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Mapping the preposition, the effects and the implications of a large-scale Advanced Metering Systems (AMS) implementation in Norway

by

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ABSTRACT

An implementation of Advanced Metering Systems (AMS) may release end-user flexibility in providing incentives for consumption adjustments and improved information to base the adjustments on. This demand response represents an increased ability for the system operators to maintain the load balance in the power system.

In addition, AMS may increase consumer awareness, induce energy saving improve market efficiency, increase measurement quality, open for new products and environmental benefits

The effects are dependent on several factors in the regulative framework, the market design and power pricing mechanisms, the chosen technology, and the enrolment pattern.

This thesis will try to assess the current status, the prepositioning towards as well as the potential effects and implications of an AMS implementation.

PREFACE

What initially started out as a desired wish to discover something important and revolutionizing was soon to be naturally limited by the short time horizon, the missing prospected figures and my lack of specified knowledge.

Initially I lost a lot of time preparing for a subject of which my prospected cooperating partners in the project eventually withdrew from. Eventually landing on the subject of AMS was a motivation in both own interest on the topic and prospects of a promising cooperation with a company able to provide me with figures of interest. Even though my contact in the company had to retreat the cooperation caused by unforeseen incidents, the subject was increasingly of interest both politically and for me personally, and it encourage further assessments.

What I discovered throughout working on my thesis is that on my planned way to completion I came across several fields that was opportune and interesting for further assessment. Many of which are subject to a negligible amount of public available research. What I initially had considered to be a narrow issue for assessment turned out to be broad and filled with interesting subjects. Nevertheless the time horizon forced me to stay on the path towards completion, disregarding that I was unable to exhaustively understand and map the issue.

I want to thank my advisor Linda Rud. Additionally I would like to thank the following for crucial help and highly appreciated guidance on my way through despair and enthusiasm to partly understanding;

Guro Henriksen (OED), Torgeir Ericson (Cicero), Bente Halvorsen (SSB), Ove S. Grande (SINTEF), Christian D. Andersen (NHH), Frode Skjeret (NHH), Mari Røhmesmo Westeng (Statnett), Rolf Andreas Olsen, Silje Narum and Joachim Amland. In addition to several authors, lecturers, journalists, organisations, companies, public authorities and scientists for articles, lectures, reports, web pages and books.

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1 INTRODUCTION

"An intelligent power system means that electricity consumption should be adjusted to/in balance with the resource situation in the power system at all times, also taking into consideration bottlenecks in the grid."

Ove S.Grande

An active demand side responding in the short-term is an important component in an efficient power market. The Norwegian power market however, is not characterised by such demand response. Periods with peak prices do not necessarily cause adjustments in consumption. This absence of adjustments can be explained by disconnection between the end-user market and the spot market where the power providers purchase the power. For customers with a yearly consumption below 100 000kWh, comprising about 40 percent of the Norwegian consumption, the electric meters measure only accumulated consumption. Hence the running consumption is disregarded and the invoiced consumption is based on the accumulated consumption distributed according to a stipulated consumption pattern. The consumers are not faced with the relevant marginal cost of power provision and have no incentive to adjust to short-term fluctuations.

Advanced Metering System (AMS) is thought to accommodate this disconnection by providing the consumer with frequent prices that reflect the area specific cost of power provision. This enables a more accurate invoicing by charging real-time consumption with more accurate costs. AMS is an intelligent electricity meter that enables frequent measuring of power consumption and provides extensive communication between the power provider, the end-user and different devices.

By providing the consumers increased and more accurate price information AMS is thought to increase awareness on energy consumption and stimulate energy saving. Reallocation in consumption from peak load to low load hours will be both manually incentivised by saving potential and through remote and local control. Thus can the power-output be limited in the short and the long-term, and contributing to the power load levelling and possibly reduce the need for reserve capacity in the transmission grid. Load levelling and increased information on consumption may finally provide consumers with a more constant price.

Though society may have considerable gains from an AMS implementation, it is not necessarily corporate profitable for the network companies responsible for such implementation. Hence, a governmental initiative may be crucial to realise the socio economic benefits of increased power market efficiency.

This paper will explain the functionalities of AMS and elaborate on the effects and implications of an AMS implementation in Norway.

2 INTRODUCTIVE INFORMATION

In Norway about 50 percent of the total energy use is covered by electricity. Ample access to hydropower has historically caused relatively low power prices in comparison to other energy carriers and other countries. However, increased cross-border power exchange, increased consumption, low investments in transmission capacity, ancillary increased prices of electricity and the necessity to handle energy shortages motivate changes.

As a commodity power has unique qualities and characteristics. Special aspects of the trade routes, the market participants, the load patterns and the commodity trade all contribute to a rather complex market for power trade.

2.1 Electricity

Electricity is momentary in existence and continuous in production and consumption. It cannot be stored on a large scale. Long distance transport induces energy losses. Furthermore, network features such as loop flows[1], network externalities[2], and non-traceability[3] have important implications for production and consumption scheduling, investments in network and production capacity, as well as for the design of metering and invoicing systems.

2.1.1 Energy vs. Electric Power

The two terms is often used interchangeably, but electric power and energy represents two related, but different concepts. Energy is a quantity that is in physics understood as the ability to perform work. This quantity can be ascribed an object, particle or system of objects as a result of its physical state. The different forms of energy include potential, kinetic, thermal, gravitational, elastic, electromagnetic and sound energy (Hansen, 2010).

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[1] Loop flows indicates that electricity flowing from a producer to a consumer may move through all lines connecting the two, not only the shortest distance connecting the two. The production and consumption needs to be carefully balanced to avoid the network to be overloaded.

[2] Network Externalities are the effects on a power consumer of others consumers also consuming power.

[3] A kWh provided the consumer couldn't be traced back to the producer that generated that specific kWh. (Rud, 2010)

Electric power is the rate at which electric energy is transferred by an electric circuit, expressed in Watts or given as the amount of work performed in a unit of time.[4] Electric current that flows in a circuit can transfer energy into mechanical and thermodynamic work (Hansen, 2010). Electric energy can through different devices be transformed into many useful forms like heat, light, motion, sound or chemical changes.

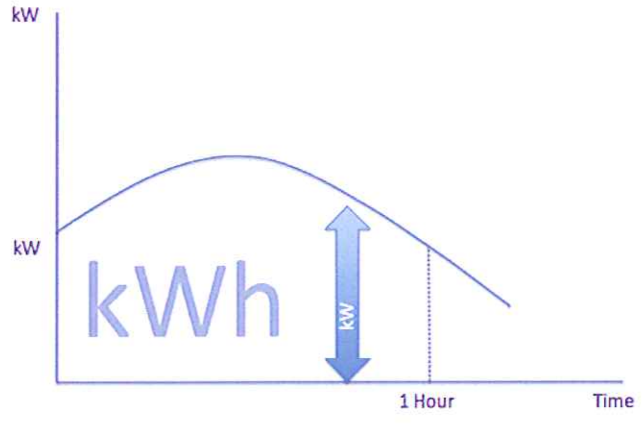
Electricity can be produced mechanically by generation that creates electricity from other forms of energy, by the movement of a loop of wire or disc of cobber between the poles of a magnet. Electricity may also be produced chemically or by direct conversion of light through photovoltaic cells. Batteries carry the potential of chemically storing the electricity.

2.1.2 Electricity as a commodity

The momentary and continuous nature of electricity demands a balance between aggregated production and consumption at all times. To measure electricity it is useful to differentiate between the instant power that is produced or consumed at a given instant in time, and the total energy produced or consumed in a given time period. This is respectively measured in kW[5], MW, GW and TW, and kWh[6], MWh, GWh and TWh.

Figure 2-1

Illustration of the difference of Instant power and energy. The energy amount is the total area underneath the curve measured in kWh.



[4] Electric power is given from current measured in Amperes times voltage measured in volts. (Hansen, 2010)

[5] kW is an acronym for kilo watt which is a SI unit (International system of units) for the measure of 1000 Watts of electrical power. MW, GW and TW stand for respectively Mega Watt(10^6Watt), Giga Watt (10^9Watt) and Terra Watt (10^{12}Watt)

[6] A kWh is the acronym for kilo Watt hour which is the amount of energy that correspond to a power drain consumption of 1 kilo Watt over a periode of 1 hour. Then follows; MWh = Mega Watt hour = 1000 kWh, GWh = Giga Watt hour =1000 MWh, TWh = Terra Watt hour = 1000 MWh

On an economical scale, electricity is not storable and is dependent on a transmission grid for delivery. Hence is electricity as a commodity a bundle of both electricity and transportation (Rud, 2010).

2.1.3 Power balance

Electricity is produced, bought, sent and consumed. For the power system to work sufficiently there must be balance between consumption and power available. The available supply depends both on the production and transmission ability.

Short-term Balance

Because of the momentary and continuous nature of electricity, combined with poor possibilities for storage, the aggregate production and consumption must balance at all time. This means that the amount of electricity withdrawal from the power network in one point in time must at momentarily be compensated for with input from production. This balance is distorted by unforeseen variations in consumption or production, congestions[7] and area specific power shortages. The system operator holds the responsibility to maintain the balance in the electricity system at all points in time through access to immediate capacity, so-called ancillary services[8].

Long-term Balance

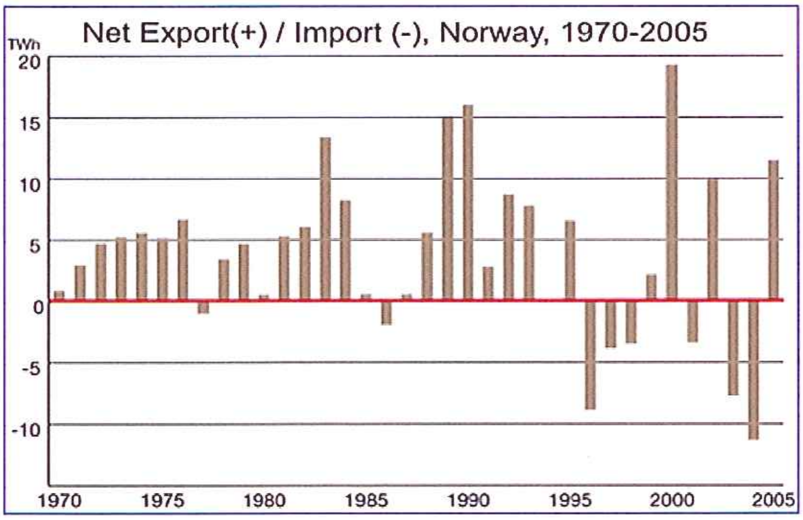
The long-term domestic power balance is defined as the relationship between production and aggregated consumption of electricity through the year. Primarily[9], Norwegian electricity is generated from hydro resources, and consequently the resource base, which is precipitation and inflow in the power basins, influences the balance. The general power balance may be evaluated by assessing consumption in relation to the production of electrical energy in a year with normal precipitation. The inflow to the power basins will normally determine the possible power production. In years with high inflow, domestic production will often exceed domestic consumption, and excess power may be exported. Low inflow years will induce the opposite effect, and we may call for power import. The net export varies accordingly as illustrated in figure 2-2. Cross-

[7] Congestions accrue when the desired exchange of energy exceeds the transmission limit in the network. FOR 2002.05.07, nr 448. (Lovdata-FoS, 2010)
[8] Ancillary services is vacant capacity for adjusting real-time power load that can be phased in on a short notice, supplied by both designated producers and consumers.
[9] 99 percent of a total Norwegian power production of 121 TWh in a normal year is generated from Hydro resources. (OED, 2010-1)

border exchange contributes to reduce the influence of the volatile hydropower production on the consumption and strengthens the security of supply. Accordingly, primary measures to meet the variations in yearly inflow is to strengthen the cross-border transmission capacity, develop new production capacity, and stimulate for increased consumer flexibility.

Figure 2-2

Net export /import, Norway, 1970-2005 (Statnett 2010-3)



To attain an efficient power balance a well-functioning power market with equal information access is crucial. It is intentional that when the power price increases as result of a negative power balance it will induce increased production and reduced consumption.

2.1.4 Electricity demand

Electricity provides consumers with energy that is easily translated into everyday energy needs such as lightning, heating, cooling, device specific energy and mechanical power.

General Drivers of demand

Several aspects influence Norwegian electricity demand. To some extent the general economic situation is of direct influence on the consumption. The power consumption will normally co vary with the purchasing power and the production activity. Empirically power consumption increases with economic growth, because an increase in production of goods and services will induce an increase in energy demand.

Furthermore, economic growth will provide an increase in private and public revenues that will be partly used for increased energy consumption (OED, 2006). The effect of economic growth on the energy use depends on which sectors in the economy that grow. There are large divergences within the different industries, both considering the composition of the energy use and the energy intensity in production.

The demand for energy depends on the size of households, population growth rate, settlement pattern and the populations' age structure. Population growth will induce increased energy need by virtue of e.g. building development and increased demand for goods and services. For example, in Norway, a stable evolvement towards more households with fewer persons[10] on larger living space[11] causes power consumption to increase. Use of electric devices in households and industry has increased with increasing accessibility, decreasing prices on devices, and increased income. However, power consumption in the households has overall in last years tended to decrease. Assumed reasons are more energy efficient devices and a reduced dependence on electricity for heating. A climate change incited temperature increase[12] is also associated with the reduction in households' power consumption, because a significant share of the consumption is used for heating purposes (SSB-5, 2010).

Price elasticity of demand is a measure used to show the responsiveness of the demanded amount of electricity due to a one percent change in the price of electricity. It is generally assumed that consumers' have a limit for what they are willing to pay for different use of electricity (Grande et al, 2008). Higher electricity prices make the use of electricity more expensive. Normally this will decrease consumption (OED, 2006). The price elasticity of demand is generally assumed to be low in Norway, implying that a change in price on electricity has had very little effect on electricity consumption (Rud, 2010). This will be further elaborated on later in this assessment.

Consumption Characteristics

The demand pattern depends on the specific characterisation of the consumption. For example, the type of use, the size of consumer and consistency of consumption all influence the load profiles. Different sectors like the industry, the service sector and

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[10] The average number of residents per households has decreased from 2,7 persons in 1980 to 2,1 persons in 2006. (SSB-5, 2010)

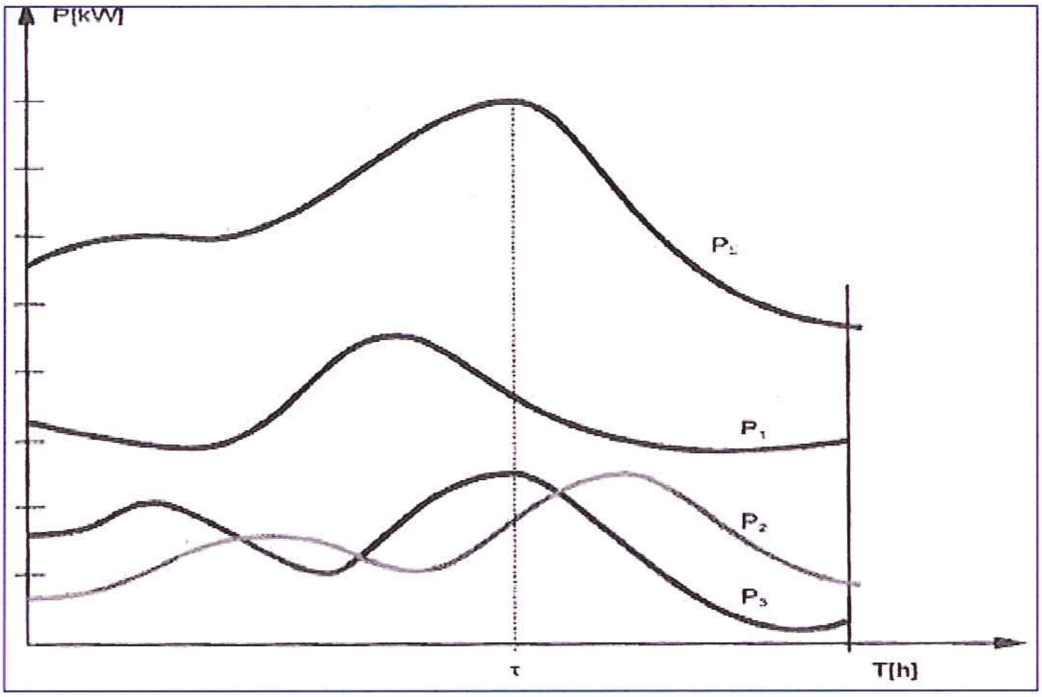
[11] Net living space has increased from an average of $101m^2$ in 1981 to an average of $119m^2$ in 2006. (SSB-5, 2010)

[12] With the exception of the year of 1996, the average temperature in the period between 1990 and 2006 was higher than the average from 1960-1990. (SSB-5, 2010)

households do not necessarily have coincident consumption patterns (Wangensteen, 2007). There are contrary variations in load profile between for example households with peaks in the morning and afternoon, and for offices during office hours. These variations in load do to some extent even out because they do not co-vary. Thus the aggregated maximum load may be less than the sum of the individual maximum loads (See figure 2-3).

Figure 2-3

Individual load profiles ($P_{1\text{-}3}$) and aggregated load profile (P_{Σ}) (Wangensteen, 2007)

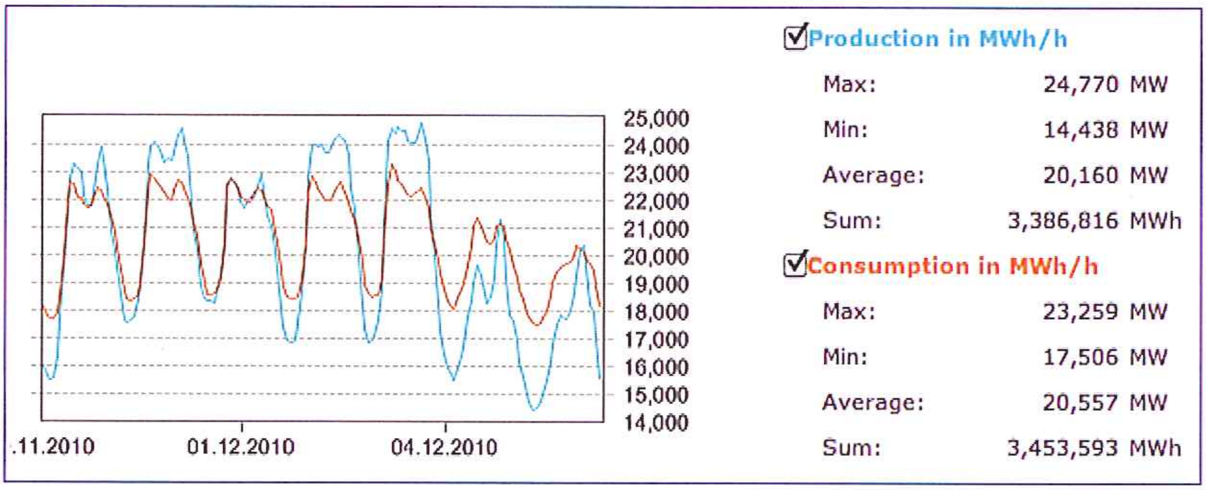


Time and Temperature

The dynamics of the overall demand is characterised by variations depending on season, week day and time of day, as well as on weather and temperature. Weekly variations are characterised by low consumption during night hours and during weekends. Consumption peaks occur in the morning due to heating, water heaters, cooking and use of electric devices. A slight reduction in consumption accompanies working hours however, with a following peak in the afternoon coherent with dinner preparations, laundry and heating purposes. The weekend tends to have related, but lower consumption patterns. See figure 2-4.

Figure 2-4

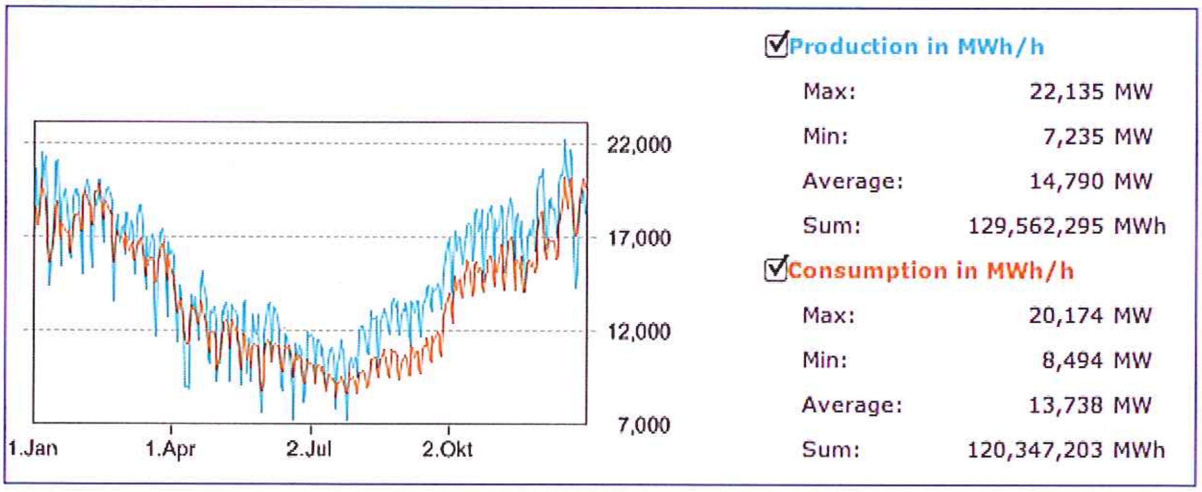
Weekly Production and Consumption Loads in Norway Week 45, Monday 15th-Sunday 21st of November. (Statnett 2010-2)



On a yearly basis Norwegian aggregated consumption variations are highly coincident with temperature and daylight, with a significant divergence between consumption during the summer and consumption during the winter as shown in figure 2-5. One causal reason for high electricity consumption during winter months is lighting and heating purposes (SSB, 2010).

