus, Appendix 1 shows that the identified projects tend to fall into two overall groups: *Either* they focus on (load management of) heating/air-conditioning or EV charging – *or* they do not focus on a specific consumption area, but address the household electricity consumption more generally.

In the following, the household smart grid projects of each country will be described in more detail (including similarities and differences between the countries).

## 4.1 Denmark

The Danish survey shows that load management is the area that attracts the most attention in relation to Danish R&D and demonstration projects (12 out of the 18 projects address this theme). The focus is particularly on the load management of electric heating (particularly heat pumps) and EV charging, despite the fact that heat pumps and EVs still have a very limited penetration in Danish households. This exemplifies how the development of new household smart grid solutions is to a high degree based on visions of future changes in the composition of the electricity consumption in households.

The load management projects differ with regard to their approach to and conceptualisation of the users. While some projects focus on automated remote management of appliances (implicating an understanding of the user as someone who should not be actively involved in performing the load management), other projects aim at motivating consumers to change their daily practices (e.g. defer their laundering) in response to spot prices and information about real-time electricity prices.

An example of active involvement of consumers are the eFlex project (by DONG Energy), which finished in 2012 and involved about 120 households (predominantly households with heat pumps). The test families were equipped with a home energy management system, which enabled feedback at appliance level, apps for smart phones and remote control of appliances. During the test period, the families were offered real-time dynamic prices. The project showed some potential for load management in relation to heat pumps, but also limitations to this potential such as in periods of extraordinarily cold weather.

While load management is a key area of the Danish projects, there are also a number of the reviewed projects (5) that address the potential for electricity saving. While the load management projects in general focus on specific consumption areas (like heating by heat pumps or charging of EVs), the projects addressing electricity saving tend to have a broader perspective on the electricity consumption of the household. Most of the projects develop and test solutions with general feedback information to the residents about their daily or hourly electricity consumption. These projects seem to be based on a general representation of the consumer as an informed, rational-choice agent, who will change his/her daily electricity consumption patterns on the basis of more detailed information about his/her electricity

consumption. Interest in saving money or environmental concerns are usually assumed to be the primary driver for changing practices.

Electric vehicles are, as noted above, considered by many actors to play a particularly important role in the future Danish smart grid. The idea is that with the (expected) penetration of electric vehicles, these will represent considerable storage capacity for electricity. At times with high wind power production (due to high wind speeds), the electricity surplus (or some of it) can be stored in the batteries of electric vehicles through intelligent management of the charging. At the time of the COP15 summit in Copenhagen, two major electric vehicle demonstration projects were launched: “Better Place” and “Test-an-EV” (the latter run by CLEVER). Both projects aimed at introducing electric vehicles to the Danish market and promote sales, but they differed with regard to the basic battery charging design. While the “Test-an-EV” project made use of traditional electric vehicles, the “Better Place” project developed a design with switchable batteries; thus, depleted batteries could be replaced with new, fully-charged batteries at special-designed “battery switch stations”. However, Better Place went bankrupt in May 2013 because of low car sales, while the “Test-an-EV” project is still running.

## 4.2 Spain

The Spanish survey includes five recently finished or ongoing smart grid projects in relation to households. The projects are: Smart City Malaga, MUGIELEC (Development of infrastructures and energy management systems related to the EV), PROYECTO GAD (active demand management), BIDELEK and ADDRESS (Active distribution networks with full integration of demand and distributed energy resources).

Like in Denmark, load management constitutes the main focus of the household smart grid projects; all five projects address load management, although to varying degrees. Two of the projects (BIDELEK and MUGIELEC) focus primarily on the potential of EVs, while the remaining projects have a more general focus on the potential of household electricity consumption for demand management (e.g. heating/air conditioning and laundering). The Smart City Malaga project is somewhat different from the other projects (and also the Danish projects) as this has a system perspective of the city instead of focusing on specific sectors like households or large customers. Also, some of the projects mainly focus on developing the infrastructural hardware and software for smart grid solutions (MUGIELEC and BIDELEK).

Energy saving is not a prevalent theme in the surveyed Spanish projects. Thus, like in Denmark, the focus on load management dominates the household smart grid projects in Spain. Furthermore, the development and testing of new hardware and software solutions (and to some degree also new business models, e.g. the ADDRESS project that develops models for aggregators of small customers offering load management services for the electricity market) are the primary focus of the projects, while studying users’ perception and developing new approaches to the active involvement of users (households) in general seems to be underrepresented.

## 4.3 Norway

The Norwegian survey includes three projects: Demo Steinkjer, Smart Energy Hvaler and Demo Lyse. The Demo Steinkjer and Smart Energy Hvaler projects have a broad focus on different smart grid solutions

(electricity saving, load management, micro-generation and power balancing capacity) as well as different areas of household consumption. Both projects, which are still in their initial phases, are characterised by being based within a specific geographical area (the town of Hvaler and the area of Trøndelag) and have a specific focus on smart meters and their potential use for developing smart grid solutions. Demo Steinkjer and Smart Energy Hvaler are subprojects of the DeVID (Demonstration and Verification of Intelligent Distribution grids) project, which is a demonstration project with the aim of providing knowledge and experience for the planning of the coming roll-out of smart meters in Norway.

The third project, Demo Lyse, focuses on the potential for combining smart meters with new ICT infrastructures like fiber optics and new devices like tablets etc. Energy-related aspects like load management or energy saving are not the primary focus of this project, which instead focuses on the potential of new technologies for home automation (like controlling appliances or heating and lighting) and developing new welfare services like tele-medicine. Thus, this project exemplifies the diversity of ideas and solutions that is often associated with the smart grid concept.

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## Appendix 1: Household smart grid projects by type of smart grid activity and consumption area (Denmark, Spain and Norway)

	Electricity saving	Load management	Micro-generation	Other
Heating/air cond.		DK: Price-sensitive electricity cons. in households DK: EcoGrid EU DK: eFlex DK: Intelligent remote control of heat pumps DK: Trials with heat pumps on spot agreements ES: ADDRESS		
Cooling		ES: ADDRESS		
Laundering		ES: ADDRESS		
Cooking				
Lighting & other appliances				
Transport		DK: EDISON DK: EcoGrid EU DK: eFlex DK: Intelligent charge stands DK: Test en elbil ES: MUGIELEC		DK: Test en elbil DK: Better Place DK: Etrans
Household electr. cons. in general (excl. transport)	DK: ConsumerWeb DK: EcoGrid EU DK: Intelligent home DK: EnergyFlexHouse DK: Feedback-motivated energy savings DK: Several "feedback light" solutions in relation to smart meters (provided by DSOs) NO: Demo Steinkjer NO: Smart Energy Hvaler ES: Smart City Malaga ES: BIDELEK	DK: eFlex DK: iPower DK: Energy Forecast DK: FlexPower DK: EnergyFlexHouse NO: Demo Steinkjer NO: Smart Energy Hvaler ES: Smart City Malaga ES: PROYECTO GAD ES: BIDELEK	DK: EnergyFlexHouse NO: Smart Energy Hvaler	DK: IMPROSUME NO: Demo Lyse
Other				DK: Innovation Fur