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Environmental Aspects of Load Management

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Report

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ENVIRONMENTAL ASPECTS OF LOAD MANAGEMENT

by

Juozas Abaravicius

February 2004

Report

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Assoc. Prof. Lena Neij from the International Institute for Industrial Environmental Economics at Lund University has been supervisor and examiner of this study. Assoc. Prof. Jurek Pyrko from the Division of Energy Economics and Planning, Department of Heat and Power Engineering at Lund University, has been the project leader and supervisor.

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Summary

Load problems in electricity markets occur both on the supply and demand side and can have technical, economic and even political causes. Commonly, such problems have been solved by expanding production and/or distribution capacity, importing electricity or by load management. Interest in load management differs depending on the perspective of the actors involved: from customer, utility, or producer to state policymaker.

Traditionally, load management is evaluated from the economic and technical viewpoints. This study, however, approaches load management from an environmental perspective. It identifies and discusses the possible environmental benefits of load management and evaluates their significance, primary focusing on CO_2 emissions reduction. The analysis is carried out on two levels: national – the Swedish electricity market, and local – one electric utility in southern Sweden.

Our results show the importance of considering the influence of site-specific or level-specific conditions on the environmental effects of load management. On the national level, load management measures can hardly provide significant environmental benefits, due to the high hydropower production in Sweden, which is the demand following production source. Emission reductions will rather be the result of energy efficiency measures, which will cut the load demand as well as the energy demand. However, when it comes to a local (utility) level, where load management is considered as an alternative to an installation of peak diesel power plant, the benefits are clear. It is demonstrated that significant CO_2 emissions savings can be achieved due to avoided peak diesel power production.

Table of contents:

1.Introduction

While electricity demand continues to increase all over the world, playing an essential role in economic and social development, this process also results in increase in emissions, overexploitation of natural resources and other negative environmental effects. The creation of sustainable electricity supply system, able to maintain economic growth and social progress whilst protecting the environment and conserving natural resources, is a strategic issue in every country. The major prerequisites for environmental sustainability in energy systems are typically the use of renewable energy sources and energy efficiency. However, the environmentally sustainable solution sometimes might create a tremendous economic and social burden. On the other hand the consideration of only economic effects might lead to the environmental degradation. The development of consistent, creative and compromise solutions while implementing energy policies is extremely important.

Load management is normally considered solely as a technical and marketing measure for improving the economic performance of the electricity system. Research has been mostly devoted to issues such as harmonizing the relations between supply and demand sides, optimising the power generation and transmission and increasing the security of supply. These economic and technical effects, however, have the influence on the environmental performance as well. Unfortunately, the research has rarely identified and underlined this impact.

1.1 Objective

The objective of this study is to gain the knowledge how and to what extent load demand (variation in load demand) influences the environmental performance of electricity system and to estimate whether the load management measures could contribute to the decrease of the negative environmental impact. The situation on Swedish electricity market with respect to load question is discussed. An attempt is given to estimate if (what) emission savings could be achieved in Sweden due to load management measures. The study is also illustrated by the case at Skånska Energi, a power utility in Southern Sweden, where load management is considered as an alternative to the construction of peak diesel power plant.

1.2 Method

This study is based on a broad literature survey focusing on load demand, load management and environmental issues. It is also supported by personal communications on these topics with researchers and industrial representatives. In both the literature and personal communications, the benefits that load management techniques provide or are aimed to provide in electricity markets and their environmental consequences were emphasized. The systematic approach is used: through the analysis of the basic aims and effects of load management in power market the links to the environmental impact are established (see Figure 1).

Fig 1. *Analysis frame*

The survey was, in addition, supplemented with statistical data on electricity demand and supply. Based on the survey, the data and the discussions, an analysis is carried out of the Swedish electricity market.

Since hourly load data is essential while analysing load questions, different institutions were approached in order to obtain the required data. These primarily are the Swedish Energy Agency, Svensk Energi (Swedish electricity supplier's association) and Svenska Kraftnät (Swedish national system operator). The hourly data on the electricity consumption, total production and import to Sweden was obtained. Furthermore, the import data, provided by Svenska Kraftnät is specified according to the countries the electricity comes from. However the available hourly data does not specify the production sources neither for Swedish side nor the import, therefore it is impossible to say what are the production sources every hour. This kind of statistics is available only on weekly basis. One of the reasons that this kind of detailed statistics is not available is that the electricity producers at the moment are not obliged to provide it.

The study analyses the variation of CO_2 emissions originated from the Swedish electricity demand. The average emissions data [kg/MWh] of the total electricity production in Sweden and the countries exporting to Sweden is used. The average emissions from Swedish production and the emissions from the exporting countries are different. It is obvious that the emissions vary every hour as different sources are used, but as the data is not specified on hourly basis, it is not possible to establish exactly how the emissions vary. Therefore the assumption that the emissions are the same from every MWh is used. The emission varies with the increase or decrease of electricity use. Load demand and emissions are connected.

The analysis of the collected on load demand data and resulting emissions in Sweden was carried out in several steps, including:

- The presentation of hourly load data in form of annual load curve
- Identification of the highest load peaks in years 2001and 2002
- Identification of the relationship between the total electricity production within Sweden and import (specified by the exporting country) during the analysed peak periods
- Identification of the emissions during every hour of the analysed load peak period

The analysis is continued with the discussion of the possibilities to decrease the emissions with help of different load management techniques.

Load situation, load problems and solutions at energy utility Skånska Energi are analysed based on personal communications and hourly load data, provided by the utility. Information on the implementation of load management strategies and the plans to build the peak diesel power plant is obtained during the multiple interviews and cooperation with the utility's representatives. Both alternatives are discussed. The discussion covers different aspects, but primarily focuses on the environmental ones.

2. Background – electricity market, environment and load issues

2.1 Electricity market and the environment

Sweden, as well as other Nordic countries, provides interesting cases for study of load problems and environmental impact of electricity use due to high consumption of electricity per inhabitant and the effects of electricity market reform. Sweden uses around twice the amount of electricity per inhabitant than EU average. One of the most important reasons for this is the electricity use for heating requirements (Swedish Energy Agency, 2003).

The production of electricity in Sweden primarily comes from hydro and nuclear power plants (93%). Remaining part comes from wind and thermal power plants, and import (see Table 1). The countries that export electricity to Sweden are Norway, Denmark, Finland, Germany and Poland. The Nordic countries have a common electricity exchange known as Nord Pool on which players from Norway, Finland, Sweden and Denmark can trade in electricity (Swedish Energy Agency, 2003).