Figure 2-5

Yearly Production and Consumption Loads in Norway 2009. (Statnett 2010-2)



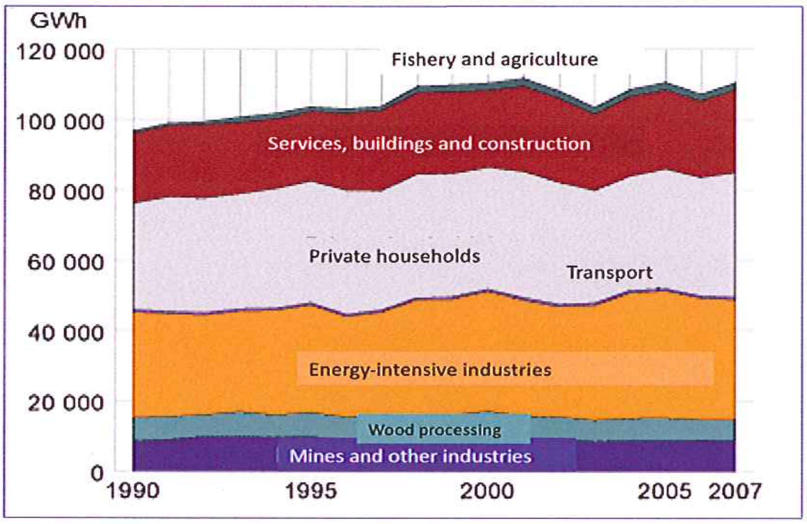
Combining the pattern of aggregated daily electricity consumption loads, with the seasonal variations we see that the largest load peaks occur in cold winter mornings around 09.00 am (SSB-2, 2010).

Complexity of consumers

The composition of the Norwegian consumption is complex. By sectoring the electricity consumption, both private households and energy-intensive industries each account for around one third of the overall consumption. (See figure 2-6) The tertiary industries (represented by the services, buildings and constructions), and the less energy-intensive industries (such as wood processing, mining and other industries) both comprise almost two fifth of the consumption, while the primary industry in Norway strains the power system insignificantly (SSB-1, 2010).

Figure 2-6

Electricity consumption distributed on different sectors 1990-2007. (SSB-1, 2010)



The electricity consumers in the primary sector have a divergent consumption pattern in the sense that they use relatively much during the night, but decrease their consumption from mid-day. They also have considerable variations in their pattern from one month to another due to seasonal dependent work. However, the relatively small share of clients with this consumption pattern implies that their divergent pattern has insignificant influence on the aggregate overall electricity demand pattern.

The secondary and tertiary industries have similar patterns of consumption, with the lowest consumption during the night with a rapid increase in connection with commenced operations in the morning. On average the secondary industry has the largest variation in consumption. Industrial clients reach a peak demand at the ninth hour. Then follows a reduced consumption level with a marked fall at 16.00-17.00. In virtue of their large level of consumption per client, they also have a considerable influence on the total consumption.

The households produce two demand peaks, one in the ninth hour and one in the evening, time-dependent on season. Despite the low level of consumption per household, the large magnitude of households causes their consumption pattern to be of important influence on the aggregated load pattern. It is primarily the share of total consumption originating in households that is topical to this assessment.

All sectors except the primary industry has concurrent peaks around the ninth hour. Some of the evening peak caused by the households is cut back by the marked reduction in secondary and tertiary industries, so the largest daily peak load is most likely to be observed in aggregated total consumption around the ninth hour (SSB-3, 2010). During days of severe winter temperatures in Norway, these peaks have on several occasions pressured the production and transmission capacity towards the limit, threatening the security of supply.

2.1.5 Electricity Generation

Electricity is produced from other energy sources such as fossil fuels, falling water or nuclear fission. Most commonly electro-magnetic generators generate the electricity. These are typically driven by steam produced from fossil fuels, heat as a result of nuclear reactions or from kinetic energy extracted from wind or flowing water (Hansen, 2010).

Norwegian Generation Sources

In Norway, 99 percent of our electricity production is based on hydropower, which in a normal year amounts to about 120TWh. In addition Norway produces electricity from wind, gas and thermal plants[13] (OED 2010-1).

Due to foreign trade, our available production capacity comprises production plants in Norway as well as production plants in connected countries, thus constituting a portfolio of electric generation based on hydro, coal, gas, nuclear, wind and other

[13] In a thermal power plant, mechanical power is produced by a heat-engine that transforms thermal energy, primarily from fuel combustion into rotational energy (Hansen, 2010).

renewable sources. Hydropower represents 50 percent of the Nordic electricity portfolio, while the rest is mainly thermally based power (Bye et al, 2010).

Hydropower has extraordinarily low variable costs. However, hydropower plants have a limitation in fuel access, and depend totally on precipitation and inflow to the power basins (OED, 2010-1). The possibility of retaining the water for later utilisation gives the water in the power basins an opportunity cost (Rud, 2010). In addition the hydropower system has limitations connected to the water regime, the storing capacity of the basins, and the production capacity of the power plants. These are shadow-priced and used for optimising the long-term allocation of the water resources, thus replacing the payable variable costs (Bye at al. 2010).

Thermal power production typically has variable production costs that exceed the production costs of hydropower. The fixed costs in a thermal production plant to keep the unit running are often dominated by capital cost and some routine maintenance. The operation costs consists of fuel costs, emission-costs and unintended maintenance- and repair costs. It can be simplified in a cost equation;

Operation Costs = $a + bX + cX^2$, where a, b and c are constants and x is the production quantity

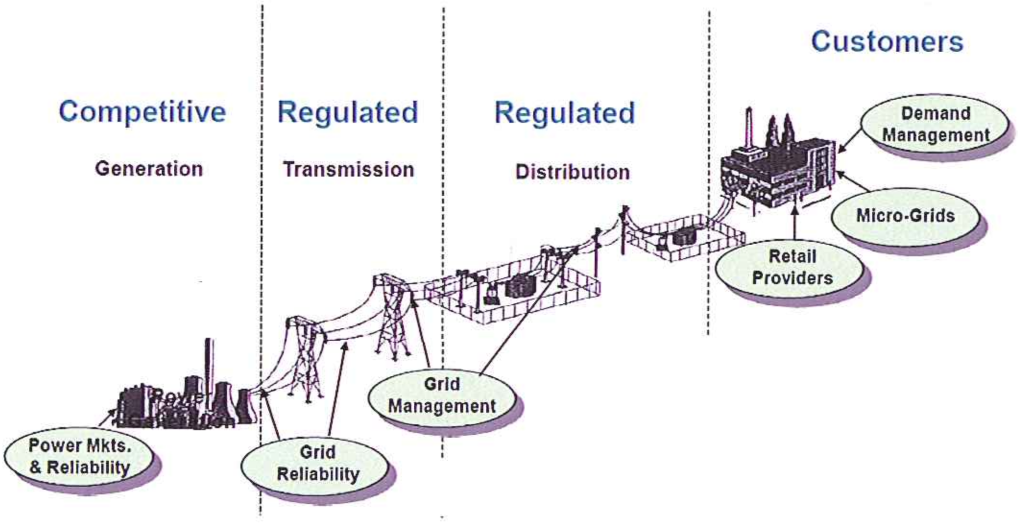
This implies marginal costs that are a linear increasing function of output. However further characteristics complicate the cost estimation: thermal units have large start-up and shutdown costs that entail minimum uptime and downtime to cover the costs (Wangensteen, 2007). In practice this means that in times of low consumption base load production is running on a price only based on their low variable costs, while at high levels of consumption, the units with high variable costs will set the price.

2.2 The Norwegian Power Market

There are several participants of the Norwegian Power Market. On top the Ministry of Petroleum and Energy[14] holds the responsible post, and has the primary task to arrange for a coordinated and integrated energy policy (See figure 2-7).

Figure 2-7

Illustration of the distribution chain of electricity



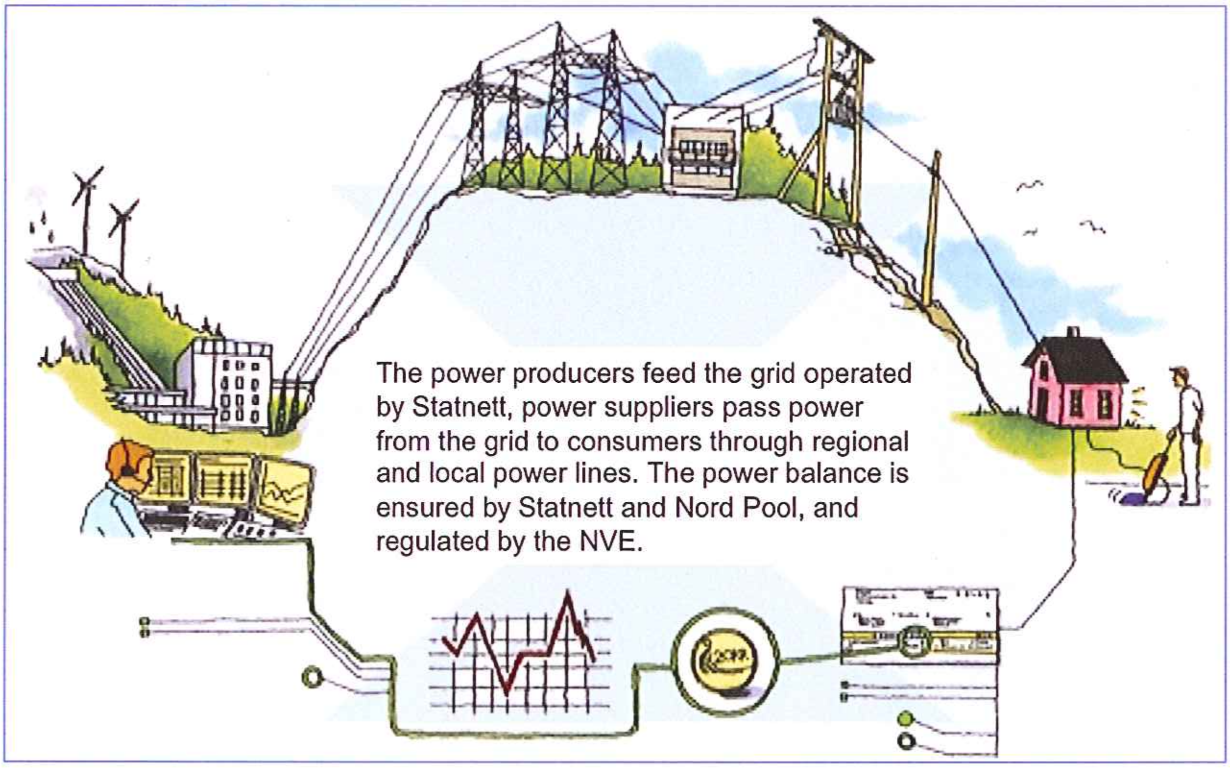
Subordinated the OED is the Norwegian Water Resources and Energy Directorate[15] whose primary responsibility it is to manage the domestic water and energy resources. Along with OED and the Norwegian Competition Authority, NVE have the superior regulative responsibility in the power market. Due to its nature as a natural monopoly the grid and its system operators are subject to regulation. The power producers and the power retailers are subject to competition to assure socio economic optimisation.

This chapter will provide an overview on the structure and functions of the Norwegian power market. In figure 2-8 the complex Norwegian power system is simplified in a readily understood overview.

[14] The Ministry of Petroleum and Energy will in this paper be denoted as the OED concurrent with the Norwegian acronym.
[15] The Norwegian Water Resource and Energy Directorate will in this paper be denoted as the NVE concurrent with the Norwegian acronym.

Figure 2-8

The Norwegian Power Market – an overview.



2.2.1 *The Power Grid – a Natural Monopoly*

The construction of transmission and distribution grid is costly, giving high fixed cost. The average cost of each kWh transported decreases with increased utilisation of the grid until the capacity limit. This implies that parallel grids and competition in grids would be economically insufficient. Thus the grid development, operation and maintenance of the power grid have the characteristics of a natural monopoly, where each end-user is tied to their local distribution company (OED-grid, 2010). In the absence of competition, the transmission and distribution sector is subject to monopoly regulations to ensure consumers rights, efficient grid operation and development, as well as to contribute to a well-functioning power market.

Regulation and Income Cap

The responsibility of monitoring operation and development of the grid lies with the NVE. Grid regulation is also needed to avoid unreasonable monopoly profits, and to ensure efficient cost efficiency and potential cost reductions to benefit the consumers. To do this NVE determines an income cap for each network company. The income cap represents the maximum level of income derived from transmission tariffs, and is stipulated to compensate for operating expenses and grid maintenance, and also provide a reasonable return on invested capital given efficient operation, utilisation and development of the grid. To account for the area-specific costs such as topography, settlement patterns and climate differences each income cap is set individually on a yearly basis. The cap of today is determined by a 60 percent weighting of the cost norm, which considers the performance and costs relative to other companies in the sector. The remaining 40 percent weighting is based on each company's previous cost two years back. The companies are additionally compensated for possible present value losses originating from recent investments (NVE-1, 2010).

Administrative regulations[16] further conduct guidelines for the design of the network tariff. The main principles are that the network companies are obliged to provide grid access on non-discriminating and objective conditions, and that the network tariff is designed to communicate signals to the net users on efficient usage and development. Further, when differentiating the network tariff, it should be based on objective and controllable criteria based on relevant network conditions.

The network companies are also delegated the responsibility of collecting the measurements values of input and output to the grid in each measurement point in their net. The values for the large users are measured and registered automatically, while for small users they predominantly rely on the consumers to personally report their metered consumption. Measurement points with an expected consumption level of the short side on 8 000 kWh per year, the metered consumption is to be read at the turn of each year. For measurements points with an expected consumption above 8 000 kWh the terms are either each month, or every second or third month (ECON, 2007).

System Operator

Statnett is a state-owned enterprise that is responsible for the operation, maintenance and development of the central grid and to administer the abroad connections. Their

[16] Regulation nbr.302 of the 11th of March 1999, concerning economical and technical reporting obligation, revenue cap for network operation and tariffs part V (NVE-1, 2010).

monopoly position as a system operator and central grid owner[17] makes strong regulation necessary.[18] This regulation is provided by the NVE.

Statnett's responsibility is to promote an efficient power market and to ensure the security of supply of the system. Security of supply is denoted as the power system's ability to deliver electricity to the end-users. It is dependent on reliable energy access, adequate power-capacity and influenced by long-term grid development, operation and framework. To do this they carry out long-term grid-development plans with several years' time-horizon, operation planning from a yearly to a weekly basis, market clearing and daily operation. The responsibility comprises the use of market-based measures to promote efficiency, security of supply and efficient communication between market participants.

Monitoring the power balance and conducting system-analysis to form the basis for prospective grid-development plans make the foundation for the long-term security of supply. The recent years have encompassed frequent records in electricity use. This increase has not been accompanied by corresponding increases in production- and infrastructural capacity. The cross-border connections, as well as the potential increase in renewable energy with little regulative ability, increase the pressure asymmetrically on the capacity. This brings on a gradually tightened long- and short-term power balance, inducing an increased danger of temporary pressed situations with capacity-shortage, revealing the importance of an improved balance clearing in the power market.

For daily operation planning, an important instrument is the establishment of el-spot areas. El-spot price areas are important tools for managing congestions[19], which will normally occur in a network like the Norwegian one. Recently the number of areas has been increased from three to five price zones, and a further number of pricing areas have been debated (Bye et al, 2010).

[17] Statnett owns approximately 90 percent of the central grid, aiming to own 100 percent. Mainly municipalities own the remaining 10 percent. (Statnett, 2010-9)

[18] The responsibility is regulated through the regulation of System operator in the power system; FOR 2002.05.07, nr 448. (Lovdata-FoS, 2010)

[19] Congestions accrue when the desired exchange energy exceeds the transmission limit in the network. FOR 2002.05.07, nr 448. (Lovdata-FoS, 2010) Congestions leads to a socio economic loss in the regard of exclusion of less expensive production that needs to be replaced by costly production or reduced consumption.

Statnett is also responsible to ensure satisfactory quality of supply, reflected in e.g. voltage and frequency. To maintain a satisfactory frequency in the system the power production and consumption in the power system must balance at all times. If production tends to exceed the momentary consumption, the observed frequency will rise above 50Hz[20], and vice versa. This has to be adjusted. By a comprehensive monitoring and automatic frequency regulation Statnett provides for the momentary balance in the power system, and thus a stable level of frequency. A change in production or consumption causes immediate reaction in the rotating mass in the power system, which subsequently causes the frequency to change and the frequency-controlled reserves are activated. This is called the primary balance regulation and is dependent on vacant effect in spinning reserves[21] (Statnett, 2010-6). Additionally, Statnett controls a secondary manual balancing instrument, which on a one-minute response-time may ensure spinning reserves in the quarter before a planned load-change in the power system.

The tertiary regulation is handled through the regulatory power market. It works as a common balance market within the Nordic power market to ensure sufficient reserves to maintain reliable running in the hour of operation. The participants in the regulatory power market announce the price for adjustments in their power production or consumption that the system operators can utilise to be able to handle faults and imbalances in the system (Statnett, 2010-6).

2.2.2 The Wholesale Power Trade

Wholesale trade maintains the balance between supply and demand. As such the power price reflects the balance between the availability and cost of power on one side, the need and willingness to pay on the other side. An increasing price signals that more power is needed to meet demand. It promotes increased power production and decreased power consumption.

Norwegian power trade has been based on competition after the deregulation in 1991. Prior to the deregulation, authorities held the responsibility of maintaining security of

[20] The frequency of the power system expresses the balance situation between consumption and demand at all times. If the set value for production is higher than the momentary consumption, then the frequency tend to be higher than 50Hz. If the set value for production is lower than the momentary consumption, then the frequency tend to be lower than 50Hz. 50Hz is the power line frequency of which alternating current (AC) is transmitted from the power plant to the end-user.

[21] Frequency controlled reserves is primarily delivered from production with spinning reserves, but big consumers may also participate in primary operation disturbance reserves (Statnett, 2010-6).

supply. The focus was then on ensuring enough capacity to cope with demand and to avoid shortages at all times, together with a tariff-coverage of investment risk. This led to a substantial overinvestment and lack of cost efficiency in the grid and the production capacity in the power sector (Bye and Hope, 2005). The deregulation was introduced to promote a more efficient utilisation of resources.

In 1996 Norway established a common power market with Sweden, and in recent years Norway has shared a common Nordic power market with Sweden, Denmark and Finland. Nord Pool is the market place for power trade within the Nordic power market, and is owned by the countries' respective system operating net companies.

Nord Pool El-Spot

The Common Nordic Market for power functions as a marketplace where power producers, power suppliers and large industrial clients trade power on the Nordic power Exchange Nord Pool. Nord Pool here lays the foundation for a well-functioning Nordic power market. While there is an increase in the number of bilateral financial contracts, the power traded bilaterally outside the power exchange is increasingly rare. The market price is determined in the interaction between supply and demand, where the power price clears the market. Increased demand in the total Nordic market will thus force up the prices. The power price from the power exchange thus also creates a reference price for other trade agreements.

Nord Pool's services comprise their core activities of trade and the clearing of physical and financial power contracts, and in addition trade and clearing of el-certificates and CO_2 emission quotas.

More specifically, the physical market is arranged with an auction held every day of the year on Nord Pool Spot. This determines the price for each of the upcoming 24 hours based on supply and demand. The market clearing-price balances supply and demand. Assuming a competitive market the producers' bid will reflect their marginal costs, and the consumers' bid their marginal willingness to pay. Thus for low levels of demand the producers able to produce at the lowest cost serve the market first. Then as consumption increases, the more expensive power is phased in. The last traded unit represents the market clearing-price. Thus the price varies and reflects the marginal running costs of consumption, production, transmission and limitation in the Nordic market. This induces an optimal utilisation of the resources and provides the Norwegian market with power at the lowest cost. This pricing system is called marginal pricing (Energy Norway, 2010).

The market demand and supply bids create a basis for the calculation of the system price, which does not account for congestions. This price is also the reference price for the financial market. The participants in this el-spot market are power producers, industry, power suppliers, distribution companies and powerbrokers. The participants are required to be physically connected to the central grid in the Nordic area and to have a balance agreement with the system operator in the area of traded electricity.