Table 1. *Electricity generated and consumed in Sweden in 2000-2002 and forecasts for 2010, TWh/a (Swedish Energy Agency, 2003).*

	2000	2001	2002	2010
Generation, totally	**142.0**	**157.8**	**143.4**	**147.8**
Hydro power	77.8	78.6	66.0	68.6
Wind power	0.5	0.5	0.6	3.9
Nuclear power	54.8	69.2	65.6	63.6
Conventional thermal power	8.9	9.6	11.2	11.8
- CHP in industry	*4.2*	*3.8*	*4.7*	*4.9*
- CHP in district heating	*4.7*	*5.7*	*6.0*	*6.8*
- Condensing power, incl. gas turbines	*0*	*0*	*0.5*	*0.1*
Consumption	**146.6**	**150.5**	**148.7**	**152.0**
Network losses	11.1	11.6	11.6	11.4
Imports-exports	**4.7**	**-7.3**	**5.4**	**4.2**

The electricity market in Sweden was deregulated in 1996. Since 1999, all customers are free to choose the electricity supplier.Annual increase in electricity demand in Sweden is around 1-2% (Swedish Energy Agency, 2001).

Electricity system influences the environment in many ways. The most important to mention are the emissions, residuals and waste, visual intrusion, electric and magnetic fields (Electricity association, 2002).

Two largest power producers in Sweden,Vattenfall and Sydkraft, have performed a Life Cycle Assessment (LCA) of the electricity generated in different modes they possess. The key results are presented in Figure 2 (Olausson, 2001).

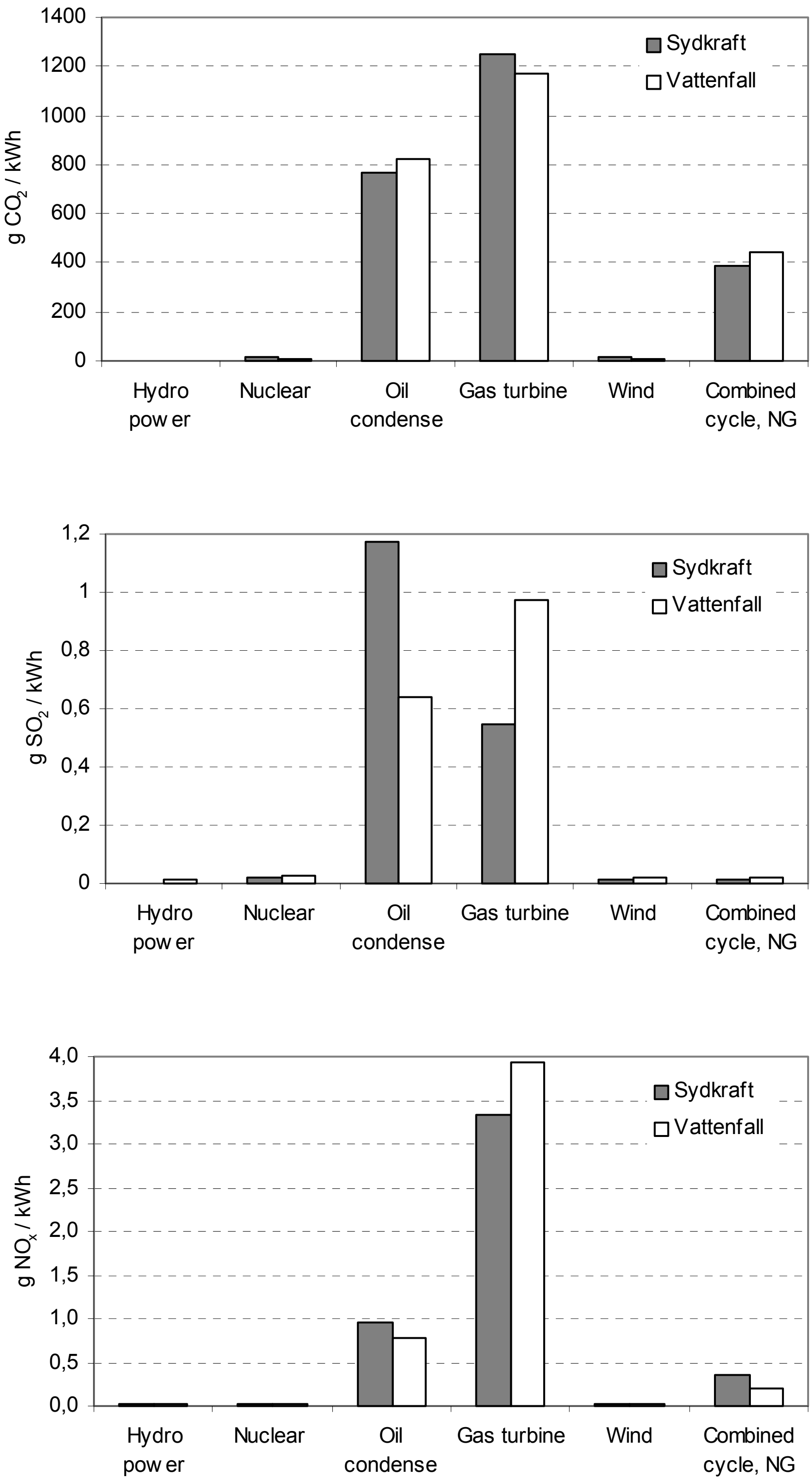

Figure 2 . *Comparison of LCA's made by Sydkraft and Vattenfall (Source: Olausson, 2001)*

The environmental impact of electricity production varies in time as the supply side follows the demand every moment and different production sources are employed to meet the load demand.

Average emissions and marginal emissions

Due to the complexity of electricity generation and supply system, several complications can appear in relating the power consumption with emissions. This is primarily due to the variation of the mix of generation resources to meet load demand at different times of day or in different seasons, as well as electricity transportation over long distances from the generation place. Marnay et al. emphasize that

> "*The emissions resulting from electricity consumption vary considerably depending on* ***when*** *and* ***where*** *it is used since this affects the generation sources provided the power*"(Marnay et al, 2002).

The study by Marnay et al explores various approaches to estimating the emissions responsibility of California customers´ electricity use. One of the conclusions is that

> "*there is no practical way to identify where or how all the electricity used by a certain customer was generated, but by reviewing public sources of data the total emission burden of a customers' electricity supplier can be found and an average emissions factor (AEF) calculated. These are useful for assigning a net emission burden to a facility. In addition, marginal emissions factors (MEFs) for estimating the effect of changing levels of usage can be calculated. MEFs are needed because emission rates at the margin are likely to diverge from the average*"

2.2 Load issues on electricity market

Energy system has to be designed to meet not only the energy [kWh] but the load demand [kW] as well. Load demand depends on several factors:

- Customer type (household, commercial, industry, etc.)
- Customer's equipment
- Climate (outdoor temperature, light)
- Human factors (consumption patterns, habits, etc.)

The energy demand during specific period of time e.g. day, month or year might be rather constant; however the load demand might vary drastically within a given period. An example of load demand variation in a household during 24 hours is presented in figure 3. This variation affects the environment accordingly to what the production sources are employed. Energy system has to be designed to meet not only the energy (expressed in kWh) but also the load demand (expressed in kW) with least negative environmental effects.