The financial market offers trade in futures and options for participants that want to hedge against future price fluctuations. This is now administered by NASDAQ OMX/Commodities that additionally functions as a clearing central where it acts as a counterparty and guarantor for contract execution. Their ability to do so results from the requirement of collateral furnished by the trade participants. Actors in the financial market are generically power producers, power suppliers or large industrial customers wanting to reduce price risk (Energy Norway, 2010).

The physical[22] and the financial[23] power market are tightly bound and highly dependent on each other to be well functioning to ensure an efficient power market.

The Regulatory Power Market

The market clearing for the up-coming twenty hours takes place at 12.00 every day, i.e. ahead of the actual hours of operation. With a clearing based on demand- and supply-side tenders of participants that possess imperfect information on the actual load in the operative hour, deviations will occur. The deviations are handled through the regulatory power market. If the customers withdraw less power in the hour of operation than the assumed amount in the day-ahead market, Statnett must balance by downward adjustment. Statnett may do this by paying a producer in the regulatory power market to decrease his power-input. Similarly in an unbalanced situation where consumers demand more power than the originally market clearing presumed, then Statnett must

[22] Represented by the spot market El-spot at the Nord Pool.
[23] Previously represented by the financial market El-termin at the Nord Pool, now by NASDAQ OMX/Commodities.

adjust upwards either by paying a large consumer to reduce consumption, or by paying a producer to launch input reserves (Statnett, 2010-6).

Price areas

It is of great political interest to provide a fair and non-area discriminating price for such an important commodity as electricity. However, in a far stretched country like Norway, with an impassable nature and scattered settlements, congestions[24] in the grid capacity are hard and costly to avoid. The Norwegian power system has a long history and the capacity has gradually been expanded concurrently with increased production and consumption. Customarily, industries have been established in close vicinity of power stations scattered across the country. The grid capacity is originally founded on this pattern, and still today there is not sufficient capacity for power to be produced and consumed in all possible locations. In fact, a capacity level that covers all needs may not even be socio economical efficient due to high investment costs (Statnett 2010-7).

Investments in network capacity are costly and are furthermore dependent on a long-term political and bureaucratic process. The system operator, pursuant to regulations on the system responsibility in the power systems, carries the responsibility of handling large and long-term congestions in the regional and central grid. In the daily operations instruments to handle immediate energy shortages and congestion problems are crucial. In the short run congestions in Norway are handled by the establishment of el-spot areas for long-term congestions, and internal trading (special regulation) for congestions within the price areas (Lovdata, 2010).

Until the 11th of January 2010 Norway was up split in three el spot areas. NO1, NO2 and NO3 represented respectively the south, mid- and northern part of Norway. On the 11th of January 2010 however Statnett considered it necessary to introduce a further price area by dividing NO1 into a new NO1 and NO2 in the light of congestion problems between the south western and the eastern part of Norway (Statnett, 2010-4). A further increase in the number of price areas followed merely two months later when Statnett on the 15th of March 2010 defined yet another price area comprising parts of Western Norway, due to the severe situation with low levels in the power basins (Statnett, 2010-5). This expansion reflects the current situation where increased utilisation of the

[24] Congestions arise when the desired transmission exceeds the transmission limit or figuratively speaking a formation of a queue in front of intersection in a system that is intolerant of queues (Bye, 2010).

capacity caused by increased production, consumption and cross-border capacity, has not been followed by a necessary complementary increase in domestic grid capacity.

Note also that the el-spot areas are market areas for area specified announcements of power trade on the Nord Pool Power Exchange for the upcoming twenty-four hours. Hence the market price of each area partly reflects the supply and demand in the specific area. However, Statnett sets the operative transmission capacities between the areas in advance, ahead of knowledge of consumption and production proportions and placement. The large price areas also entail a variety of congestions and capacity constraints within the areas. As such the area pricing models do not perfectly reflect the marginal value of power supply and a common area price thus partly provides misleading price signals.

Price equalisation across areas to meet the area specific price variations has been a long-term political attractive argument. In one respect, such price equalisation currently exists through the existing price areas.

Price Development

More than 60 percent of the total energy use for stationary purposes is covered by electricity. This is partly due to an abundant access to hydropower, which has historically been low priced relative to other energy carriers and to power prices in other nations. With the increase in cross-border power exchange this situation is changing, causing domestic prices to come closer to the prices of neighbouring nations (OED, 1998). Hence, the power price is increasingly being influenced by fuel costs of coal, gas, and oil[25] (OED, 2006).

Because electricity production in Northern Europe primarily is thermal based, fossil fuel taxes or similar measures causing increased production costs will increase the prices of electricity also in Norway. Different Norwegian instances have additionally proposed a raise in power price to allay domestic power consumption. The incitement for such special measures is partly to improve pricing of environmental issues and partly to reduce the Norwegian need for power import.

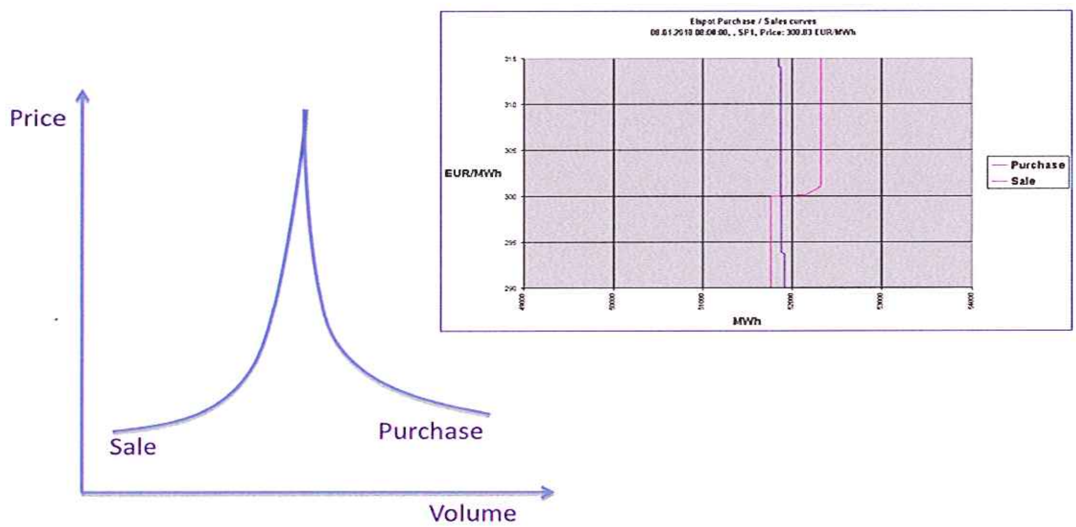
[25] As we become closer interconnected with adjacent power systems the price signals from continental fossil fuel based power generation will influence also the Nordic power market. Fuel cost in that regard refers to cost of coal, oil and gas.

Extraordinary price peaks during the winter of 2009/2010 revealed capacity concerns and caused Statnett to initiate an analysis of the market aspects of these particular situations (Statnett, 2010-9). Econ Pöyry gave an account of the power market situation supported by an analysis prepared by Nord Pool Spot. They found that several unfortunate factors were instrumental. A number of Nordic production units were idle, including a large part of the Swedish nuclear capacity. The cross-border transmission capacity was limited, both internally in and into the Nordic market. The temperatures were additionally very low and caused a Norwegian consumption record. Note that this consumption record happened in a period when the industry not yet had recovered from the financial crisis, implying that the consumption level was lower than in a period of economic expansion (Econ Pröyry, 2010).

When these factors caused prices to rise significantly, the demand side displayed little price sensitivity and caused the demand curve to be remarkably steep. Combined with a clearing price located near, almost on the production capacity limits and thus an equivalently steep supply curve, small variations in either consumption or production would cause large effects on prices, as shown in figure 2-9.

Figure 2-9

Simplified illustration of the steep curves in market clearing where small changes in consumption/production may have large influence on prices. Added is an example of a market clearing from the peak-hour 08.00 at the 8th of January 2010 (Nord Pool Spot).



2.2.3 The End-User Market

All household clients purchase their power from a power supplier that obtains a licence[26] to trade power (Energy Norway, 2010). The suppliers buy the power on behalf of their clients from the Nord Pool power exchange, or directly from a power producer.

Before 1991 power trade was highly regulated. When the energy law took effect, the trade was liberalised and the market instrument was introduced to improve the balance between supply and demand. The law differentiated between the grid as a natural monopoly and exposing the producers and retailers to competition in the market. It enabled third party access to the grid to ensure competition. This provided access to the market for new suppliers and rendered the possibilities for customer to change suppliers[27], as well as inducing variations in contract forms[28] (Energy Norway, 2010).

Generally, the customer relates to two different companies. The power supplier procures the power, but the local grid-owner provides the physical power into the building. These charge the customer separately, but may summarise the bill in the same invoice.

Composition of the End-User Price

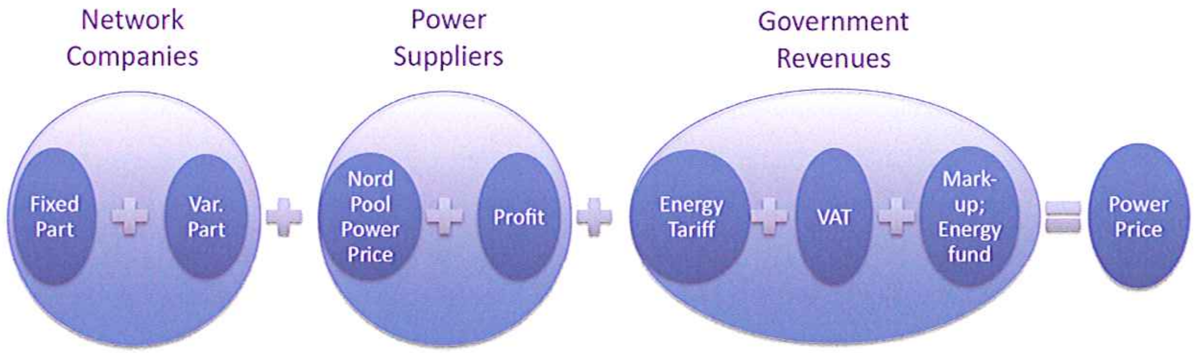
The power price is an important communication instrument between producers and consumers. By variations in price the producers and consumers of power are stimulated to adjustments that are necessary to maintain the power balance. When the price follows from a well functioning market, it will in principle ensure sufficient power in the grid, and that the power floats to where it is most needed.

The total payment by the end-user of electricity may be broken down into several parts. In figure 2-10 the different parts to be received by the network company, the power supplier, and governmental interests are illustrated.

[26] Norway has approximately 233 power suppliers with trading licences today (Energy Norway, 2010).
[27] Since 1997 more than 1.6 million changes of suppliers have been observed, and more than half of the 2.1 million Norwegian households have changed power supplier at least once (Energy Norway, 2010).
[28] While households in the early 1990's were parties to standard contracts, 30 percent of household-customers today are under spot-price contracts, while 10 percent are under fixed-price contracts (Energy Norway, 2010).

Figure 2-10

Power price broken down to parts and payment recipients.



The Network Companies

The network companies collect their network tariff consisting of a fixed and a consumption-dependent part. The network tariff designed to contribute to efficient use of resources on a short and long term. In addition the network tariff is meant to provide revenue to cover the costs of the network companies and the connection to potential regional networks and to the central grid. Because the power consumers are bound to their local network owner providing them with natural monopoly, their activities and revenues are regulated by the NVE.

The network tariff for households is constructed of a fixed part and an energy part. The fixed part is designed to cover the fixed costs of the network companies, and is detached from consumption. The network tariff further consists of a variable part, dependent on the use of power. It is to reflect the burden on the network inflicted by a connection point, which normally is the value of the marginal loss that follows from changes in transmitted amount of power. The marginal loss varies with the running network load. The change in loss may be positive or negative dependent of whether the change in input or withdrawal contributes to an increase or a decrease of the power losses in the network (NVE-2, 2010).

Out of the total network tariff, the central-grid tariff constitutes about 20 percent for regular consumers. The central-grid tariff has been characterised by large variations. Statnett has however decided to arrange for a more stable development of the network tariff through price equalisation across a four-year period.

The Governmental Revenues

Together with this compound network tariff, the network companies also holds the responsibility to collect the consumer tariff and the mark-up for the energy fund[29] from customers, with the exception of most power intensive industries and some municipalities in the northern part of Norway (OED, 2007). Like other commodity goods and services, power is also a subject to 25 percent VAT, with the exception of consumers living in the counties of Nordland, Troms and Finnmark[30] (OED, 2007).

The Power Suppliers

The power supplier charge their client for the power consumed pursuant to the spot price plus profit. For the end-user the payment for electricity is explicitly specified on the electricity bill or presented on a separate bill. The supplier is part of a competitive market where the clients easily can change contracts and contractors to ensure efficiency[31]. The price level and terms of agreement from different suppliers may vary. The suppliers either purchase the power on the Nord Pool Power Exchange, buy power directly from the producers, or they produce their own power. The suppliers invoice the quantity of consumption at a price per kWh that reflects their cost of power purchase and profit margin.

The consumers may choose between several alternative power contracts. Contracts directly based on the el-spot price follow the market clearing from Nord Pool Spot with a mark-up. The price that the consumer pays is based on the follows the development in

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[29] Enova, the energy fund, is established to promote a shift towards more environmental energy consumption and production. Enova is subordinated the Ministry of Petroleum and Energy and additionally funded through the national budget.

[30] An example of power price calculation, retrieved from the area of Trøndelag the 30th of November 2010; The power price from Nord Pool was 71.3øre/kWh, adding the company profit of 1.5øre/kWh and the VAT of 25 percent gives a power price of 91øre/kWh. Additionally adding a consumer tariff of 14øre/kWh (OED, 2007) and the network tariff of 30øre/kWh, both inclusive VAT, provides a price of 135øre/kWh. This price does not include the fixed part of the network tariff that is detached consumption, which at the time amounted to 2 300NOK per year. This power price was considerably high and caused by low temperatures inducing high consumption, combined with reduced power access caused by several nuclear power plants in the closely connected markets of Sweden and Sjælland being out of order. Further, the out-of-operation Kontek-cabel between Sjælland and Germany aggravate the situation and necessitating two power plants in Sweden to provide reserve power (Hauge, 2010).

[31] The number of households that changed supplier in the third quarter of the year 2010 was 45 400. This implies approximately 2.3 percent of the total number of households (NVE, 2010-5). A number the Consumer Council of Norway consider to be to low. A higher rate of supplier replacements would improve the dynamics of the market and induce decreased power prices (Øines, 2010).

the Nordic power market. The supplier purchase the power previous to the resale and thus the end-user carries the risk of price changes.

Standard variable contracts are also subject to price variations, but the suppliers must announce the price change 14 days ahead. This cause the price for the end-user lags behind the market price when it decreases or increases.

Over time statics show that standard variable power price exceed el-spot founded price with between 0.02 and 0.03 NOK/kWh (SSB-9, 2010), caused by dawdle in downward adjustments subsequent to reduced el-spot prices (Øines, 2010). Fixed price contracts are comparable to fixed interest rate in that the consumers are charged a given price in a given period of time with a risk premium and with that renounce the potential price fluctuations.

Households in 2010 have the following distribution of power price contracts with their suppliers, 4.2 percent on different fixed price contracts, 57.6 percent on contracts connected to the spot price, and remaining 38.2 percent on standard variable contracts (SSB-8, 2010).

The consumption data between the meter readings is based on an input-profile that is estimated utilising the average consumption profiles for all consumption without hourly measurements. It is this profile and not a reality-based, accurate profile that provides the basis of which a normal consumer is charged (ECON, 2007).

3 CURRENT STATUS OF DEMAND RESPONSE

Based on the assumption that there is a limit to what the customers' are willing to pay depending on use of electricity, a price exceeding this limit will result in a response in the customers' reducible load. This could be used as an expedient tool in situations of shortages and peak loads. To promote this desirable course of events SINTEF have specified three objectives with improvement potential (Grande et al. 2008):

- Increased demand side price elasticity. *In a customer friendly way motivate to flexible use of electricity in periods with shortage of energy and/or power.*
- Technology improvement. *Measure and document the changes in consumption and contribute to quality improvements and efficiency in the 'meter value chain'.*
- Demand response resources. *Provide input to and exchange experience with the international DRR[32]-project and to demonstrate Norwegian technology and market based solutions for demand response.*

In this chapter will try to map and assess the electricity consumption potential that is available for adjustments. Such dormant consumer flexibility can be a useful tool in maintaining the power balance.

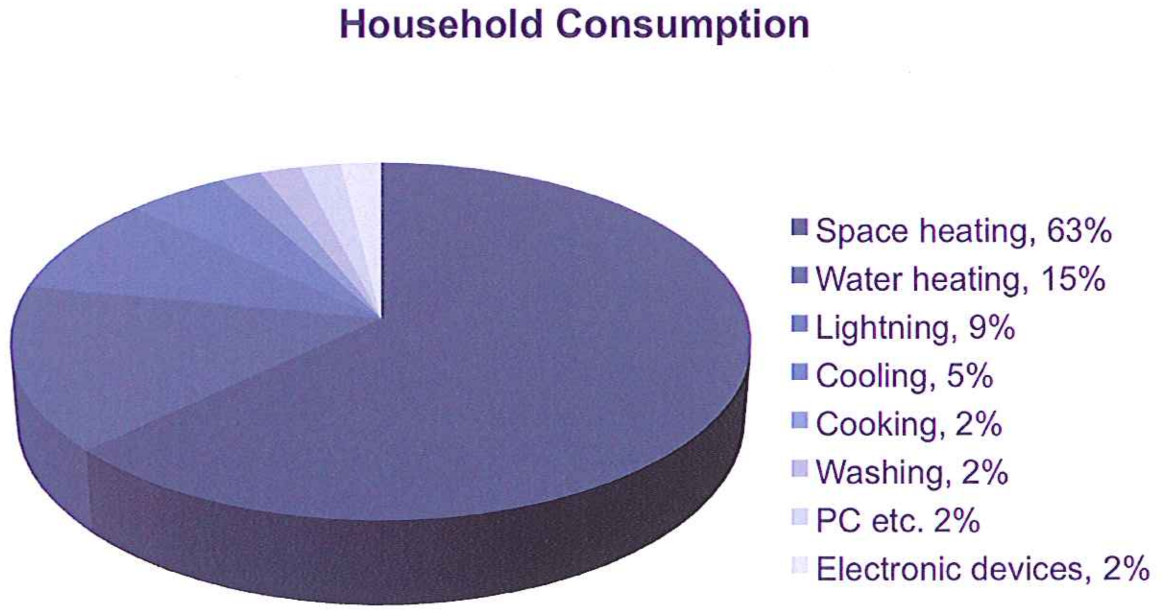
3.1 Low Prioritised Consumption

Norwegian households have a power consumption pattern that reflects the standard of living, the technological development and climate. Figure 3.1 shows that a significant share of 78 percent of the electricity consumption is used for space and water heating. A further share of 13 percent originates from the use of electrical devices, and lighting occupies around nine percent of electricity consumption (EU/REMODECE, 2010).

[32] Ongoing IEA/DSM project 'Demand Response Resources' (DRR, 2010).

Figure 3-1

Distribution of electricity-use in the households (EU/REMODECE, 2010).

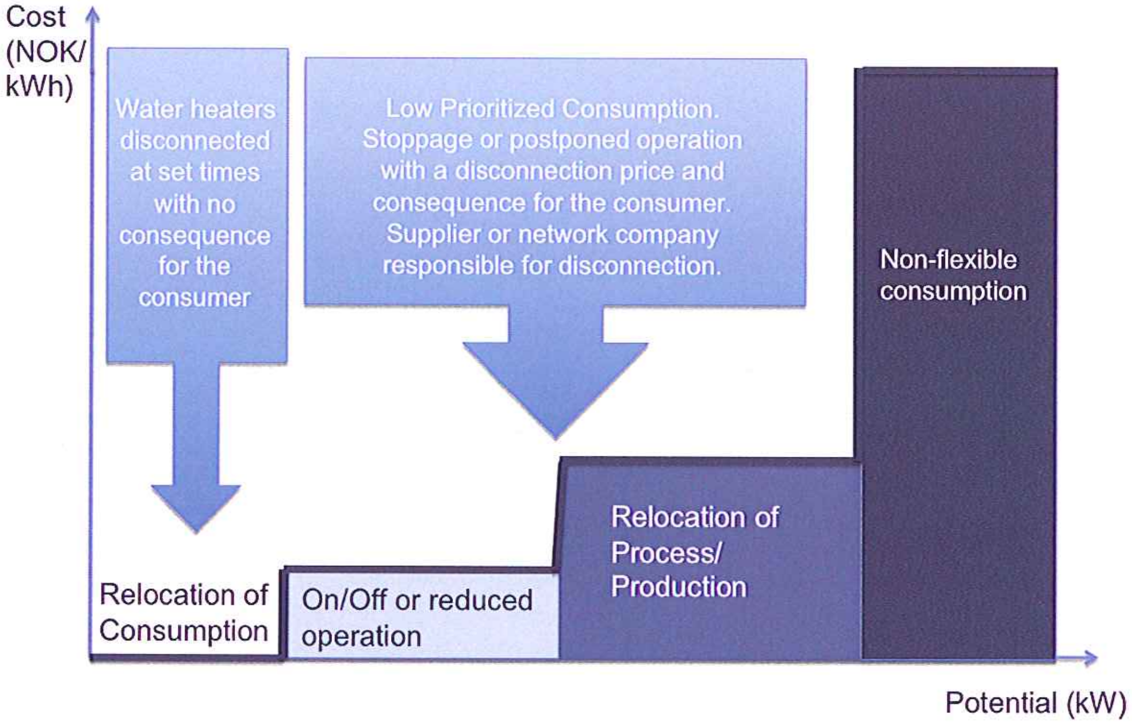


In assessing the benefits of a more price sensitive and flexible consumption it is important to distinguish between *power-economisation* and *energy-efficiency* improvement. While a reallocation of electricity consumption may lead to *power-economisation* through load shifting and load levelling, it may not necessarily involve energy saving. Replaced consumption as a result of saving-measures or substitution to other energy carriers will on the other hand cause a reduction in the overall electricity load. Improved *energy-efficiency* covers two concepts; *energy saving* means a decrease in energy use, and *energy efficiency* indicates a more efficient use of each energy unit (Løvås, 2010).

The degree of low prioritised consumption is a key number. Low prioritised consumption is defined as the share of the consumption that can be temporarily reduced, either by the hour, but in times of energy shortage and high power prices, also consumption that potentially can be disconnected for several days or weeks. An overview of the different degrees of flexibility in consumption is shown in figure 3.2. Activating the potential of the low prioritised consumption and increased flexibility in terms of load shifting as well as reduced consumption, has a socio economic value due to decreased need for new production and transmission capacity. In addition it has value in terms of improved short-term resource allocation. For the individual consumer, an important incentive is the desire to reduce electricity costs (Grande et. al. 2008).

Figure 3-2

Flexible Consumption (Grande et. al. 2008).



A report elaborated by SINTEF[33] identifies potential demand response objects suitable for load shifting in the peak hours. Some of the applicants' objective to heating purposes, like water heaters and other heating with storage, can be temporarily disconnected without any cost or discomfort for the customer. The loads associated to these disconnections are suitable for moving consumption from peak to off-peak periods (Grande, 2010).

Norwegian electrical heating of water, as apparent in figure 3-1, represents 15 percent of total power consumption. Previous research[34] on the temporarily reducible volume represented by household water heaters revealed that the average reduction potential was largest (0.6kWh/h) in the peak hour in the morning (see figure 3-3). This implies

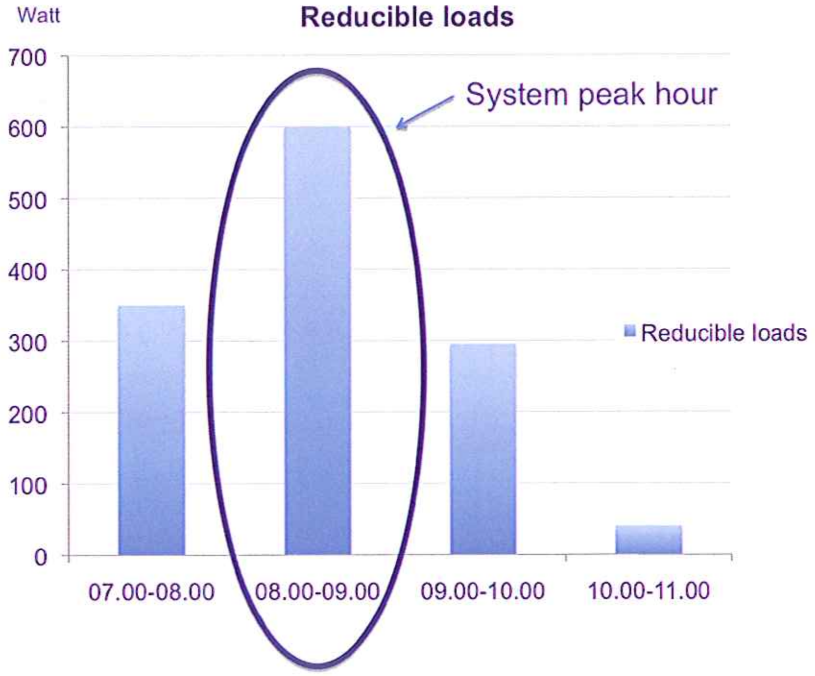
[33] Grande et al. 2008. Marked Based Demand Response Research Project. A report from 31st of December 2008 by Ove S. Grande, Hanne Sæle and Ingeborg Graabak, SINTEF, Norway.

[34] A large-scale project involving disconnection of water heaters for about 1250 customers (Grande et al. 2004). Consumer flexibility with efficient use of information and communication technology. Cost-Benefit assessments and recommendations. A report from July 2004 by Ove S. Grande and Ingeborg Graabak, SINTEF, Norway.

that with a 50 percent contribution from Norwegian households an aggregated load reduction of about 600MWh would occur[35]. In comparison, this capacity is higher than the output of the largest production unit in Norway. Nonetheless these reducible loads are scattered across the country relative to consumer settlements, providing a measure that can be specifically aimed to remedy local grid or production capacity constraints.

Figure 3-3

Demand Response Potential from water heaters in the morning hours (Grande et. al. 2008).



Other appliances that may be reallocated from peak load to periods of lower loads are tumble dryers, freezers, washing machines and dishwashers for households, and cooling- and ventilation for commercial customers. For example, a pilot performed by SINTEF using a combination of time-of-day tariffs, remote load control and an el-button[36], provided a significant load response in peak hours by including the avoidance

[35] Relative to the California crises in June 2000 where prices increased 10times historical level, rolling blackouts were instituted and several institutions went bankrupt, only a 300MW load reduction (of a total load of 50 000MW) for a few hours would have been sufficient to avoid the rolling blackouts (Hunt, 2002).

[36] A small, watch-like, magnetic token that can be placed on different power intensive appliances to remind the households to avoid usage in peak hours.

of energy intensive appliances such as washing machines and dishwashers (Grande et al. 2008).

Figure 3-4

Average Demand Response (Grande et. al. 2008).

	08.00-10.00	17.00-19.00
Customers with electrical waterborne space heating system	2.5-3 kWh/h	1.3 kWh/h
Customers with electrical water heater	1 kWh/h	0.5kWh/h

3.2 Price Elasticity of Demand

In a market, prices are important signals for altering consumption. In general the price elasticity of demand will vary in the short and long term. The price elasticity of demand for power is in general very low in the short-term. This is reflected in a steep and relatively inelastic demand curve. This means the demand response on a price increase depends on the consumers' ability to reduce unnecessary consumption or to substitute away from electricity. In the longer term the consumer may change the composition of capital goods to substitute away from the expensive energy carrier. Thus, in the long term the electricity demand is more elastic.

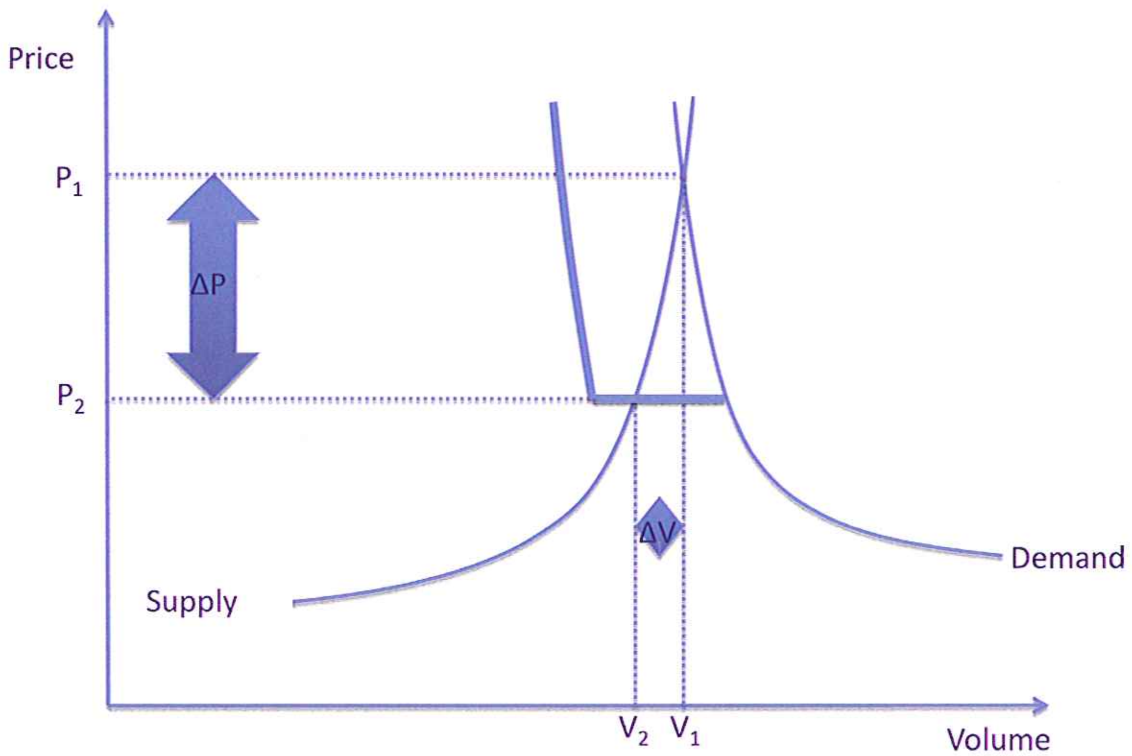
The price elasticity of demand may not be constant, but may vary along with the demand curve coherent with the price level. The demand for electricity normally is more and more inelastic as price increases, because further reductions are harder as the consumption is reduced to a minimum. When initial prices are high a price increase will provide lower demand response relative to a situation where initial prices were low. At high prices households will already have undertaken the most profitable measures, and thus possess a low potential for further reductions.

Peak situations comprise rapidly increasing prices and increasingly inelastic demand relative to prices. This causes a small change in either consumption or production to have great influence on price[37]. This is illustrated in figure 3-5. Here the increased

[37] In extreme situations following substantial price increases combined with increasingly inelastic demand for electricity, market clearing by prices might in principle be impossible and the market must take measures of rationing.

consumer flexibility may lead to an adjustment in demand (ΔV) at high price levels that contributes to lower prices (ΔP) in such situations.

Figure 3-5
Description of potential changes in electricity volume and price due to price elasticity in situations of peak-load (Grande, 2004).



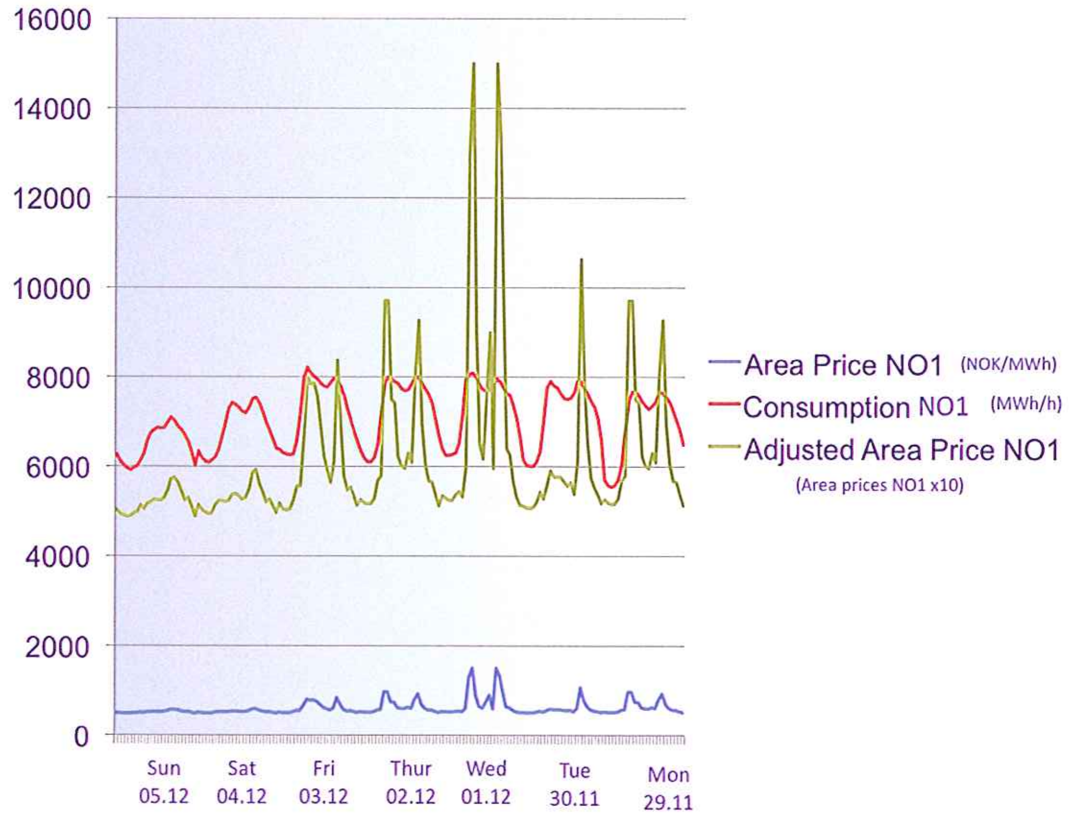
In general, the electricity price has less influence on consumption than normally presumed. As we see in figure 3-6 representing data from week 49 in 2010 from the area NO1, real-time consumption stays fairly stable with regular peaks. This is so even given the large variations in spot price. Even when prices rapidly increased on Wednesday, the consumers' response is insignificant; in fact there is a slight *increase* in real consumption relative to the day before and after[38]. This indicates a market where demand responds poorly to price changes. Note that this was the case even though in this specific week the power situation was given broad media coverage. Partly due to the cold weather and prospective high prices, and probably due to the presentation and

[38] The adjusted area price is only a supplement clarify the variations relative to consumption. Because the price is preset ahead of the hours of consumption and the consumption data is real-time consumption, the price increase is not a direct consequence of the slight increase in demand.

debate on a new research report[39] that elaborated on the price structures and organisation of the Norwegian power market.

Figure 3-6

Area prices and consumption related to el-price area NO1, Week 49, 2010 (Numbers retrieved from Nord Pool Spot and real-time consumption data from Statnett).



Nevertheless many consumers today seems to reduce their demand subsequent to the market clearing if it reveals a high spot price. This effect occurs even if the consumers are not directly compensated for it.[40] The effect is not always reflected in the demand estimates of Nor Pool, but is represented in a tendency of larger need for downward adjustments in the regulatory power market. It reveals consumer flexibility and significant potential demand side learning effects. An actual utilisation of this flexibility would promote the high el-spot prices to be lowered (Bye et al. 2010).

[39] (Bye et al. 2010)

[40] Even if the observations of demand-side upward adjustments (reduced power-withdrawal) may in main be caused by purchasers at the El-spot market e.g. large consumers and power suppliers, it is still an action of irrationality. If explained through expectance of high prices for downward adjustments they nevertheless exposed themselves for great risk. Other consumers are primarily charged by an average price and have likewise few incentives for such action (Bye et al, 2010).

3.3 Potential for increased Price Elasticity of Demand

Surveys impart that the two most important motivation factors for a more flexible use of electricity is the potential reduction in the electricity bill and the increasing environmental focus (Grande et. al, 2008). This implies that an accurate price signal provided to the customer, combined with communication on the environmental benefits of load levelling and reductions are likely to motivate consumption adjustments.

We have seen that even though the price is cleared for every hour of the day, it is the monthly average that is decisive for the price that consumers pay. Hence there is less incentive to react to price variations for the consumer, because the effort feels insignificant and may be freeloaded by other consumers.

For the demand response to be an efficient tool to maintain the power balance aligned with area specific capacity constraints, the area prices provided the consumers must accurately reflects the cost of power provision. The relatively large el-price areas with a common area price do not necessarily reflect costs in a satisfactory manner. An increased number of prices adjusted to constraints would potentially release a more efficient production and consumption pattern. Because an intentionally high price presented in the area of shortage would promote rationalised consumption and increased production. A constant price variation with increased price information would promote a more attentive demand.

The incentives for responding to prices are intangible. Information is covert and measures for improved energy saving and energy efficiency is not well communicated for the passive consumers. Many end-users are not informed that each hour is connected to a price and are insecure on how to act on price (Pedersen, 2008). Certain measures for energy saving in general such as subsidised installation of triplex glass, isolation and heat pumps are irregularly communicated through authorities. Nonetheless, electricity price has been deprived as an energy saving measure (Grande et al, 2006).

Most importantly the benefits of demand response is not directly benefited the consumer through savings on the bill. Thus demand response effort rather contributes to a Dutch treat where each reduced kWh contributing to a peak reduction or load levelling is spread throughout consumers. A consumer charged directly by real time consumption will have larger incentives for adjustments. Benefits from energy saving or investments in economic beneficial substitutes must nonetheless be clearly communicated.

However, note that actual response of reducing electricity consumption also depends on the ability to reduce consumption. A certain amount of the consumption is largely non-flexible, and primarily not subject to the reducible consumption. The low prioritised consumption however has a potential for temporary reduction, implying a potential for load shift and peak load reduction.

Nevertheless, Norwegian consumption also has a significant potential for energy saving, with a permanent reduction in energy use. The committee of energy-efficiency prepared a report issued in 2009 that revealed a potential for reduced energy use from 80 TWh in buildings today, to respectively 70 TWh in 2020, 55 TWh in 2030 and 40 TWh in 2040. Further they present a reduction potential of 20 percent in the industry and primary sectors towards 2020 (The energy-efficiency committee, 2009).

The energy saving potential for households is not yet sufficiently mapped, and is currently described through scattered statements and estimates. Further research on the subject is required.

One method to avoid consequences of high electricity prices is to substitute away from electricity to other energy carriers. Most potential substitutes are dependent on the characteristics of the equipment, and investments in such capital equipment presuppose long-term investment horizon. This reinforces the importance of price signals over time.

3.4 Required Technology for Demand Response

The underlying technology of the power system is of great complexity and imposing innovation. Opposed to the technological development within power production and electricity-based consumption, the transmission technology have barely benefited from renewal.

3.4.1 The Traditional Grid

The Norwegian Power system has a long history of grid development. Traditionally, industry was established close to power production sources and followed by settlement and thus consumption near the employment possibilities. Following this, transmission lines were built connecting different areas of the country. The resulting grid however still impose restrictions on the location of consumption and production (Statnett, 2010-4)[41].

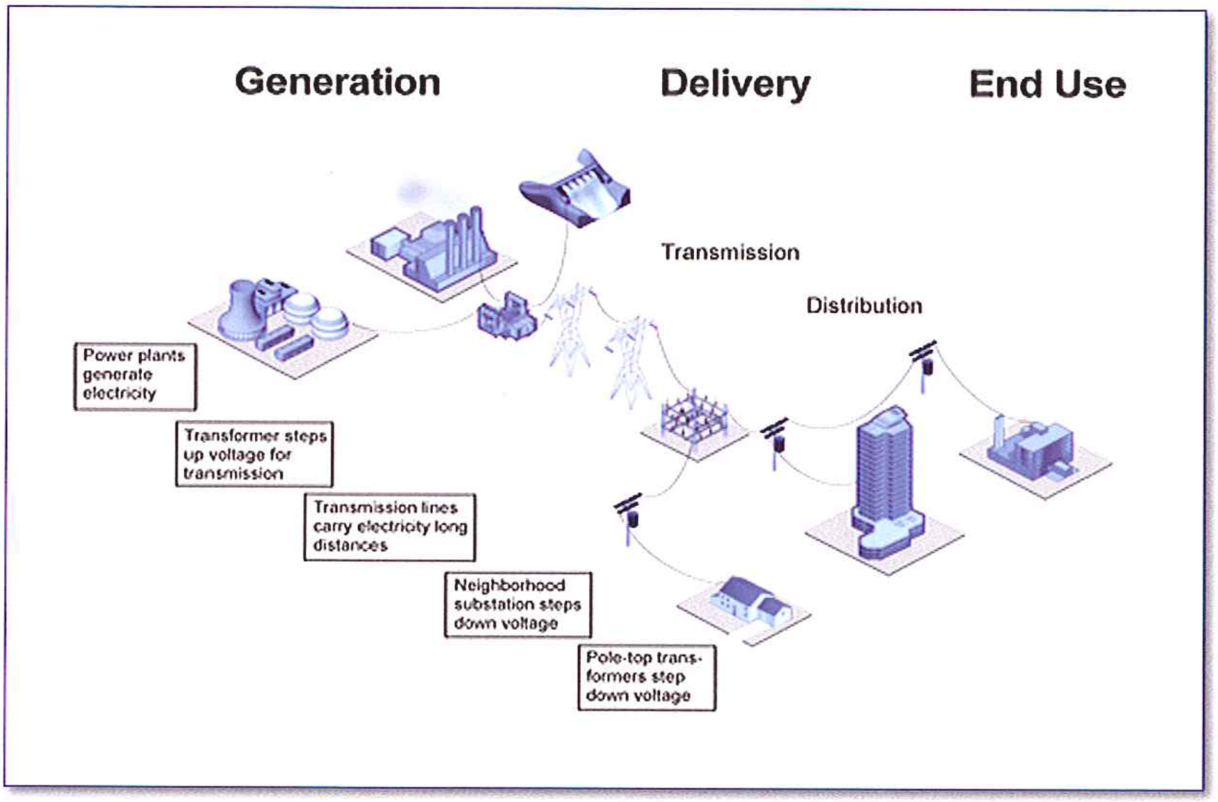
The Norwegian transmission grid consists of about 300 000 km of overhead lines, sea and earth cables. The grid can be divided into a central, a regional and a distribution network. The central network represents the arterial highway of power flow that binds the country's power veins together. The central network provides high voltage for long distance transmission with a voltage that generally varies from 300 to 420 kV, but in parts of the country transmission cables of 132 kV is also included. The regional and distribution networks provide voltage of respectively 132-45 kV and 22-0.23 kV dependent on distances (OED-grid, 2010).