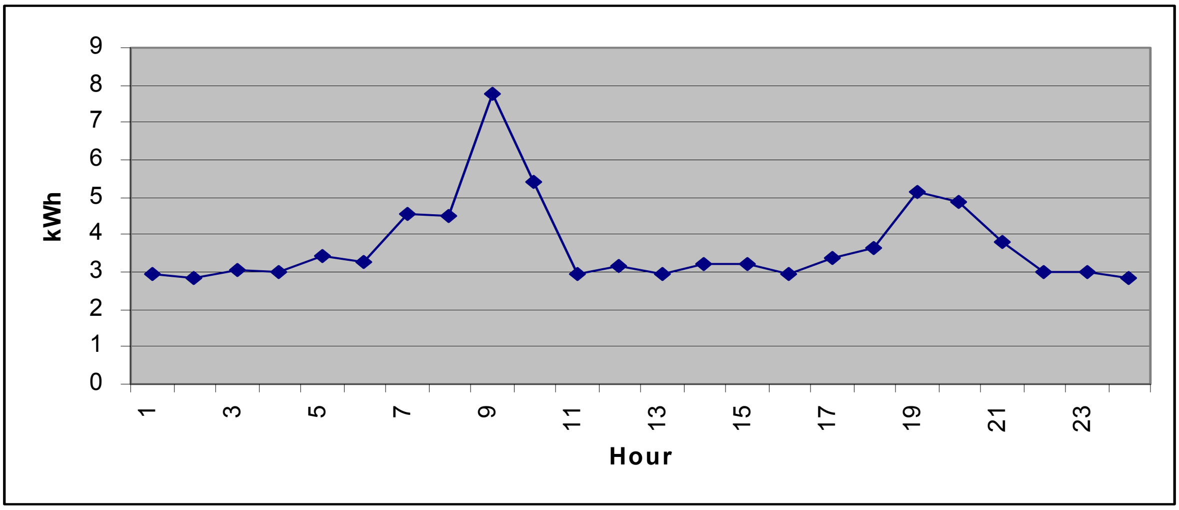

Figure 3. *Example of demand variation in a household during one day (Source: Skånska Energi)*

2.2.1 Load demand situation in Sweden

The load demand situation in Swedish electricity system is presented below. Hourly load data is essential while analysing load questions. It was obtained from Svenska Kraftnät - the Swedish national system operator. The data is presented in form of annual hourly load curve in Figures 4 and 5.

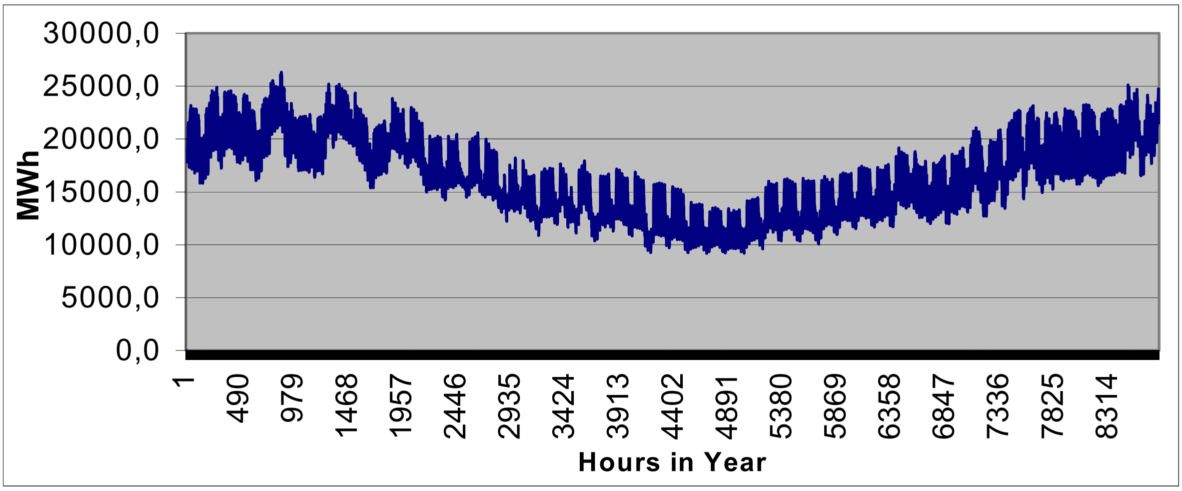

Figure 4. *Load curve for Sweden, 2001. (Source: Svenska Kraftnät)*

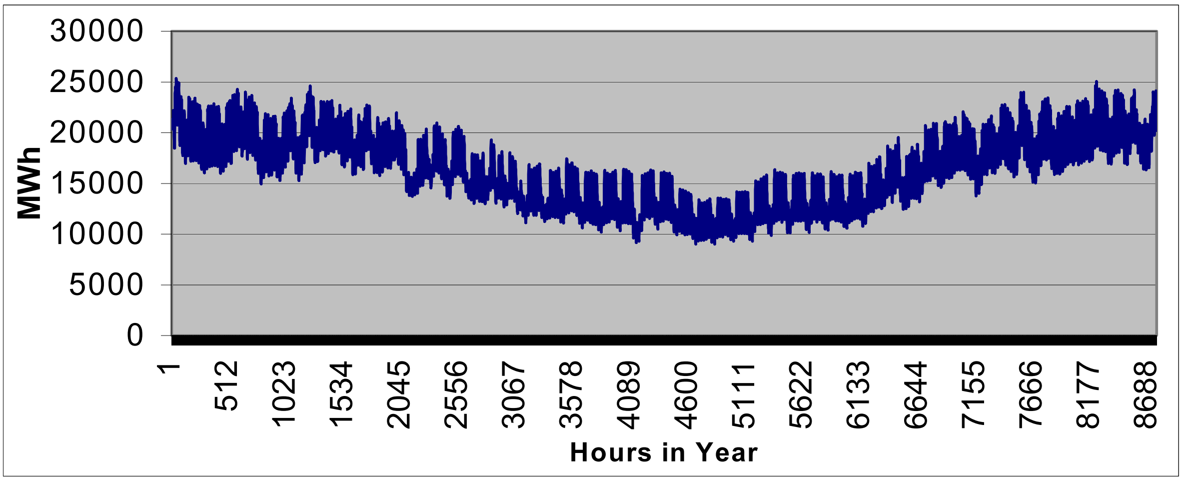

Figure 5. *Load curve for Sweden, 2002. (Source: Svenska Kraftnät)*

2.2.2 Production and import sources to meet the demand

The data for the Swedish production mix is available only on weekly basis. The data for imported electricity, specified by the country of origin, is available on hourly basis. Svenska Kraftnät provides this information. Figures 6 and 7 define the hourly production and import to Sweden during the analysed years.

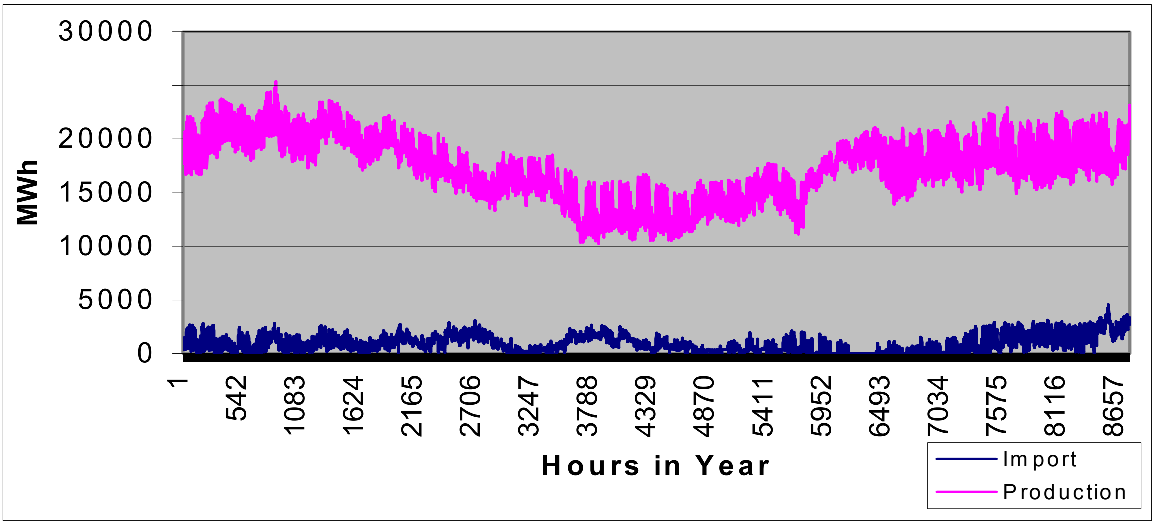

Figure 6. *Hourly production and import to Sweden, 2001 (Source: Svenska Kraftnät)*

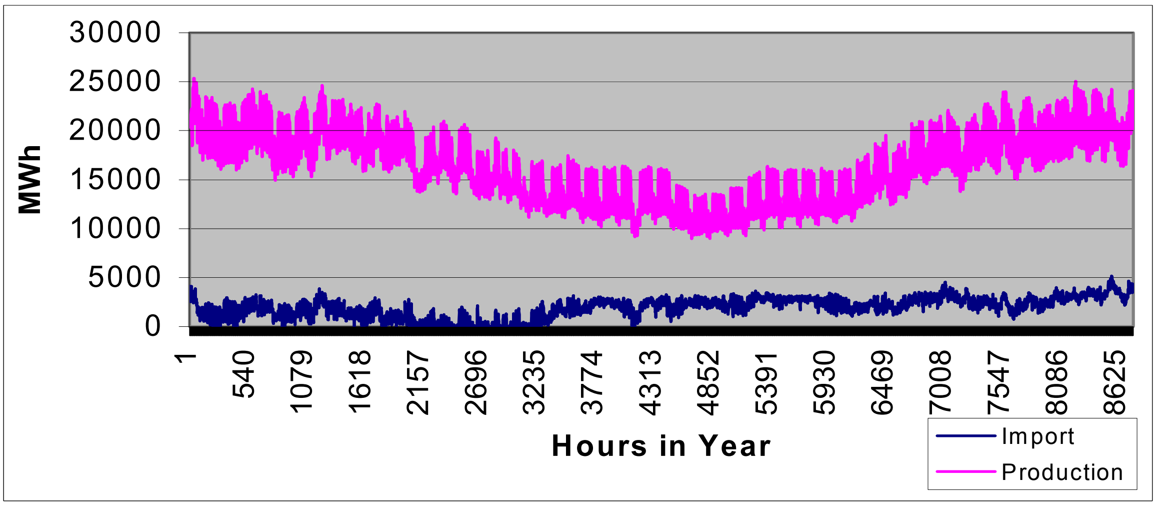

Figure 7. *Hourly production and import to Sweden, 2002 (Source: Svenska Kraftnät)*

Import is higher and more constant during the second half of year 2002. The reason is very dry summer in 2002, which resulted in decreased hydropower availability.

2.2.3 Load problems

Inappropriate dimensioning of the network might restrict the possibility to cover momentary demand. For example, the Swedish power network is dimensioned on total energy need, which is not useful if load demand cannot be delivered on a momentary level. This is the most important reason for system blackouts (Pyrko, et al, 2003). Some parts of the network can form "bottlenecks", not capable to transmit the demand required.

As a consequence of the liberalization of the energy market, many energy generation plants have been decommissioned or preserved for economic reasons. One nuclear power reactor (Barsebäck 1) has been decommissioned. The amount of reserve capacity plants has dropped by about 3 GW, resulting in the margin between maximum load capacity and maximum load demand decrease (North, 2001).

Another important problem is uneven generation location. This problem becomes evident when studying the main areas of production and consumption of electricity in Sweden. The highest demand is located in southern Sweden, where the majority of Sweden's population resides. However, the most important areas for energy generation are located in the north of Sweden. This means that it is necessary to transfer electricity from the north to the south and even to buy electricity from other countries. The south of Sweden is highly dependent on load imports. This also causes bottlenecks within the transmission network (Pyrko, et al, 2003).

2.3 Load management

Load management is defined as sets of objectives designed to control and modify the patterns of demands of various consumers of a power utility. This control and modification enables the supply system to meet the demand at all times in most economic manner (Paracha, Doulai, 1998).The purpose of load management techniques is to reduce peak demand to level daily, seasonal or annual electricity demand. The techniques help to economize system operation by making best use of its available generation and transmission (network) capacity. Thus it is also divided to **network** and **generation** load management, depending on the prevailing need in a system (SEDA, 2003):

> ***Network Load Management****, includes activities that reduce the peak demand on the electricity network, thereby deferring or avoiding the need to augment the network.*
>
> ***Generation Load Management****, includes activities that reduce the peak demand in the generation market, thereby avoiding the need to call on the most expensive electricity generators and deferring the need to build new power stations.*

Load management does not aim to decrease the overall electricity consumption, rather approaches (or replies to) the consumption pattern. It could be applied both on energy demand and on supply sides.

2.3.1 Load management - supply and demand side

Supply-side load management are the measures taken at the supply side to meet the demand. The concept has been very popular in the seventies of the twentieth century. If the society demanded more power, the power companies would simply find a way to supply users even by building more generation facilities. This was the essence of the concept.

However, the supply-side management nowadays include energy storage technologies, such as pumped hydro, compressed air energy storage and thermal storage.