The traditional structure of the power production, transmission, distribution and consumption is displayed in figure 3-7. In this simplified presentation power flows in one direction, and the interaction and information flow between the participants in the market is limited.

[41] Capacity to meet unlimited production/consumption at any location is however not desirable, because it would not be socio-economic beneficial (Statnett, 2010-4).

Figure 3-7

Traditional interaction between Power producer and consumer (Smart Grid, 2010-1).



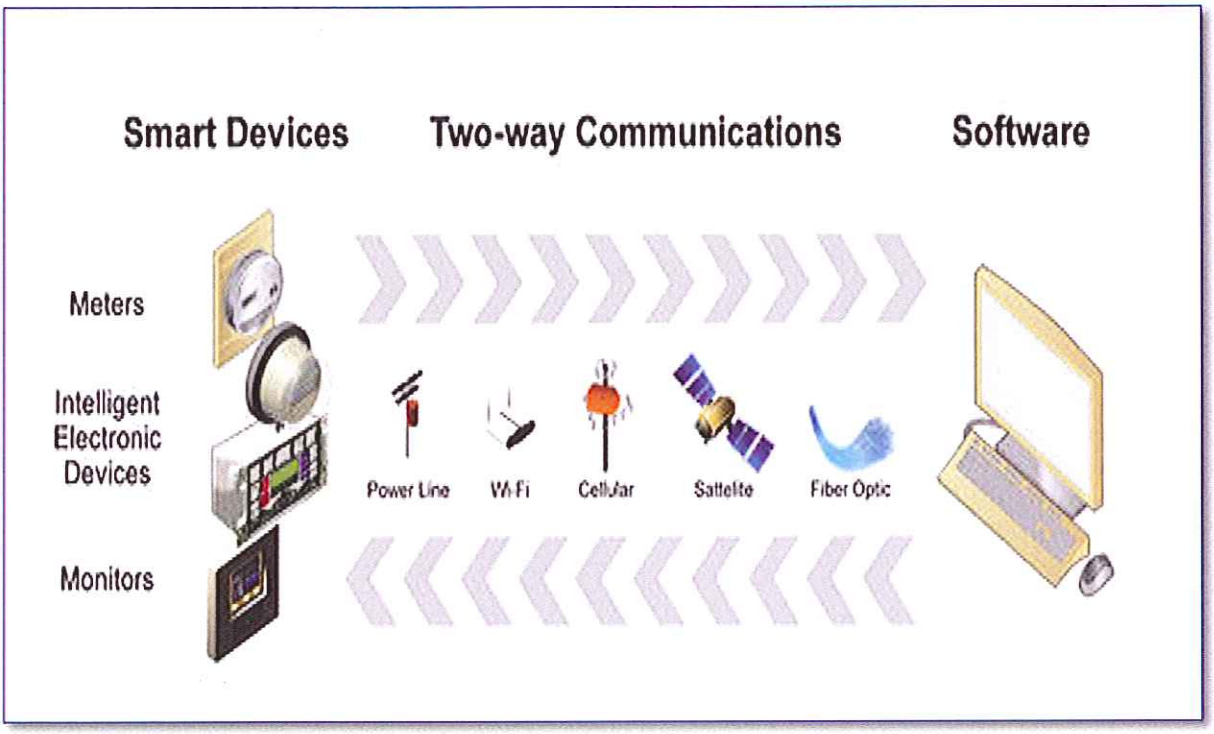
At all connection points to the grid there are meters for measuring the input/output of energy to/from the grid. For consumption measurements in Norway four out of ten power meters are old technology meters with a rotatable disk that measures the consumption. The consumers are normally meant to report their metered consumption on a monthly basis. Hence the consumer is charged based on the total amount consumed and a weighted average price for the period. Also note that the consumer has to recall the last metered consumption in order to calculate the amount used in the current period. Further more the total amount of the power consumption reveals little information on the consumption pattern within the period.

3.4.2 The Smart Grid and Advanced Metering Systems

The smart grid represents a further development in meters and communication. However the concept is not clearly defined and applied in a variety of different ways. But a certain consistency do exists. At a basic level, the smart grid is an electricity network that utilise digital technology, constituting a basic information technology foundation that will enable a widespread penetration of new technologies, not necessarily supported by the grid today (see figure 3-8). This may refer to cutting-edge advancements within transmission, distribution, electrical metering and storage technology. Additionally, increased communication is thought to improve products and customer service, as well as releasing increased flexibility, providing information and increasing efficiency.

Figure 3-8

Interaction between Power producer and consumer in a smart grid with two-way communication systems (Smart Grid, 2010-2).



Advanced Metering Infrastructure - AMI

Advanced Metering Infrastructure[42] comprises the concept of smart meters coupled with communication networks that allows for two-way communication between the meter and the power provider. This provides the consumer, power providers and other potential interests access to real-time consumption and creates a platform for dynamic pricing of electricity consumption. As opposed to charging the consumer with an average price for each unit of electricity time, dynamic prices reflect the cost of providing the consumer with power, normally with high prices in peak hours and lower prices in times off-peaks (Hedlik, 2009). Additional software that may be introduced

[42] Hereafter Advanced Metering Infrastructure will be denoted by the abbreviate AMI.

within the smart grid concept is programmable communicating thermostats and in-home information displays. These technologies are commercially available, and will increase the consumers' responsiveness and flexibility by providing information on consumption together with the concurrent prices. Future potential for the smart grid concept is the development of smart distribution networks, increased penetration of new generation and storage technologies, plus houses and plug-in hybrid electric vehicles (Hedlik, 2009).

Advanced Metering Systems – AMS

Smart Grid is a broad concept comprising all the new smart technology inventions in the electricity grid. AMI is the concept that comprises the technology innovations attached to the measurement technology and communication. This assessment will particularly evaluate the main fork within the AMI, namely the Advanced Metering Systems[43].

To ensure that responsive customers are awarded for their flexibility in periods of high prices, frequent metering is a necessity. AMS are electric meters that register the power consumption, but that are additionally equipped with communicating technology that is able to communicate power-related information to the consumer and the supplier, as well as provide bidirectional information exchange between the two. The AMS include an electric meter with information-display situated at the end-user, communicative technology between end-user and supplier, and a data collecting register with the power supplier. AMS applications may also be extended to areas of for example consumption measurement of additional commodities such as for instance gas, remote heating or water.

Important ingredients of the AMS are;

- *Information Display*

The information display is the key to availability and user friendliness. It provides an overview of the electricity consumption given in kWh per time unit and what it amounts to in expenses. The display further holds potential for additional communication of information related to e.g. device specific consumption, energy savings statistics,

[43] Hereafter Advanced Metering Systems will be denoted by the abbreviate AMS.

consumption related carbon emissions and consumption statistics, of own consumption also relative to the average user (SINTEF, 2010). The customer can optionally adjust the settings, determine price ceilings for disconnection of certain consumption, and in addition preset disconnection levels relative to temperature and time. The indoor localisation of the display combined with user-optimised user interface will preferably provide easy information access and increased potential for responsiveness.

- *Two-way Communication Technology*

For the traditional meter the power supplier has at most received unidirectional information on power consumption. Two-way communication exists when the power supplier both can receive signals such as information on metered consumption, as well as send signals to the end-user for instance to provide load control (NVE, 2004).

The hourly measurements can be stored locally or in a concentrator[44] before being sent to the data collecting register. The communication may be effected through different technologies; for example the electrical network (high- and low-voltage), GSM[45], GPRS[46], SMS radio[47] or via fixed connection (telephone line or broadband).

- *Data Observation frequency*

Electric metering information collected on the traditional monthly basis gives the customers little incentives for changing their consumption pattern. Dynamic time-varying prices do in contrast to a higher degree reflect the marginal cost based on the load-condition in real-time. When real-time consumption is coordinated with the real-time marginal price, the invoice do to a larger extend reflect the true costs of providing electricity. Because price responsiveness is partly motivated by compensation, a more accurate invoicing based on real-time consumption and hourly prices will thus provide greater incentives for consumption reallocation and reductions.

[44] A concentrator can be used as an intermediate data storage capacity in localizations where the electric metering points are closely localized, e.g. in an apartment building.

[45] GSM is the acronym for Global System for Mobil communications, and it is the most widely used standard for mobile telephony in the world.

[46] GPRS is the acronym for General Packet Radio Service, and it is a packet oriented mobile data service on the 2G and 3G cellular communication systems GSM (global system for mobile communications).

[47] SMS acronym for Short Message Service, and is the text communication service component of phone, web or mobile communication systems, using standardized communications protocols that allow the exchange of short text messages between fixed line or mobile phone devices.

This provides thus the necessary basis for higher short-term flexibility. In principle, hourly measurements pricing may be replaced by a 15 minutes frequency of prices and metering. However, the benefits of this further refinement must be balanced against higher costs of operation and implementation.

Surveys indicate that most customers do not manually pay attention to hourly market prices (Grande et al. 2008). Hence, the quality of the overall response is also dependent on the use of automatic load control schemes relating to predefined time of day and/or prices.

- *The Response functions*

Local load-management indicates the end-users have possibilities to manage and program own electricity load. Centrally managed load is achieved through remote disconnections and adjustments preformed by central units like network companies, power suppliers, energy consultants etc[48].

AMS still offer a substantial potential of demand flexibility and energy saving. Note that this can be released without relying on direct consumer attention and interference. The local load management is possible with specific devices in households and buildings with predefined limits on price-level, temperature or time and may release a disconnection or scale-down on low prioritised consumption[49]. Central load management can for example be temporary disconnections of water heaters with no inconvenience for the consumer represent potential for peak load reductions and reallocation of consumption. This is rendered possible through remotely controllable devices that are made available for disconnection. Low prioritised consumption as such represents both an energy saving potential as well as a potential for reallocated load (Grande et al. 2008).

[48] Remote load control also simplifies the process of inauguration and close-offs.
[49] Usually performed through a power relay or thermostat.

3.5 AMS – Status report

The implementation of AMS in Norway today represents an issue of great political interest. While the opposition calls for an answer to why the process is subject to delays, the government awaits the final resolution from the NVE, who is negotiating with power suppliers and awaiting a European standardisation process.

3.5.1 Status for European Roll-Out and Standardisation Process

Many nations have already implemented AMS on a large scale. Because we are closely interconnected to the European power market interoperability this is in many ways advantageous.

Italy and Sweden have fronted the AMS implementation in Europe. By 2006, Italy had provided virtually all consumers with AMS. Sweden is gradually providing its consumers with new meters and was the first legislator in Europe to mandate AMS. The remaining Nordic countries, the Netherlands, Portugal and Austria appear to follow. Furthermore, the EU commission has appointed a committee to prepare standards for an extensive European AMS diffusion, to ensure cross-boarder interoperability and sharing of knowledge.

M/441 – European Standardisation

Two thirds of the European objectives of 20-20-20[50] in 2020 are directly connected to energy use: A 20 percent increase in renewable energy, a 20 percent increase in energy efficiency and 20 percent reduction in CO_2 emissions. The latter aspect is closely related to energy due to the large share of fossil fuel based energy generation on the continent (EU, 2007). In the light of these objectives, the European Union has proclaimed a mandate; *'Mandate for standardisation to CEN[51], Cenelec[52] and ETSI[53] in the field of measuring instruments for the development of an open architecture for utility meters*

[50] 20-20-20 in 2020 is a catch phrase that represents the demanding climate and energy targets to be met by 2020 prepared by the EU Heads of State and Government. These objectives comprise; a reduction in EU greenhouse gas emissions of at least 20% below 1990 levels. 20% of EU energy consumption is to come from renewable resources. 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency (ECCA, 2010).

[51] CEN is the European Committee for standardization (CEN, 2010).

[52] Cenelec is the European Committee for Electro-technical Standardization (Cenelec, 2010).

[53] ETSI is the European Communications Technology Standards Organisation (ETSI, 2010).

involving communication protocols enabling interoperability' The mandate was to meet the lack of open standards that are capable of guaranteeing interoperability between different systems and devices (NTE, 2010). The intention is to open up the metering market, enable demand response, provide data security, and to promote industries within the EU to attain world leadership in metering technologies.

The process is split in two phases. The primary phase on the communication standard was presented in December 2010. The secondary phase concerning auxiliary functions is in progress and expected to be presented at the turn of the year 2011/2012 (NTE, 2010).

Even though the final prescript is yet to be presented, the minimum functional requirements are already available:

- Remote reading of metrological registers and provision to designated market organisations
- Two-way communication between the metering system and designated market organisations
- Meter supporting advanced tariff- and payment systems
- Meter allowing remote disablement and enablement of supply
- Communicating with (and where appropriate directly controlling) individual devices within home/building
- Meter providing information via portal/gateway to an in-home/building display or auxiliary equipment

In addition to the M/441- European Standardisation, the Open Meter project initiated by some of the largest network companies and technology suppliers in the European market also has important influence on the Norwegian requirements decision (NVE, 2010-4).

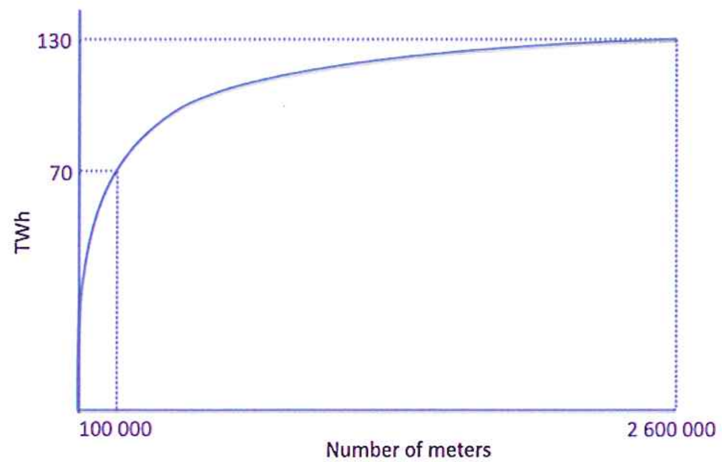
3.5.2 *Status for Norwegian Roll-out*

The Norwegian electricity market consists of about 2.6 million electric meters. In 2005 the Ministry of Petroleum and Energy required[54] the installation of equipment for hourly measurement for all monitoring points with an expected electricity consumption above 100 000 kWh per year. This represents approximately four percent of all electric meters, but accounts for as much as 60 percent (approx. 70TWh) of the Norwegian power consumption due to the size of the consumers (NVE 2006-2). Many of the minor consumers in this category are however not bound to contracts that reflect the short-term variation in the el-spot price (Ericson, 2007). In the last quarter of 2010 barely six percent of the power consumption related to power intensive and wood processing industries were based on contracts connected to the el-spot price (SSB-6, 2010). The corresponding share in the remaining industries was 32.6 percent (SSB-7, 2010). These industries hold an approximate share of between 40 and 50 percent of the total Norwegian electricity consumption (see figure 2-6)

The remaining 2.5 million electric meters are not covered by such requirement, and are thus many, but cover a minor part of the consumption relative to those who are subject to these requirements, as illustrated in figure 3-9. As a consequence a replacement of the remaining meters will have relatively greater costs because of the multitude and relatively diluted benefits caused by the low consumption per meter (ECON, 2007).

Figure 3-9

Illustration of the relationship between number of meters and TWh (ECON 2007).



[54] The bill of hourly measurement was proposed to further comprise yearly consumption of above 100 000KWh was promoted by the Ministry of Petroleum and Energy and valid from 1st of January 2005 (OED, 2003).

For the segment of below 100,000kWh yearly consumption, today's investment rate in advanced meters is inconsiderable. The prospect of an unprovoked, natural replacement of existing meter technology may be time consuming (ECON, 2007).

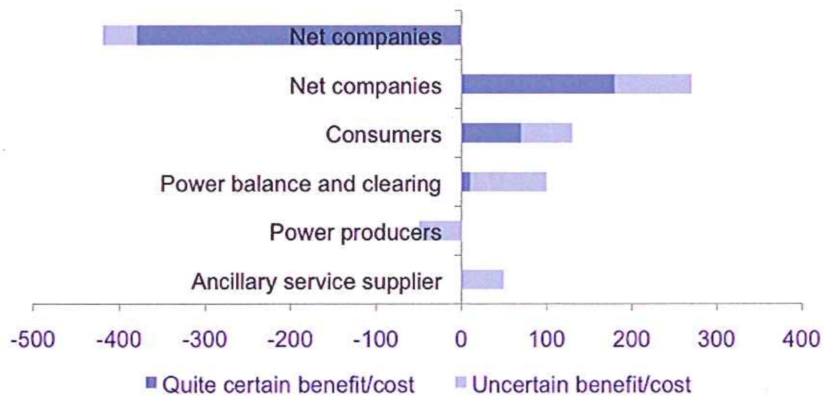
Costs and Benefits of AMS in Norway

The Ministry of Petroleum and Energy presented the question of an AMS enrolment process in 2004. NVE initiated a follow-up ECON cost-benefit report in May 2007.

The report revealed that the AMS offers high potential benefits for the net companies, but even higher net costs. This lack of net positive benefit for the net companies gives them low incentives to implement AMS (See figure 3-10). Experiences from pilots conducted by the NVE/EBL[55] also indicate negative net benefit for network companies (Grande, 2004).

Figure 3-10

Distributional effects between market actors caused by an implementation of new process measuring and control technology (ECON 2007).



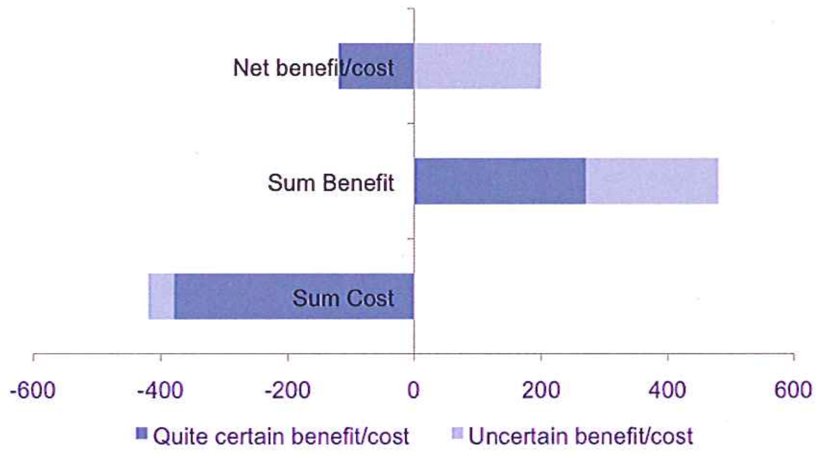
In figure 3-11 the results of the ECON reports are illustrated. The quantified benefits are prospected to be negative. However, the uncertainty related to both benefits and costs are large. These are due to uncertainties in the quantifications or lack of quantification methods of certain effects. The ECON report concludes that due to the unquantifiable, but likely benefits, the upside of positive socioeconomic benefits for society are likely to be larger than the potential downside of costs. Positive benefits arise from amongst

[55] EBL is the acronym for the national association for the energy companies in Norway.

other benefits increased price elasticity, improved load control, improved management and quality of measurement data, reduced net losses of approximately 10 percent, environmental benefits and increased consumer flexibility (Grande, 2004). Compared to thermal based power systems with lower flexibility and higher cost related to peak loads, the benefits of an AMS implementation in Norway would inevitably be relatively lower.

Figure 3-11

Depiction of the net benefit for society (ECON 2007).