Demand-side load management describes the planning and implementation of activities designed to influence customers in such a way that the shape of the load curve of the utility can be modified to produce power in an optimal way. Peak clipping and load shifting from peak to off-peak periods techniques are used to achieve these purposes. Demand side load management includes not only technical or economic but social measures as well, since it is directly related to the behavioural issues.

2.3.2 Load management – direct and indirect

Load management measures are both **direct** and **indirect**. Direct load management (control) is based on technological measures and controls the load demand by directly switching different equipment on or off. Satisfactory service can be maintained without the continuous use of electricity. For instance, water at a satisfactory temperature can be supplied from a previously heated tank.

> *" If the value of the intensive parameter is maintained, e.g. shower temperature, then the consumer is satisfied even if electrical supply is interrupted. Such demand that is satisfied by intermittent power is an interruptible load, also called switchable load"* (Twidell, 2003).

Modern communication technologies are used nowadays to implement load control measures.

Indirect load control is based on economical measures. Different tariffs and pricing mechanisms are introduced in order to encourage customer to optimise load demand.

2.4 Other measures contributing to load optimisation

Implementation of energy efficiency (conservation) measures can also contribute to the decrease of demand peaks. For example, use of efficient lighting bulbs would both decrease the energy and load consumption. Energy efficiency measure in this case could be considered as load management measure. Often, when discussing load issues, energy efficiency is named as a strategic conservation. In strategic conservation, utilities adopt focused programs to encourage efficient energy use to reduce demand not only during peak hours, but also at other hours of the day; this can reduce average fuel cost and can postpone the need for future utility capacity addition (Bellarmine G, 2000).

Distributed Energy Options also contributes to load optimisation. The Distributed Energy Options include both supply side and demand side measures. Distributed energy primarily refers to (SEDA, 2003):

- *energy that is generated by or close to the end users of energy within the low voltage distribution network*
- *energy saved by the end user through energy efficiency activities and changes in consumer behaviour (load management)*

Many experts forecast a rapid expansion of the Distributed Energy Options in future. This is primarily due to several reasons, such as the development of generation technologies, gradually requiring lower investments, the penetration of IT technologies and energy security.

3. Analysis and discussion – environmental benefits of load management

3.1 Environmental benefits – the systematic approach

The diagram below aims to identify the ways that load management could influence the environmental performance of energy system. Load management aims to achieve the following effects in power system: it is a tool helping to decrease the operation of peak units, helping to avoid generation and network capacity addition, ensuring the most optimal operation of base generation units and increasing renewable energy generation. These measures in principle affect the environment in two ways – by emitting less emissions and preventing the distortion of territories.

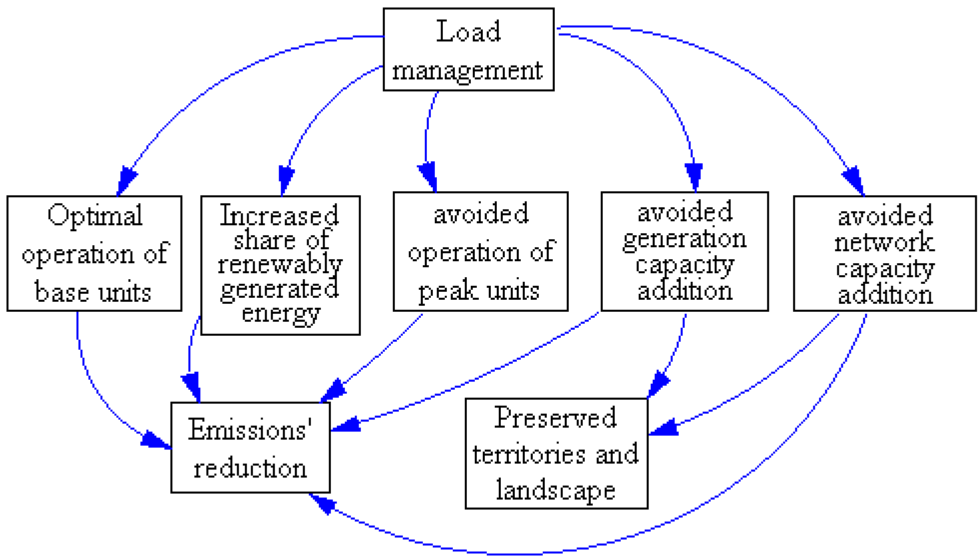

Figure 8. *The ways load management could influence the environmental performance of electricity market*

Load management: avoided operation of peak generation units based on fossil fuels

Marginal production in power market depends both on demand and production structure. In a well functioning market the demand would always choose the production technology with lowest costs. Production technology at the market is a combination of production facilities with varying characteristics and costs. A production technology used at the margin is the one used to cover the last demand unit on the market. In a well functioning market without bottlenecks it will be the production unit, which has the highest marginal costs from the units that are in operation (Swedish Energy Agency, 2002).

The most spread technologies used to meet peak power demand (operating at the margin) are usually condensing power units, gas turbines and diesel generators. The technologies are flexible in terms that they could be started in a short period and respond to sudden demand increase. However these technologies are based on fossil fuels, have lower efficiency and produce higher emissions per unit of output than the base ones (see Table 2). Furthermore, during the period of starting the combustion equipment, the emissions, particularly of CO and particles are much higher (due to incomplete combustion). The more starting periods there are the higher are the emissions. Most often, the peak load following technologies are gas turbines and diesel generators, having low efficiency and high emission factors.

Table 2. *Plant and fuel characteristics. (Based on "Plant and Fuel Characteristics" from the report by Meyers et al, 2000)*

Type of Plant	**Type of Fuel**	**Conversion Efficiency, %**	**Emissions Factor, kgC/MWh**
Conventional hydro			0
Coal thermal	Coal	35	260
Combined cycle	Natural gas	40	137
Fuel oil thermal	Fuel oil	32	225
Diesel generation	Heavy diesel oil	25	288
Gas turbine	Heavy diesel oil	28	257

Load management: optimal operation of base generating units

Under optimal conditions the generation equipment works more efficiently and saves fuel. It also reduces the maintenance costs by stopping and starting less frequently.

If for example bio-fuelled technology is installed for electricity (heat) production, it is very important that it operates as constant as possible. That kind of equipment is sensitive for load fluctuation. The constant operation ensures lower emissions and longer life span of the equipment.

Load management: increased share of renewable generation

Twidell, (2003) points out that

> *"for renewables, the primary source is essential free and usually dispersed, whereas for fossil or nuclear energy the primary source is expensive, yet concentrated. Consequently renewable power economics is capital intensive, with no economic savings obtained by switching off supply".*

Therefore it is extremely important that maximum amount of renewable energy is utilized within the capability of the renewable energy generation systems. Matching of supply and demand is essential and load management measures, such as for example energy storage or variable voltage systems, is the tool to achieve this.