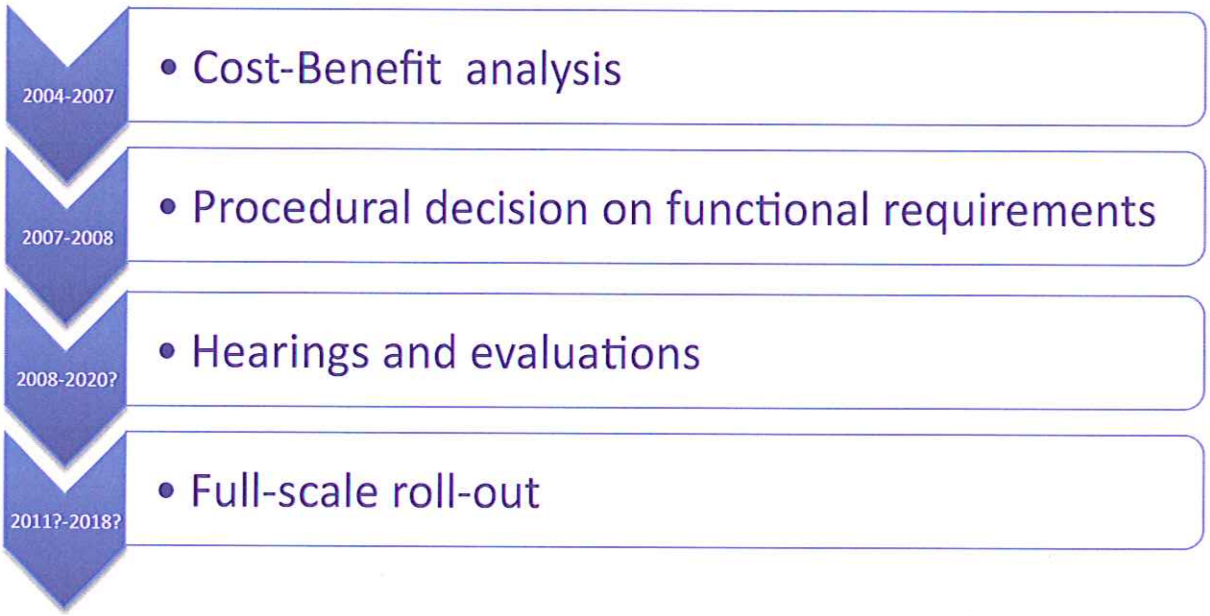
While the implementation of AMS could have followed the natural replacement of outdated technology, ECON (2007) recommended expediting the enrolment. To ensure process acceleration they suggested two means, either by generating incentives in the income regulation or by setting a final date of implementation. In this latter alternative was recommended. It was argued that such gentle pace of development would ensure benefits from exchange of experiences and avoid pressure on the suppliers of AMS technology and installation services.

This caused the NVE to actuate the AMS process. Subsequent studies and reports followed elaborating experiences abroad and potential functionality requirements. The reports, in addition to a constant discussion with net companies, the supplier industry, interest organisations, and governmental interest, resulted in several consultative proposals from NVE with subsequent consulting rounds concerning decision feedback and functionality proposals (NVE, 2010-4).

To effectuate the process of enrolment NVE must decide upon future regulations. The summary presented on the statements proposed at the last hearing an adjournment motion to comply with the EU-commissions standardisation mandate[56], thus causing a delay compared to the initial time horizon of the full-scale implementation. The postponement prepositions the net companies to meet the opportunities that result from the standardisation mandate. This is thought to promote competition and entry of new suppliers, and hence enable the net companies and consumers to choose the best and most cost-effective solutions customised to their needs. Furthermore, a postponement is considered to contribute to realising additional useful capacity in the AMS technology. The events has resulted in the prospected development phase illustrated in figure 3-12.

Figure 3-12

Towards a full-scale development of AMS in Norway (NVE 2010-1).



Expectations as to Norwegian Regulation on AMS

The process of implementing AMS in Norway is not yet settled and done with. Important decisions still waits, and the enrolment pace is still uncertain and characterised by constant changes. Current indications however points to several aspects of future AMS development in Norway.

[56] M/441 – Standardization process of the AMS technology in the European Union.

- *Governmental Mandate*

The skewed distribution of estimated costs and assumed potential benefit of an AMS implementation, indicates that AMS leaves network companies with a net cost and lack of profitability, and society with net potential benefits. This provides little direct incentives for the net companies to accelerate the replacement of existing meters (ECON, 2007).

Following this, a future implementation of AMS will probably require a governmental mandate. It is expected that the regulatory authority of NVE will present a proposal mandate for the Norwegian power system following the release of the primary part of the standardisation mandate[57] from the European Union (NVE, 2010-4).

- *Allocation of responsibilities and costs*

Different participants in the power market may have a disparate understanding of what needs to be subject to regulation, and what should be dedicated to the market to regulate. The answer here is not obvious. A superior criterion on which to base the measures and the regulations on, are the basic objectives of energy market regulation (Lovdata, 2010-2). For projects where the network companies hold incentives to make good decisions in accordance with the energy regulation's intensions, regulation is less needed. Regulatory measures are especially important in situations where the projects hold great socio economic value, but are considered to hold little business profitability for network companies.

It is to be assumed that the costs[58] and responsibility of installation probably will be assigned the network companies, however accompanied by a change in the income regulation with an increase in the income cap. Eventually part of the investment cost will be charged the consumer with a mark-up on the network tariff (Hafslund, 2010).

As such the network companies will in the last instance carry the potential risk of an AMS implementation, but it is the responsibility of NVE in virtue of their regulatory power to reduce this risk to the greatest extent. Hence, a central part of NVE's function is to clarify what framework the investment is to be developed within (NVE, 2010-4).

[57] M/441 – Standardization process of the AMS technology in the European Union.

[58] The estimated cost on a national basis for an AMS implementation including equipment, installation, system costs and communication costs is approximately 5 billion NOK, or 2000-2500 NOK per metering point (Hafslund, 2010).

Further it is the responsibility of the NVE to arrange for the network companies to act neutral and non-discriminating. This is important also to in the implementation and utilisation of AMS (Lovdata, 2010-2).

- *Requirements*

The final NVE regulation on AMS is expected within the first half of 2011. Some requirements are however already clear. The requirements for time resolution are 60 minutes, with an additional possibility of down to 15 minutes. Installed equipment must enable on-demand meter reading and data collection from each individual consumer. Additionally, it is required that the AMS-equipment can be connected to external devices through standardised interfaces.

Note that standardisation requirements are important tools to ensure interoperability and communication between devices from different suppliers. Such requirements will induce increased competition between suppliers and lower cost on AMS-equipment. Moreover, the standardisation and open solutions also contributes to risk-reduction for the network companies in their long-term investment decision in AMS-equipment (NVE, 2010-4). It is assumed that the standardisation requirements to the greatest extent possible will be harmonious with the European standardisation. To prevent discrepancy it is assumed that the standard requirements from the NVE will over-comply those intimated by the M/441-mandate.

- *Final date of enrolment*

NVE emphasises the increased efficiency in market and technology development enabled by awaiting the M/441 Standardization Mandate. For the network companies this will reduce the investment risk of an AMS implementation. It is expected that NVE at least will await the decision on the primary part of the European mandate, though the outcome from the secondary part of the mandate process still is uncertain. However, neither the information from other ongoing process nor the fact that many countries have started the AMS implementation processes already, seem to indicate additive functionality requirements that are not commercially available or compatible with existing equipment. So if premises stay unaltered, NVE will propose an administrative regulation in accordance with the primary part of M/441 in the first six months of 2011 (NVE, 2010-4).

It is preferable that network owners in Norway benefit from and participate in the potential technology development that accompanies the European mandate, and that they additionally are provided an adequate time-horizon to adjust to the secondary part of the M/441. NVE estimates that an adequate enrolment period is six years, whereof the last period is necessary simply to gain strenuous access to remaining consumers, vacation residences and remote cabins. Given a regulative decision in the first six months of 2011, then the enrolment is expected to be completed by 1st of January 2018 (NVE, 2010-4).

However, a recent report (Bye et al. 2010), initiated by the Ministry of Petroleum indicates that the implementation of AMS in areas with severe capacity constraints, should be done earlier. They argue that the benefits of exploiting the consumer flexibility in these areas might exceed the cost of implementing non-standard and more advanced meters.

4 UNDERLYING DRIVERS

The implementation process of AMS is driven by a medley of different motives and driving forces. Since it is not directly motivated in corporate profitability for the network companies, the development process is also influenced by political considerations. Some of the main factors driving the need for AMS are the following;

4.1 Renewal of outdated technology

Eventually, all meters irrespective of technology will require replacement investments. This also refers to the 2.5 million meters without hourly measurements requirements today. Many of these are also based on an outdated technology such as rotatable disks. These meters have originally represented a cost efficient method for estimating the electricity consumption of smaller end-users for the power suppliers. However many of these meters today provide inaccurate and false measurements (Hafslund, 2010), as well as giving the consumers the possibility of stating incorrect consumption metering.

The continuous need for reinvestment in meters will thus eventually cause advanced meters to replace old technology, also for small consumers and households, even if not expedited by a mandate with a time limit of implementation. However, to speed up the implementation and to influence the installed functionalities, a mandate is useful.

4.2 Improvement of the Power Balance

In the recent years Norway has been facing a tighter power balance. This is due to many factors. Investments in transmission and production capacity have not followed in the same pace, while there has been a rapid increase in consumption. This tighter power balance may also be met by developments in infrastructure that increase demand side flexibility. Ericson (2007) impart that even a small increase in price response may contribute to a more well-functioning market by increasing efficiency, reducing price volatility, mitigating the exercise of market power and contributing to a more reliable power supply (Ericson, 2007).

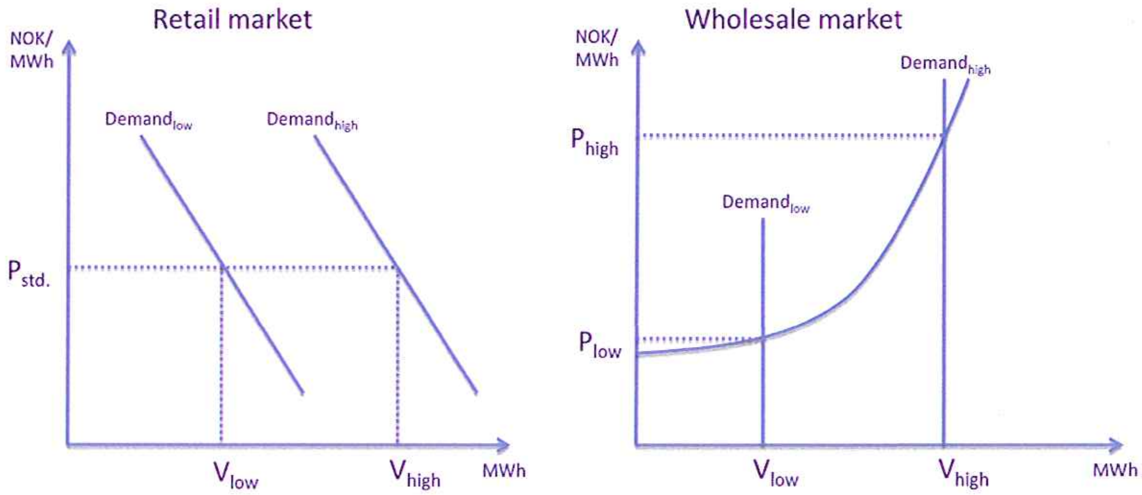
As an instrument of balance, demand response and increased consumer flexibility is also argued to be efficient for achieving an improved load control. A study conducted by SINTEF implies that time-differentiated tariffs will provide an incentive for the consumer to act upon price changes, and this induce a potential for load balancing through price signals which in turn reflect capacity constraints. Likewise a pilot on remote load control of residential water heaters indicates that direct load control may be a helpful contribution to necessary peak load reductions (Grande et. al, 2008). Automatic load control imposed by timers, and thermostats that respond to preset hours, temperature levels or price levels, may furthermore be instrumental as they do not require a continual response by consumers. Because price induced demand response represents an unaccustomed adjustment for the consumer, good and emphatic information and guidance is important for sufficient approval and action (Grande et al.2008).

4.3 Price Efficiency

Today Norwegian electricity consumers are predominantly charged by their accumulated consumption, while their power suppliers purchase power based on hourly market clearing. This represents a disconnection between the wholesale market in which the power supplier buys power, and the retail market in which consumers purchase their power, as shown in figure 4-1 (Ericson, 2007).

Figure 4-1

An illustration of the disconnection between the retail market and the wholesale market.



The left graph illustrates the households' demand in respectively low and high consumption periods over a period of twenty-four hours. The $P_{std.}$ resembles the price of a standard variable contract that is fixed in a short term. The two elastic demand curves indicate that consumers in fact are price sensitive, but are not provided incentives for responsiveness and hence to adjust to the fixed price. The power suppliers however, must serve the consumers' demand by bidding an inelastic demand in the el-spot market on behalf of their consumers, represented in the right graph.

In many respects, the market prices do not reflect the available information in the market; the price signals provided to the consumer do not reflect the rapidly changing costs of electricity and on a short-term basis, and the consumers' willingness-to-pay for electricity is not reflected in the market. As a consequence, this disconnection contributes to neglecting the possibilities for increased efficiency in market performance, and does not release the full potential of flexibility in the end-user market. In this sense the price efficiency of the market may be improved.

To some extent price efficiency may be enhanced even without advanced metering systems. This would be the case in an ordinary invoicing system with an increased rate of reported metered consumption. There are however severe limitations as to how often consumers can manually report their meter status.

However since only the accumulated consumption is measured, households are consequently charged with prices that are fixed for a shorter period of time, and do not reflect the running marginal cost of supply. A time-differentiated price, however, may induce demand response by providing incentives for the consumer to constantly adjust their demand to the varying prices. The absence of such demand-regulating prices directly obstructs the consumers' ability to provide a counterbalance to capacity constraints. Furthermore an automatic price adjusted to demand would constitute a valuable tool in balancing the power market. This flexibility has yet to be utilised (Ericson, 2007).

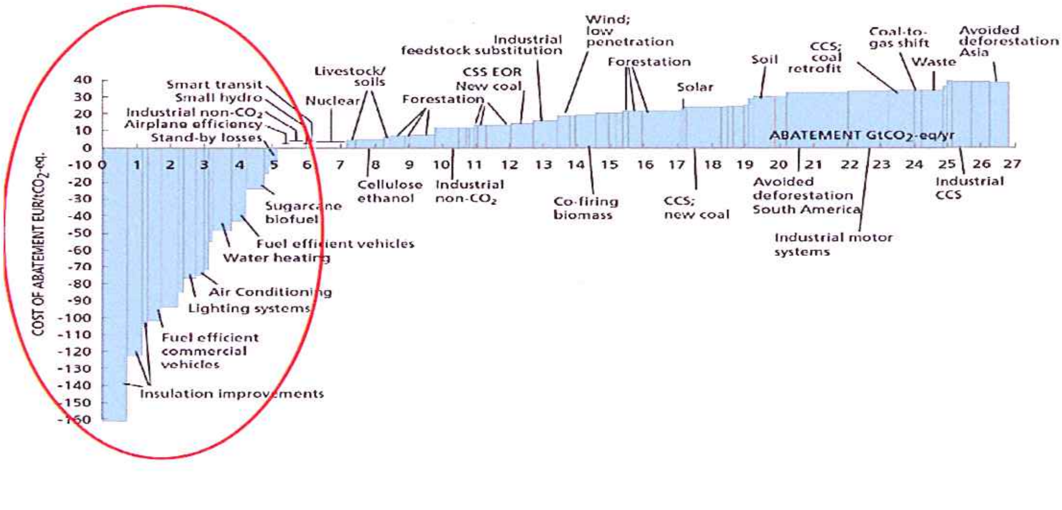
4.4 Consumers Requirements

Consumers have in general become increasingly conscious in their consumption choices, for example as to the products' origin, content and quality. For electricity, they may in the future expect to pay for the exact product and quantity they consume, so that consumption that is charged upon an estimate is not sufficient (ECON, 2007). Automatic measurement of individual consumption represents a natural and sensible modernisation of the Norwegian end-user market and hence, a beneficial effect for society.

4.5 Environmental objectives

Norway has committed to several binding contracts to acheive international objectives on environmental performance. As such, Norway is obliged to improve environmental behaviour. Certain measures and actions strongly related to the full-scale implementation of AMS will induce environmental benefits for example reduced greenhouse gas emissions. Most of these are related to improved energy efficiency in buildings (See figure 3-2).

Figure 3-2
Expenses for different environmental measures (SINTEF, 2010).



The measures related to energy efficiency in buildings are the less expensive and quite profitable in a socio economic sense. Incentives for consumers to undertake the necessary expenses may however still be substantial. Note that an array of different measures and technologies are necessary to meet the environmental objectives. (SINTEF, 2010).

The dormant consumer flexibility of the power system also represents a potential for replacing some of the regulation power utilised by the system operator to balance the load. Norwegian hydropower can then be released to offer balancing capacity to other power systems dominated by intermittent wind power or less environmentally friendly thermal power generation and spinning reserves (Grande, 2010).

By awakening households to their own consumption and relate this consumption to environmental consequences, it is assumed that consumers will try to achieve a more efficient energy consumption (SINTEF, 2010). In fact on increasing environmental focus was disclosed as one of the main motives for more flexible energy consumption (Grande et.al, 2008).

Direct environmental signals can also be provided through the in-house display, for example in showing achieved savings, further saving potentials and the environmental value of energy saving. These signals may be expressed in different ways such as the resulting reduced amount of CO_2 emissions, price signals, alternative power products and detailed information on time, general load and power consumption connected to certain devices. SINTEF also introduces the term NegaWatt referring to the potential and value of unused consumption (SINTEF, 2010).

The collected consumption data and the communicative technology may function as efficient instruments for preparing and implementing future measures for energy efficiency. As such AMS provide institutions and authorities with thepossibilities of implementing unique measures that are adjusted to the individual consumption patterns.

4.6 Integration of new technologies

The future Norwegian power system must be able to handle a more distributed network of generation resources. The increased penetration of intermittent power generation resources such as wind, solar and potentially tidal and wave energy is likely to accelerate together with binding international objectives and an increased environmental focus. Increased irregularity in power generation implies an increased need for capacity to meet production variations with flexible consumption as well as back-up production. Norway has already exploited most of its large-scale hydropower resources. A further increase in flexibility may then be released through small-scale hydro and residential power production, increased efficiency in existing hydropower production, and increased demand response to meet the future increased balancing needs in Norway and its connected countries.

A prominent share of the technologies waiting to be commercially available depends on more advanced metering systems to reap these benefits. Examples are plus-houses[59] and PHEVs[60] with an intermittent power consumption and production pattern showing alternating periods of power input into and withdrawal from the power system. Residential power production such as small scale solar, hydro, or wind power located at the consumers' location also represents a potential for increased rate of resource utilisation. An increase in such distributed generation would also reduce transmission losses that result from long distance power transport, and remedy the balancing need caused by local congestions. Nevertheless it does require that the transmission network and price mechanism can handle both irregular input and output at each connection point.

[59] Plus houses are energy-neutral houses (passive houses) that additionally provide sufficient power to provide power input to the grid. These houses are built building technically highly energy efficient with low-energy devices, proper isolation, small window-areas and natural air passage. Heating is normally provided from background heating or ocean thermal energy convention etc. Additionally, plus house provides its own generated electricity, either from solar or wind etc (Bellona, 2008).

[60] PHEV is the acronym for plug-in hybrid electric vehicles. These hold the prospective potential to serve as an alternate form of electricity storage and could deliver electricity back on to the grid at times of peak demand or capacity emergencies (Hedlik, 2009).

4.7 Between Border Power Exchange and Cooperation

There are several reasons for why power exchange across-borders being advantageous. In general increased interaction improves the efficiency of resource exploitation by allowing for increased competition to ensure that the production resources are efficiently utilised, and causing lower cost for end-users. Opening the borders for further power flow and interconnecting the jurisdictional levels enlarges both the power system and the power market, making them more robust.

Highly dependent on hydropower, Norway is vulnerable to dry years. The surrounding countries are primarily supplied by thermal generated power, of which contributes to ensure the Norwegian security of supply. The flexibility of Norwegian hydropower provides capacity for handling consumption variations abroad, of which alternatively would be balanced with polluting and costly thermal production.

5 ANALYSIS OF POTENTIAL EFFECTS OF AN AMS IMPLEMENTATION

There are many proposed effects of an AMS implementation many of which, however, are not properly tested and certified. In this chapter we will look into several of the potential effects of an AMS implementation. Many of these are dependent on each other, as we will see when looking at how an improved price signal may cause an increase in the demand response, that subsequently may induce a more efficient market.

AMS improves the information quality and access. It may change the routines and costs of measurement and utilisation of power consumption data. This creates a basis for potential adjustments in consumption. The potential increase in demand response will improve the efficiency of the day-ahead market, the real time market and create a more efficient market in the longer term. In addition the released consumer flexibility may release some of the balancing flexibility in the hydropower to other balancing purposes in thermal based systems with less flexibility.

The realisation of the benefits following the AMS implementation, is highly dependent on several factors, for example related to the choice of technology, the market design, the pricing mechanisms, the coherent investments in cross-border transmission capacity and so on.