There are the examples where load management measures were put in to increase the proportion of power from renewables. They are much more evident on a small systems. Few of these could be from two Scottish islands of Fair Isle and Foula, where load management

is used to control the matched load for wind power, thus preventing the need for a diesel set in parallel (Twidell, 2003). Other good example is from Gotland in Sweden where load management is considered as a way for increasing the proportion of wind power (Vattenfall Utveckling, 2004).

Load management: avoided generation and transmission capacity addition

Emissions could be reduced due to avoided need to construct new generation units and transmission lines, i.e. emissions produced during the production and construction of new units. There are also other negative environmental impacts, such as visual intrusion, increased magnetic field, that could be avoided if the network expansion was cancelled.

Every shortage of electric capacity can be approached by either reinforcing the already existing distribution network to meet the growing demand, or by trying to adjust the consumption to the capacity that already exists. The latter means implementing demand side management actions.

> *"The way to go are simply decided from a cost-benefit analysis, where all costs concerning the alternatives are taken into account and the cheapest alternatives are chosen"* (Nordvik, Lund 2003).

The choice, however, results in different environmental consequences.

There is a good example in France, the "French Riviera" area, where a transmission and distribution company is trying to avoid grid system capacity upgrades by load management and energy efficiency measures. The Eastern part of the region will be subject to a programme targeting both energy efficiency and load management to reduce peak demand by around 100MW both in winter and in summer (SAVE 2002).

3.2. Load Demand and Emissions in Sweden

The aim of the following analysis is to define how (or if) load demand influences the CO_2 emissions in Swedish electricity system and discuss the possibilities of different load management measures to influence, improve the situation. Years 2001 and 2002 are used for the analysis. The analysis is performed in following steps:

- Identifying and defining the demand peaks
- Calculating the CO_2 emissions during the peaks
- Discussing different load management possibilities to decrease the emissions

Identification of the demand peaks

The first step in the analysis is the identification of the consumption peaks. The highest hourly peaks in years 2001 and 2002 are identified. These days and weeks of these days are selected for a further analysis. Load demand, production in Sweden and import according to the countries are defined in Figures 9 - 12.

According to the data, the highest peak in year 2001 was recorded on Monday, Feb. 5, 2001 (week Feb. 5-11, 2001).

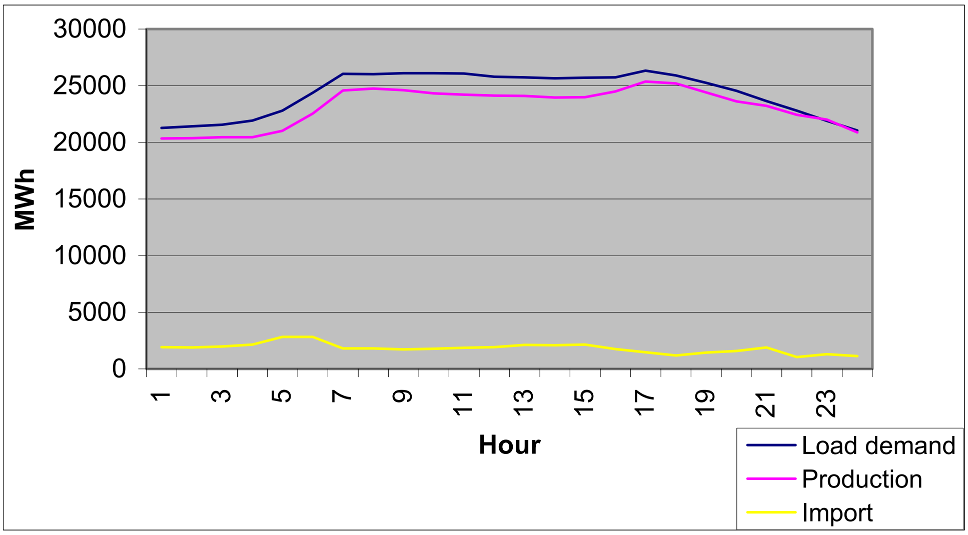

Figure 9. *Load demand, production and import to Sweden Feb. 5, 2001* (*Source: Svenska Kraftnät*)

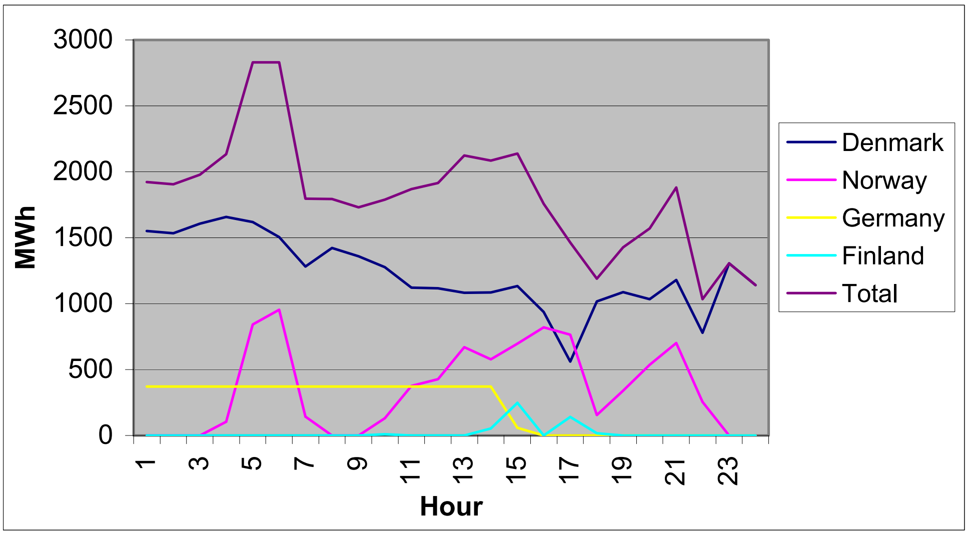

Figure 10. *Import structure Feb.5, 2001 (Source: Svenska Kraftnät)*

Figure 9 shows that the Swedish production follows the demand but not the import. In other words, import is not on the margin during the analysed peak period. According to figure 10, where the import structure is defined, the import is highest during off-peak hours 3-7. Imports from Denmark and Norway are the major ones. At the beginning of peak period (hour 8) the import from those countries decreases. Import from Germany lasts continuously until the beginning of afternoon peak (hour 15).

One important factor while analysing load questions is the difference in consumption patterns during weekday and weekend. The previously analysed peak occurred on Monday. In order to define the weekly situation the full week analysis is presented in Figures 11 and 12.

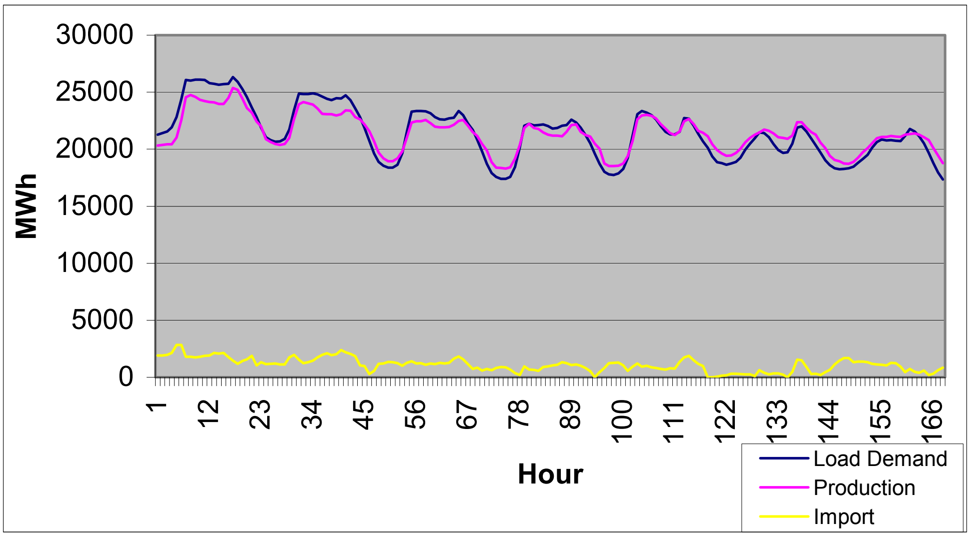

Figure 11. *Demand, production and import Monday, Feb. 5, 2001 - Sunday Feb.11, 2001 (Source: Svenska Kraftnät)*

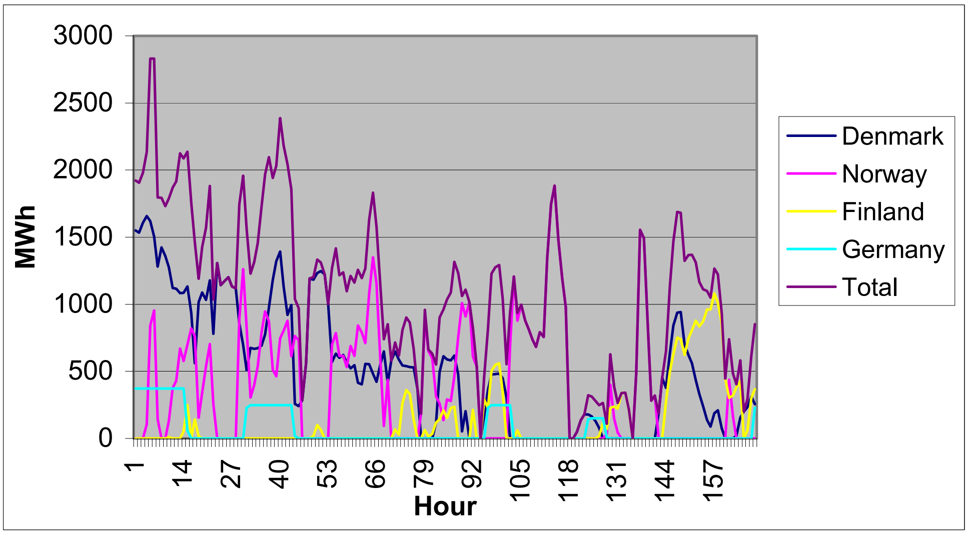

Figure 12. *Import structure Monday, Feb. 5, 2001 - Sunday Feb.11, 2001 (Source: Svenska Kraftnät)*

Weekend load shapes are slightly different from the weekday. The total demand is lower. The afternoon peaks compared to morning peaks are higher than on weekdays. Though the import pattern is difficult to compare some differences could be observed as well.

The highest peak in year 2002 was recorded in Wednesday Jan.2, 2002 (Dec.31, 2001-Jan. 6, 2002). The same analysis procedure as for year 2001 is repeated for this peak (as shown in Figures 13-16)

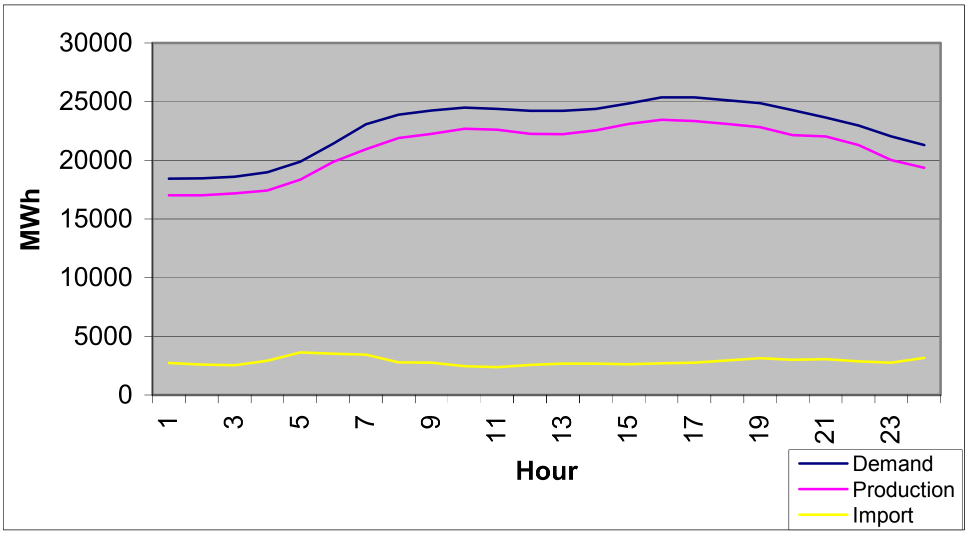

Figure 13. *Demand, production and import Jan.2, 2002 (Source: Svenska Kraftnät)*