5.1 Demand Flexibility

'Norwegian Electricity Consumption is very qualified for balancing the power system and can be a good supplement to hydropower', explains Ove S. Grande, senior research scientist in SINTEF in an interview (Grande, 2010). He refers to the potential source of further end-user flexibility that may contribute more actively to balancing the power system both in peak and off-peak periods.

5.1.1 *Price Signal*

AMS enables an accurate price signal to be provided the consumer. To a greater extent than today, the consumer will observe the actual price of the commodity, thus reflecting accurate expenses in the relevant time period of usage. In theory, the price provided the consumer will then reflect the actual cost of congestions and capacity specifically attached to his or hers consumption. However, such pragmatic prices would require a price system that reflects costs related to consumption in all connection points in the network. This is a very large number of prices. In reality, however, a compromise solution would be sought.

The Norwegian power market consists of five price areas as previously elaborated upon. These areas are defined by the largest long-term congestions. There are however, also internal congestions within each area. In this sense the prices do not necessarily reflect the real cost of providing the specific consumer with power, but are limited by the market design choices made in the wholesale power market.

At the minimum, the price signal must reflect critical congestions in the network. Consumers in areas of shortage must meet a price that signals the capacity constraint to such an extent that the demand respond is sufficient and area specific. In order to gain the most benefits from demand response, dynamic pricing[61] should follow from efficient price areas that should reflect relevant constraints in the transmission and the production capacities. This implies that prices must be allowed to vary in time and within areas (Bye et. al, 2010).

Such price variations presuppose a system of measurements and price formation[62] considerably more complex than the current system. The feasibility of developing a sufficiently advanced system to handle the challenges must be carefully assessed based on the cost of implementing and operating such a complex system of valuation.

[61] Real-time pricing often referred to as dynamic pricing, is still based on Elspot prices, however the accuracy of demand bids increase according to increased access to real-time data on demand.

[62] To account for all the nodes and congestions within each of todays' market areas, methods of optimal node pricing could be approached. Using such aggregated grid model as we do in Norway today, simplifies the market clearing, but creates efficiency losses and increased need for system regulation (Bye et. al, 2010).

5.1.2 *Price Sensitivity*

Dynamic price signal may in turn reveal the consumers' price sensitivity through their adjustments in consumption relative to price variations. In turn this flexibility potential of consumers may contribute to improved load balancing.

In practice, price sensitivity reflects to what extent an individual consumer or a group of consumers adjust their demand relative to a price change. AMS provides the consumer with an accurate time-differentiated price signal. This forms the basis of the improved price sensitivity. Reducible load should respond when the power price exceeds the consumers willingness-to-pay. However, for a high price to provoke a response in demand, the consumer must be able to adjust his power consumption, either by automated or manual downward adjustment of consumption, or by reallocation of demand from high-price periods to low-price periods. This calls for an increase in information communication.

Two-way communication enables access to power consumption data that identifyies the individual consumption patterns relative to price variations. This will provide a mapping of consumption patterns, such as the price sensitivity of individuals and of different categories of consumers. It is however, important to prevent potential incentives of price discrimination resulting from the exposure of each consumer's price sensitivity. This requires sufficient regulatory framework and increased surveillance to assure consumer protection.

5.1.3 *Demand Response*

When consumers respond to the accurate marginal price in the power market, over a period of days, weeks or months, or as a response to peak hours demand adjust to the actual cost of power provision, and the regulatory power is provided a tool to remedy temporary congestion problems. The most important benefit from demand side participation is in the situation of shortages, when a price signal may induce a downward adjustment of consumption relative to the magnitude of the reducible load of which the price signal exceeds its willingness-to-pay.

5.2 MARKET EFFICIENCY

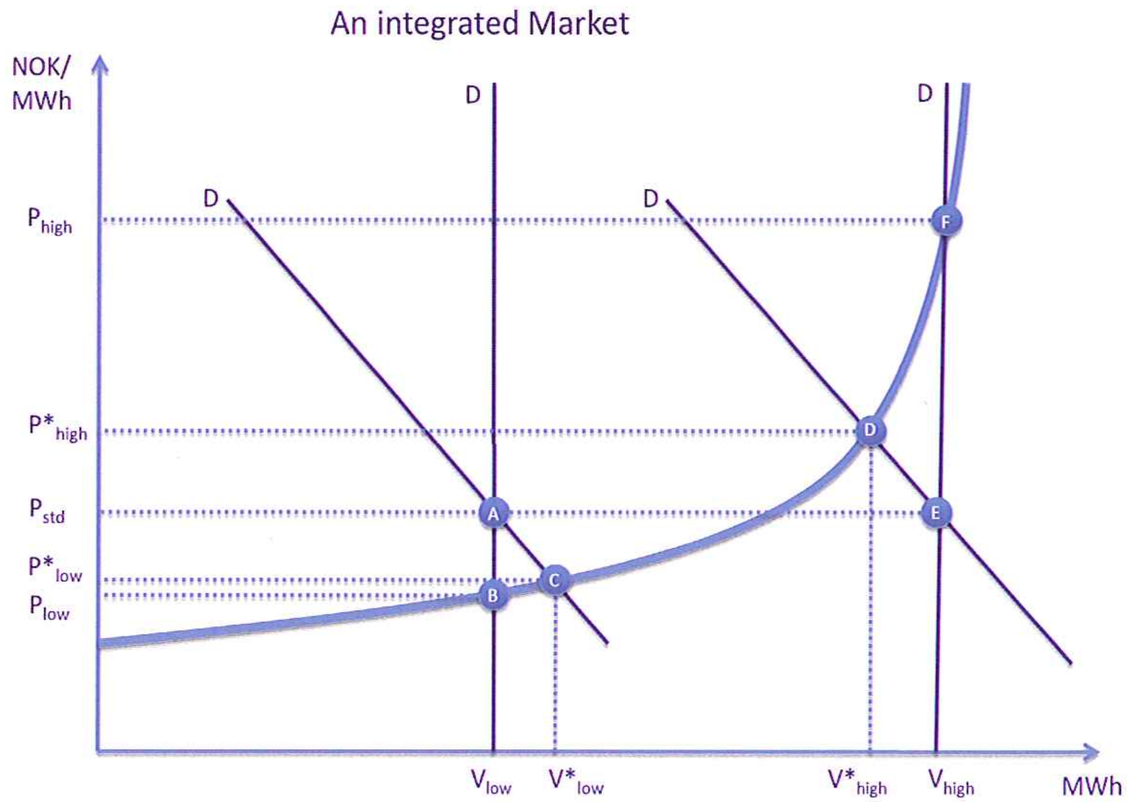
In an efficient market the consumers are charged with the accurate marginal cost of the commodity supply, and make their market decisions based on their marginal valuation of the commodity.

5.2.1 Market integration

The disconnected wholesale and retail markets are inefficient when the consumer faces a price that deviates from the el-spot price. In figure 4-1 the different market-clearing outcomes in a disconnected market situation and in an integrated market is illustrated. It describes demand and supply in respectively high and low consumption periods in a power market where consumers are subject to hourly measurement and are charged the spot price for their consumption.

Figure 5-1

An integrated market with demand responsive consumers and spot prices.



In a high consumption period the clearing in a connected market (D) provides an output with a lower spot price and lower consumption level, than the clearing in a disconnected market (F). Furthermore, in a low consumption period the clearing in a connected market (C) represents a higher price and higher consumption level than the clearing in a market with no responsiveness (B). The connected market is represented with lower fluctuations in prices and the benefit from this levelling is given in the triangular areas ABC and DEF (Ericson, 2007). A tightening of the power capacity balance is likely to strengthen the potential benefits of increased demand response and time-differentiated prices.

The improved consumption prognosis will assist power suppliers to bid in balance in the el-spot market and reduce the necessary volume traded in the regulation power market. This may also reduce the magnitude of the imbalances in the regulating power market, and possibly reduce risk for the power suppliers.

The accuracy of the price provided through AMS depends on the ability of power suppliers to satisfactorily bid the price dependent consumption reductions in the el-spot market. If the price sensitive consumption is not bid correctly into the market, the result is an incorrect scheduled power production and subsequent larger imbalances.

5.2.2 Right Incentives for Investment

In the Norwegian Power system the power producers are compensated for the power they generate, and the market price is meant to provide incentives for long-term investment decisions on capacity development. However, it is debatable whether this system structure will provide sufficient incentives for capacity investments (Ericson, 2007). If so, the cost level of new capacity installed should reflect the willingness-to-pay for it. Today's market structure does not necessarily provide the accurate price signals and does not communicate the accurate consumer valuation of power provision. Consequently, the investment level may divert from optimality. Investors also face a high degree of risk, not only price and quantity risk, but also a political risk of future regulatory policies, as well as policies related to the implementation of AMS. Clear and predictable signals as to future policies may reduce the risk of investment, and thus reduce the required risk premium.

Insufficient investments in transmission and production capacity may contribute to a situation were the market fails to clear, and the market must resort to some form of rationalisation. This is a highly unfortunate measure with significant costs. Because all consumers in a rationing situation are treated equally, one forfeits the potential benefits from variations in their willingness-to-pay. Incentives for voluntary short-term responsiveness to prices could replace rationing and induce incentives for investment where it is highest valued (Grande, 2004).

5.2.3 Efficient Management

The implementation of AMS provides further benefits in addition to revealing and exploiting the consumer flexibility, in terms of simplified data management, increased information on faulty operations and remote load-control.

Load Balancing

A main contribution to the efficiency improvements following from an AMS implementation is related to improved load management and the improved ability to manage the load relative to capacity constraints. This is possible by influencing consumption through prices, as well as through remote control of devices such as water heaters. Through a more efficient peak-demand management and load optimisation, the system is also better prepared to circumvent rationing situations.

By providing the system operator with information on supply quality on such a magnitude of measuring points, the surveillance of the power balance is enhanced substantially.

Simplified Supervision and Maintenance

Besides being a useful tool in load balancing, remote control may also increase efficiency and accuracy in handling customers, for example metering when consumers move, settlements to non-payments, change of suppliers etc. While these situations today require manual or stipulated measurements, the AMS will provide cheap and accurate information.

Automatic consumption measurement will as such provide accurate metered consumption levels. It will however also signal cases of faulty operations and malfunction. This lessens the need of patrol inspections to control and maintain equipment, as well as for verifying the measured level. However, the technology is not by itself necessarily error-free, and may to a larger extent than the mechanical meters be vulnerable to technical failure.

By moving from manual to an automatic information and communication technology, the metering and measurement data management of the network companies will most likely become distinctly simplified[63]. This will induce more cost efficient routines and influence operation cost considerably (ECON, 2007). A report initiated by NVE (2004) estimates that the cost savings for the network companies will amount to approximately 100 NOK per year per meter point[64], including measurement reporting, data management and invoicing. More recent surveys state savings up to 200 NOK and a weighted average of 180 NOK per meter (ECON, 2007). AMS also relieves the consumer of the time used for reporting consumption. On average this represents one hour per meter point a year, which contributes to an additional utility value of 75NOK[65] according to Jørum et al (2006).

I addition, system updates and functionality/service upgrades may be remotely provided. This induces a reduced need for patrollers and data management, but probably an increased need for customer services (Ernst&Young, 2010).

Improved supply quality

Increased information flow and improved consumption prognoses may lead to a situation where price no longer is the only competitive edge. The informed and aware consumer may thus demand more than pure power provision, and perhaps demanding improved supply quality. Supply quality here includes predictability, reliable infrastructure technology, sufficient customer service, environmental signals, energy and cost saving advices and technical assistance. Lower transaction cost may also induce more frequent replacements of power suppliers.

AMS technology with comprehensive functionality may enable detection of outages and deviations in quality. This provides a prospect of better surveillance and early detection of potential complications, and may result in further extensions of the quality incentives in the network regulation, and improve quality of supply (ECON 2007).

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[64] The estimated benefits are adjusted pursuant to numbers of meters and a weighted average (NVE, 2004).
[65] This estimates represents the average net wage excluded tax based on 2006 values (Jørum et al, 2006)

5.3 More Efficient Load Management

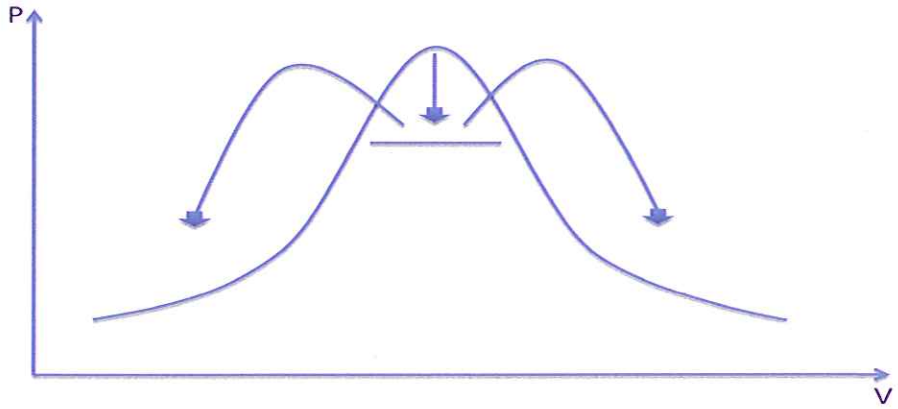
The ability to efficiently handle load variations and meet the peak loads is as important as sufficient energy when operating the power system. These aspects may be equally important drivers of grid development. A more efficient load management may imply saving potential in terms of reduced need of investment and avoidance of shortages. . The Nordic Power market is characterised by steep bid curves in situations of shortages (See figure 2-9). Small load reductions due to increased responsiveness may therefore result in substantial price reductions, and secure the power balance, and even at times prevent rationing.

5.3.1 Load Levelling

Load shifting due to AMS will not necessarily refer to a reduction in energy use. A benefit of a pure load shifting however lies in the reallocation of energy use from one time period to another, preferably from peak-periods to off peak-periods, as depicted in figure 4-2. This reallocation can either be imposed on the consumer through remote control or by providing the consumer with incentives for manual or automated adjustments.

Figure 5-2

Reallocation of consumption and reduction in effect-peaks (Sintef, 2008).



The potential for reallocation may be envisaged by mapping the low prioritised consumption prepared for a reduction over a limited period of time. Low prioritised consumption as described in chapter 3.1 may be sorted by the costs and consequences of a disconnection or reduced operation (See figure 3-2). Some of the low prioritised consumption is related to thermal slow loads that can store energy for some time. Disconnecting such power consumption enforces a consumption reduction, but does not entail any disadvantages. If the system operator were able to remotely make use of these potential load adjustments, it would represent a valuable tool for balancing the power in the system. AMS renders this possible with the remote control of devices.

Additional low prioritised consumption that may be reallocated prevails in the use of certain electrical devices such as washers, tumble dryers and dish washers. This consumption reallocation may induce an inconvenience for the consumer and must be supported by compensative incentives. Such incentives may be provided through tariffs that compensate all consumers that are willing to put parts of their consumption at disposal. Another way of compensating consumers for this kind of reallocations is by informing them about, and charging by the hourly price. Substantial peak-prices with corresponding lower off-peak prices will then motivate an adjusted consumption pattern.

Load levelling have direct implications for the power system management. Decreased load fluctuations ease regulative operations and trade for maintaining the power balance.

5.3.2 Price Levelling

Adequate demand response in peak hours will contribute to reducing the high prices in peak hours, and stabilise the overall average price for the settlement period.[66] All consumers will benefit from reduced prices, while the consumers that shift their consumption from peak hours to off peak hours would acquire additional price savings (Grande et al, 2008).

5.3.3 Prevent Market Power

When prices and load even out to a more stable level, the number of situations with market clearing close to the production capacity limit diminishes. In such a scenario market clearing will tend to be on the steep part of the supply curve. With a low price

[66] Relative to production up towards the production capacity limit with necessary effectuating expensive production, load levelling utilise production utilities with lower marginal cost.

elasticity of demand, this gives the power producers an incentive to withhold power to put upward pressure on prices. A higher price elasticity enabled by AMS may counterbalance this effect and contribute to reducing any market power. This will also improve the quality of the price signals of which investors base their investment decisions on.

5.3.4 Reduced Need for Investment

Large investments in transmission capacity are, independently of improved load balancing, needed to accompany a future development of remotely situated renewable power production. Investments in production capacity may be necessary to attend the continuous increase in consumption, both domestically and within power trading partner countries. Load levelling may however potentially lower the need for investments in transmission and production relative to business as usual. By utilising consumer flexibility as a balancing instrument, the improved load balance will weaken the fluctuations in the load. The capacity dimensioned for peak-loads may be released for a higher general average load and possibly reduce the overall need for expanded transmission capacity. Following this, the need for further investments in for example spinning reserves may also be of less importance. Alternatively, this increases the capacity for offering balancing capacity to other power systems dominated by thermal and wind power, or for handling the deployment of intermittent wind power capacity in Norway.

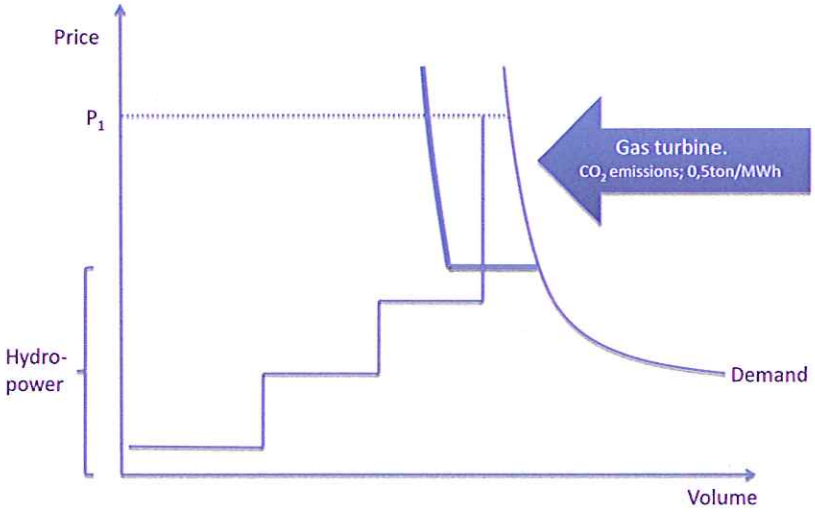
5.3.5 Environmental Benefits

Hydropower, wind and nuclear power have the lowest production costs and are primary contributors to the Nordic power system. Periods of cold temperature and subsequently high consumption will induce high power prices. In these periods the power plants with higher production costs such as gas turbines or oil-immersed capacitors, will be phased into the production portfolio on the margin, producing on a temporary basis as peak producers, and thus set the price in peak hours (OED, 2006).

Moreover, these power plants emit CO_2 in the generating process. As reduced consumption peaks may reduce the need for such back-up power production, the benefits in reduced CO_2 emissions may also occur (See figure 4-3).

Figure 5-3

Simplified illustration of potential benefits related to reduced CO_2 emissions by reduced peak load (OED, 2006).



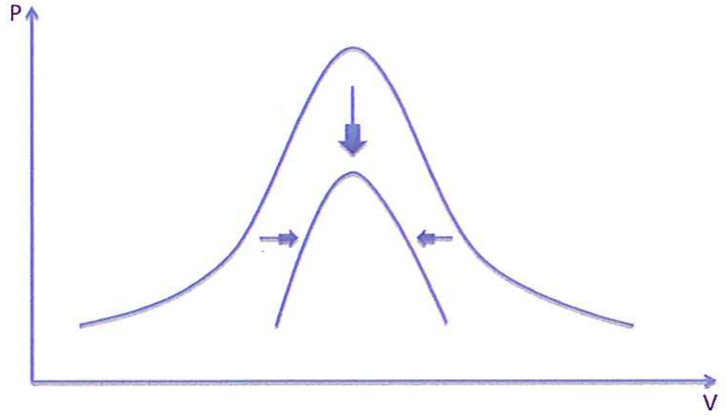
5.4 Consumption Reduction

Power load adjustment may also entail situations where consumption is reduced permanently, as depicted in figure 4-4. This occurs if consumers abstain from low prioritised consumption, or if they improve the efficiency of each unit of energy they use. Increased energy efficiency will not however necessarily provide a direct reduction in consumption load, but may impede consumption growth and reduce future consumption. Nevertheless, increased energy efficiency may replace some of the increases in energy need.

Relative to a business as usual scenario, an AMS implementation will provide information and devices that will pave the way for decreased energy consumption.

Figure 5-4

Energy saving (Sintef, 2008)



Pilot projects show that end-consumers tend downward adjust their power consumption when receiving information on their real-time power consumption and period statistics, together with incentives for saving. Motivated by potential savings and environmental effects, both correct price signals as well as proper information on environmental benefit of potential load reduction are important. It is evident, however, that consumers are reluctant and unable to follow the price development at all times. This calls for the use of automation of consumption adjustments (Grande et al. 2008).

To what extent consumer awareness will be translated into direct adjustments in the context of a full scale AMS implementation is uncertain and dependent on several factors, such as thequality of information, present energy efficiency, willingness and potential for consumption reduction, interface of devices and information provision.

Nevertheless, to promote responsiveness by price or environmental signals, communication of information is essential, either through media, parcels or web portals. AMS, however, holds great potential for information on the individual consumption pattern, statistics, saving advices etc.

In meeting the challenges of energy shortages in specific areas, decreased consumption is a relief measure that is potentially more rapid than development of transmission and production capacity, and presumably more political attractive than rationing. This may be an argument for an expedite implementation of AMS in areas of scarce power availability or large internal congestions.

Excess power released through consumption reductions may be exported as green electricity or green balancing capacity. To the extent that reduced domestic consumption replace CO_2 intensive power production in other countries this also represents an environmental measure.

5.5 New Products

AMS measures accurate consumption patterns and provide market information for both network companies and consumers. In addition it supports advanced tariff and invoice systems. This may lay the foundation for introducing several new products.

5.5.1 Tariff Products

Today 57,6 percent (SSB-8, 2010) of households are subject to a contract founded on the el-spot price. By changing to a contract that is based on hourly el-spot prics, consumers are provided a saving potential as a to the extent that they offer their flexibility. However, many consumers today prefer fixed contracts with a risk premium to ensure predictability and to avoid unexpected cost, relative to the volatile power price.

Further, the introduction of AMS prepares for a variation of supplementary tariffs in between the el-spot price contracts, and the fixed price contracts offered by the suppliers.

The time-of–use tariff is in nature similar to fixed price contracts, but differentiates prices according to different periods of the day; e.g. differentiated prices between day and night. Critical-peak-pricing is a more dynamic tariff similar to the time-of-use tariff. It is primarily low priced, except in extraordinary periods of low temperatures when prices may increase to a pre-specified level. Another tariff alternative is the two-part real-time pricing, where consumers pay a fixed price for a pre-agreed volume and the el-spot price for potential deviations. The consumer may also be granted compensation of potential unutilised power within the volume. Such contracts are more predictable than pure hourly el-spot price contracts, but do still provide incentives for consumption adjustments (Ericson, 2007).

Time-differentiated tariffs will create a direct incentive for price responsiveness, either through manual or automatic response. Suppliers may provide consumers information on high prices through mail, sms and indoor signal-lamps, or by offering automatic disconnection of devices through remote control.

A compensation agreement towards consumers who put their consumption at the system operators' disposal for remote control would provide additional means for load balancing. The compensation may vary with the extent to which the consumption is placed at disposal. A potentially large share of consumers may for example provide their water heaters as subject to remote control at a relatively low cost. Predefined low-prioritized consumption and price level limits provide an additional potential for remotely controlled balancing tools for the system operator. Consumers that possess sufficient back-up power or small self-supporting power systems of their own, may place their entire consumption at disposal for disconnection. Compensation ought to be founded on the consumers' inconvenience and the utility for system balancing, and sufficiently implemented in the network tariff.

5.5.2 Invoice Systems

The introduction of AMS and more advanced tariffs also calls for more accurate and informative invoices, including e.g. a detailed account of consumption. Further, it may provide statistics on savings compared to former consumption, or consumption relative to other groups. Also, potential improvements and saving measures may be communicated through the invoice, either related to individual consumption patterns, or general efficiency measures.

By an increased integration of communication technology, invoicing may as well benefit from the automation of interaction procedures between the consumer and the power providers. In the light of the increased metering efficiency, invoicing may also be automated, for example by direct electrical communication, through mail, sms, web portal, or directly through the indoor-display.

5.5.3 *Environmental Products*

To encourage energy saving by the environmental motivation of consumers, the consumers may be offered signals on environmental performance, related to their consumption. For example, offering actual power products for resale may inspire further environmental efforts. Environmental products are power products that improve energy efficiency. They may for example be embodied in e.g. NegaWatts and Green shares. NegaWatts show potential energy savings. Green shares are assurances that a certain share of your electricity originates in renewable energy. Such green shares are traded through voluntary guarantees of origin and obligatory arrangements of green certificates, where the certificates function as a subsidy for certificate-holders, and as a charge for the purchasers.

Direct power saving is not necessarily in the interest of the power providers, hence must sufficient incentive and compensation arrangements must form the basis of such energy efficiency measures. Authorities may provide guidelines and regulations to enforce saving measures from the network companies, or support schemes to encourage energy saving measurements and residential power production at the connection points.

5.6 Improved Quality of Information

Current technology provides very little information on prices and consumption. But some information is granted the consumer through invoicing parcels or different informative web pages. Most consumers however, attain their primary part of power related information through media. This is confirmed in studies that compare correlative media focus and pattern adjustments (SINTEF, 2008).

5.6.1 *Accurate Information on Consumption Patterns*

AMS hold the potential of more accurate in consumption measuring than traditional meters today for several reasons. Firstly, many of the traditional meters utilised today are inaccurate in practice, and the consumption is additionally reported in variant time intervals. Lastly, there is a significant risk of errors in today's reports (Hafslund, 2010).

As such AMS may reduce data manipulation problems, as measurments now are automatic and objective. More specifically, AMS reduce the potential of false measurement reports in favour of higher consumption in low-price periods, and lower consumption in high-price periods, such as respectively summer and winter. Inevitably, also the risk of disagreements on account and billing questions will be reduced when the accuracy of data observation increases.

The immense data access that AMS provides through hourly measurements each twenty-four hours throughout the year requires good data management procedures.

Pilot projects estimate that 99 percent of the hourly measurement values are received. Most of these received values seem to be correct. The remaining one percent consists of missing values and installations that are turned off and hence does not provide values. Some pilot implementations starting in 1997 experienced provision of error values even after a couple of years in operation (Grande et al. 2008). It is essential that observation systems are developed to detect unrealistic measurements and error.

5.6.2 Goal Oriented Measures

Following the accurate individual consumption patterns, consumers may be provided by tailored measures for energy saving. Such statistics expose saving potential and simplifies the process of developing direct measures for energy saving for service centres, governmental or organisational interests.

5.6.3 Data security

Intimately details on consumption pattern expose the price sensitivity of the consumer. The availability of such data must be subject to strict regulation to avoid misconduct and to assure consumer protection. Clear administrative directives should elucidate ownership and access authorisation of the data. The Data Inspectorate should provide for sufficient surveillance.

Adopting such widespread computer technology also expose the power system and metering system to increased vulnerability towards technical failure, hacking and involuntary dispersion of sensitive data material.

6 DISCUSSION

Electricity is peculiar commodity. When introduced it altered and simplified the way of life. Electricity is a resource extracted from other resources, a resource of which we are favoured and obliged to use with optimization and consideration.

Considering that Norway possess a considerable share of the overall European hydropower resources relative to the share of citizens we should to consider our flexible hydro-resources as the green battery of the European continent. If we assume future distributive politics to a larger extent consider the planet resources to be truly global aligned with the acceptance of a global atmosphere connected with the global climate change problems. Then Norway may be oblige to release a larger share of our unrevealed flexibility, due to our occupation of a considerable share of European hydro resources and its balancing ability.

A more tangible objective for the power system optimization is the fact that Norway depends extensively on electricity. Electricity is the motive power of many of the processes that the modern Norwegian society is built upon. Dependent on stable and secure power supply, utilisation of all potential cost-efficient measures to ensure security of supply would be in common interests.

The deregulation of the Norwegian electricity market caused a needed reduction in the over-investments in grid capacity. Nevertheless, some of the precarious power situations in the previous decade have indicated that some areas are now subject to insufficient transmission and production capacity. This insufficiency in capacity causes vulnerability to the security of power supply and provokes volatile power prices in periods of shortage.

The inadequate transmission capacity development has, together with an increased focus on nature conservation, fostered a stronger resistance towards power lines and power pylons. This must be taken into consideration, and is together with an impassable Norwegian nature, widespread and scattered production and consumption, important reasons that grid development is so extensive both economically and in time-consumption. Pressing energy situations in certain areas however, requires rapid remedial action.

For the Norwegian system operator, a large regulative potential lie dormant in the unutilised flexibility of demand response. As previously explained electric meters mainly installed in the households' today measure only accumulated power consumption. These do not provide the households with the continuously varying cost of power provision, and hence little incentives to adjust their consumption relative to the varying prices. This implies that in times of peak load when grid capacity is overstrained in some areas the price is an unsatisfactory tool to promote consumption adjustments. New meters with fluctuating prices reflecting area specific costs are thought to accommodate this inelasticity in the wholesale market.

With consumption adjusting to price signals, the power system is given a balancing tool. The consumer flexibility may accommodate a load levelling by replacing consumption from high-price peak periods, both through manual and remotely controlled consumption adjustment. Reducing the peak load decreases the need for substantial safety margins in the grid capacity. And by allowing prices to fluctuate between different geographical areas based on the area specific constraints, prices will reveal limitations that can be met with investments in the grid or production capacity.

The implementation of such systems represents a measure to accommodate adverse power situations such as shortages rapidly and goal-oriented. However, the actual outcome of the measure is broadly debated.

6.1 Enrolment pace

To promote robust metering systems compatible for future potential use, the functionality requirements must not be set to low. Potential disadvantages with an hasten enrolment process is unsound investments in underprepared equipment relative to prospect requirements and possess outmoded equipment ahead of natural wastage. Because of the magnitude of the AMS investment such slips may be unreasonably expensive.

Competition on technology will provide for innovation. The possibility that the European mandate will present a standard that is to confine for prospective innovative solutions must be considered. This may argument for open solutions rather than standards.

Expediting the implementation process may be reasoned in areas characterized by energy shortage. Considering that many areas of shortages require rapid solutions to their capacity constraints together with the relatively low costs, feasibility and accuracy argue in favour of a prompt phasing of AMS relative to other expedient measures.

Even though it is prudent to pursue an optimal enrolment pace, the advantage of increased demand response in problem areas must nevertheless be assessed and appraised. It is probable that the potential disadvantages of a hastened implementation and potential of premature technology decisions are outweighed by the benefits of increased regulation ability in such areas.

When estimating the projected pace of an AMS implementation, the network companies designate a substantial share of the time-horizon of completion to the time-consuming work of installation at inaccessible metering points, comprising a number of remote consumers, cabins and also reluctant consumers. This indicates that the initial installations will be the most cost effective. It is also presumable to claim that the most compliant consumers are more disposed to demand response concurrent with their courtesy towards the new technology.

The variations in the energy situations and consumer accessibility render possible a beneficial differential treatment in the decision on the final date of completion. This implies that for areas of energy shortages and capacity constraints, an earlier date of completion could be ordained to initiate start-up and promote investments. This initial provision could comprise the most feasible percentage of the metering points, postponing the less cost effective installations.

Expedite implementation benefits must compensate for potential unsound technology investments. Because the decisions of communicative technology and basic technology standards are clearly signalised prior to the final decisions in the European standardisation process, unsound investments may be evaded through technology solutions requirements that more than comply with prospected technology standards. Such over-compliance may induce superfluous expenditures, but due to the relatively long technology lifespan it also envisions avoidance of outdating and replacement. Furthermore, much of the benefits that an over-compliance may provide are socio economic benefits that are hard to measure economically.

6.2 Expedient Technology

Technology specifications will provide guidelines and constraints for areas of utilisation. Hence it is of great importance that the technology requirements are thoroughly cost-benefit analysed, to prevent value-adding benefits to be neglected or redundant functionalities to be implemented. The long lifespan of metering technology does require future areas of application also to be considered. Evidently, there is great uncertainty attached to future technologies and areas of application. Consequently, the technology requirements should to the greatest extent be open to new technologies and avoid being a barrier for technology innovation.

Providing the network companies with an instructive minimum installation requirement and cost distribution schemes is crucial to rectify the process and evade the problem of low economic incentives for installation of sufficient technology.

6.2.1 Measurement Frequency

A crucial functionality of the installed meters is evidently their ability to meter electricity. The frequency potential of the measurements should be subject to mandate requirements to meet future pricing structures. To enable the price mechanism to function as a balancing tool to remedy the rapid fluctuations within the twenty-four hours and peak variations within the hour, the installed systems should hold potential for measurements preferably on a fifteen minutes frequency. The necessity of two-way communicating such frequent measures must be balanced towards the costs and benefits. Other measures concerning peak consumption, as well as the large flexibility in the hydropower system must as well be carefully evaluated. But the invoicing and communication should be aligned with the measurement frequency that reveals the necessary consumer flexibility to manage peak reductions. This should also and maybe primarily comprise the large group of end-consumers with above 100 000kWh that already holds AMS technology.

6.2.2 Remote Control

Functionalities such as frequent consumption measuring and communicative systems between power supplier and consumer are comprehensible requirements. But the metering technology carries prospects of further functionalities that will make the AMS able to manage the consumers' incapability to continuously correlate their consumption with price variations. This includes the systems' ability to remotely control devices such as water heaters for balancing purposes. This implies that the electric meters must be able to communicate with the water heaters. This may be useful also for other devices, such as thermal slow loads, freezers and other low prioritized electricity consumption.

Simultaneous reconnection of the heaters is likely to induce a peak in consumption. This indicates remote control may have repercussions that regulators must contemplate, in order to avoid simply postponing the peak problem. By prolonging the disconnection period or by asynchronous reconnection regulators may evade postponing the peak. However, an increase in the disconnection period until periods of lower loads will induce a higher repercussion effect in reconnection. Asynchronous reconnection represents increased balancing potential, but entails attentive operation.

6.2.3 Information

As a supplement to automatic price and load dependent remote control of devices, easily accessible price information especially in high-price situations will enable consumers to adjust consumption. For further reduction beyond price-motivated reductions, information display may provide the consumer with energy saving potential, green shares and consumption statistic to meet the prospected increased demand from consumers on product information and environmental awareness.

Information magnitude provided the consumer should be assessed according to economic efficiency and relevance. But information may also be a competitive component of which consumer base the choice of supplier on. Hence should the information potential in the technology chosen be object to regulations to ensure efficient information provision and avoid preventing information functionalities in order to improve competition.

6.2.4 Metering Local Production

An important object that ought to be considered would be the metering systems ability to measure input of power from the different metering points on to the grid, lowering the barrier for diffusion of small-scale power production, and residential power production. A measure that would remedy the problems connected with congestions and energy shortage. Additionally it accommodates the potential for increased diffusion of small-scale residential power production, a potential that would enable efficient exploitation of scattered resources of variant sizes. Increasing number of flexible customers will improve the balancing capacity.

Some consumers or groups of consumers could constitute so-called mini networks. These are self-sufficient in power supply if needed and put their back-up power at the regulators disposal to be remotely disconnected at times of pressed capacity. Furthermore the mini-networks could feed power to the grid in times of supply deficit. Such system would demand much of the electric meter. In addition to measuring power input to the grid, it would require option of remote disconnection concurrent with start-up of the back-up power. To ensure efficient balancing capacity the revenue for input and cost for output should be clearly communicated to the consumer and/or producers.

6.3 Price variations

A full-scale AMS implementation with frequent measurement, but without efficient price-area division may be argued as possessing the tool without sufficient fuel. The Norwegian power market arrangement today provides little incentives to adapt to price variation because of an expressed governmental desire to pursue a domestic, uniform and stable price. When prices tend not to vary the consumer tend not to respond. Infrequent situations of beneficial response create transaction cost beyond potential benefit. Prices needs to vary continuously concurrent with area and time specific costs and the regularity of the price variation needs to be properly communicated to the consumers. Nevertheless for prices to reflect the accurate cost of power provision to each connection point prices must vary accordingly.

These price variations will additionally provide proper realistic investments signals that will rectify investment decisions, and like increased consumer flexibility decrease price variations over time.

However allowing prices to vary with time and area demands much from the pricing models and the organisation of the power market. This represents a significant barrier, because the complexity of price mechanisms, price communication and reservoir valuations implies more intricate procedures, instruments and models than currently available. Hence must the price mechanism development be coherent with the efficiency of the tools available. The level of complexity and number of prices and price areas must not prevent the market from operating efficiently. However an increase in the number of price areas today are likely to have socio economic benefits.

6.4 Efficiency

Though surveys and pilot projects provide some assumptions and evidence of responsiveness, the actual influence an AMS implementation will have on power consumption is uncertain and yet to be object to exhaustive inquiry. Every potential beneficial effect should preferably be weigh against similar effects from other measures to determine the most beneficial and economically optimal approach.

An AMS implementation in Norway will inevitably have lower benefits relative to thermal based systems with lower flexibility. The balancing abilities of Norwegian hydropower gives lower variations in prices and load over time. Thus must an AMS implementation be reasoned not only in domestic benefits of increased consumer flexibility, but in the benefits of releasing some of the flexibility of hydropower for balancing purposes for other thermal based systems. This argument emphasis the importance of following an AMS implementation with enforced cross-border transmission capacity.

The prospect of domestic precarious power situations may nevertheless, justify a expedite implementation irrespective of absence of exhaustive assessments. In the current power market with temporal situations approaching no market clearing and rationing, AMS represents a measure that not only may provide needed consumption adjustments, but that is feasible and rapid in implementation. If so areas with frequent energy shortage should be object to prioritised implementation and remote control functionalities, especially targeted slow thermal loads.

6.5 Implications

Increased number of prices and connection points with both input and output, will inevitably increase the complexity of the power system and require much from the operation systems. This complexity must nonetheless be communicated in a simplified matter to the customers. Both aspects require substantial and reliable technology features.

Information and communication technology based power is to a higher extent than the old mechanical meters vulnerable to technical failure. This must be considered through back-up systems and contingency plans. The technology must also be prepositioned to securely handle the increased magnitude of measurement data. Considering the sensitivity of the information there should be clear bindings and guidelines on the data access and usage ahead of the enrolment.

The implementation phase must be continuously supported by error detecting, customer service and technology improvements. Added the actual implementation process, the technology provision and the adjustments in the price mechanism systems to provide for such a large-scale implementation represents an upheaval project. Complications are unlikely to be avoided. However thorough supervision on incoming metering data in the initial phase may remedy potential severe errors. The shorter the enrolment period the higher the implementation cost due to pressured resources. These costs must be assessed towards the cost of postponing the rollout.

7 SUMMARY

Norwegian price and consumption statistics on power reveal an insufficient correlation between price and consumption, implying that price is an inadequate tool to provoke the consumption adjustments needed to efficiently balance the load. Recent years have encompassed several periods with high prices caused by severe capacity constraints. Preferably power consumption should adjust to the resources in the power system at all times accounting for congestions and shortages. Advanced Metering Systems (AMS) is considered to be a measure to remedy the inflexibility in consumption.

AMS is an intelligent electric meter able to frequently measure power consumption and provide extensive communication with power providers, end-users and different devices located at the consumer such as water heaters, freezers etc.

AMS promotes increased flexibility, both incentivising adjustments in providing the end-user with current prices and coherent consumption, but also in enabling compensating contracts for direct load control and remote disconnections. Confronted with accurate power prices reflecting cost of provision, consumption is thought to adjust accordingly. This reveals an end-user flexibility that can be used to remedy situations with deficits or surplus in the power system. Enabling all producers and consumers to participate more actively, AMS improves the tact and complexity of the load balancing process.

Firstly AMS will be a measure to remedy the management of different effect situations, but may additionally have influence in situations with energy shortage. More accurate price provision may also provide incentives for energy saving in general and increased substitution towards other energy solutions. By simplifying power metering, avoid stipulation of consumption profiles and improve invoicing processes AMS provides improved and simplified management for the power providers. Nevertheless, by providing accurate prices, increased transparency and accelerating supplier replacements AMS pave the way for increased market efficiency.

Norwegian power consumption -in accordance to the relatively high share of power used for heating purposes is particularly qualified for balancing purposes. Releasing this flexibility may replace some of the balancing capabilities of Norwegian hydropower production. Released hydropower may offer balancing capacity to other power system in trading partner countries with wind and heat power dominated power systems. This is dependent on sufficient investments in the cross-border transmission capacity.

Norway has long awaited the finalisation of the European standardisation process to assure that the installed technology is of sufficient quality at an acceptable price level. However, AMS also represents a measure to remedy the repeated precarious power situations in some areas of Norway. In many respects AMS represent a feasible and rapid measure relative to developing increased transmission and production capacity, and is expedient with the urgency of the problems. Hence an expedite implementation of AMS in problematic areas may be justified.

The technology implemented should be as open to future potential functionalities and areas of applications as possible without largely compromising the cost efficiency. However, the overall benefits of a full-scale AMS implementation are uncertain and hard to measure, and an expedite implementation relative to the European technology assessment should be escorted with an over-compliance with assumed functionalities to avoid unsound investments.

Certain aspects are crucial for deriving benefits from the implementation. For the demand response to adjust righteously in accordance to congestions and capacity constraints the prices must accurately reflect the costs. Ideally, this implies more prices than the five price areas today, but the optimal number of prices must be contemplated towards the feasibility and cost efficiency of increased number of price areas.

In addition to render possible demand response, AMS holds the potential increased penetration of small-scale residential power production and more direct energy efficiency measures. However, the effect depends highly on the functionalities of the technology implemented and increases the importance of a precise governmental mandate to ensure that all socio economic benefits are valued and considered.

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