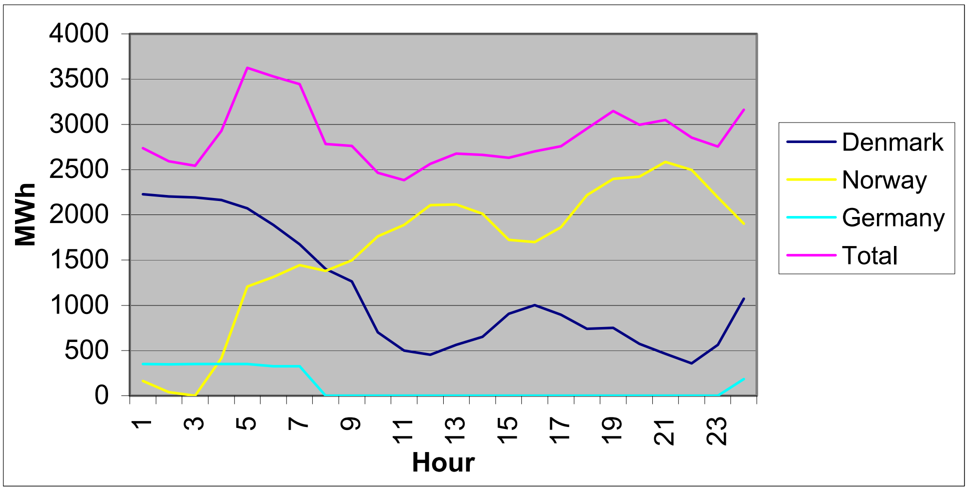

Figure 14. *Import structure Jan. 2, 2002 (Source: Svenska Kraftnät)*

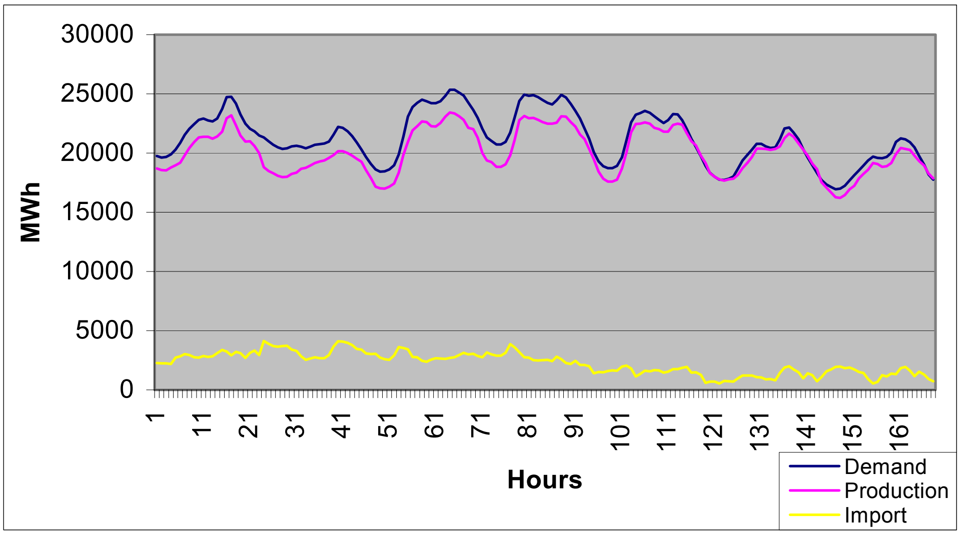

Figure 15. *Demand, production and import Monday, Dec. 31, 2001 – Sunday, Jan. 6, 2002 (Source: Svenska Kraftnät)*

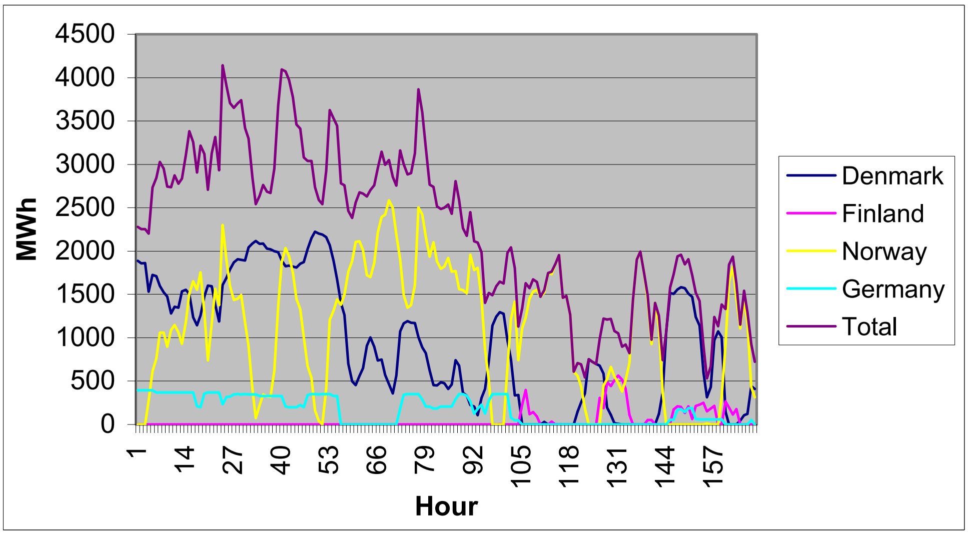

Figure 16. *Import structure Monday, Dec. 31, 2001 – Sunday, Jan. 6, 2002 (Source: Svenska Kraftnät)*

The curves in both analysed peaks show that the import is not following the demand in a short run. The Swedish production is the demand following; the Swedish hydropower units that follow the demand (Swedish Energy Agency, 2002).

The results of this analysis could be compared with the results of the study performed by the Swedish Energy Agency, focusing on marginal power production and CO_2 emissions in

Sweden (Swedish Energy Agency, 2002). By analysing the historical data, the study concludes that in a very short run (hour to hour) hydropower responds to load changes. Hydropower production increases during morning and afternoon peaks and decreases during the nighttime. It is the most flexible technology in the Nordic system. Condensing power units in Denmark and Finland to some extent also follow the daily demand.

Condensing power supply varies depending on hydropower availability. Hydropower in a longer term (over a year) depends on water availability. In case of dry year, the production in condensing power plants increases. First of all, the increase takes place in Danish power plants, but in Finnish and Swedish as well. The conclusion is that hydropower provides marginal capacity to ensure the load availability and the condensing power provides marginal capacity to ensure energy availability (Swedish Energy Agency, 2002).

CO_2 emissions from electricity production

The next step in the analysis is to define what are the CO_2 emissions per MWh of produced electricity in Sweden and in the exporting countries. Swedish Energy Agency (STEM) publishes the data for Nordic countries (Swedish Energy Agency, 2003). The data for Germany and Poland was received from the corresponding institutions in those countries. All the data is compiled in the Table 3. One important shortage of this data is that it is not reported on an hourly basis what production units are employed in each and every country. This is an average annual data. In further calculations it is assumed that every hour the same production mix is used and the emissions are the same

Table 3. *Average CO_2 emissions from electricity production (kg/MWh) in Sweden and countries that export to Sweden (sources: Swedish Energy Agency 2003, NAPE 2003, IER 2003)*

Country	Sweden	Norway*	Denmark	Finland	Germany	Poland
CO_2 Emission (kg/MWh)	12	0	361	170	588	1242

*Electricity in Norway is produced entirely in hydropower plants

CO_2 emissions for the analysed peaks are calculated in following way:

$$e_{CO_2} = \sum \left(E_i * e_{CO_2,i} \right)$$

Where:

E_i – production or import of country *i,* [MWh]

$e_{CO2,i}$ – average CO_2 emissions from electricity production in country *i*, [kg/MWh]

During the analysed peaks the following countries contributed to electricity supply in Sweden: Norway, Denmark, Germany and Finland. There was no import from Poland during the analysed peaks. As mentioned previously, electricity in Norway is generated entirely in hydropower plants without CO_2 emissions.

The relation between power consumption and CO_2 emissions during the analysed peaks is presented in the figures below:

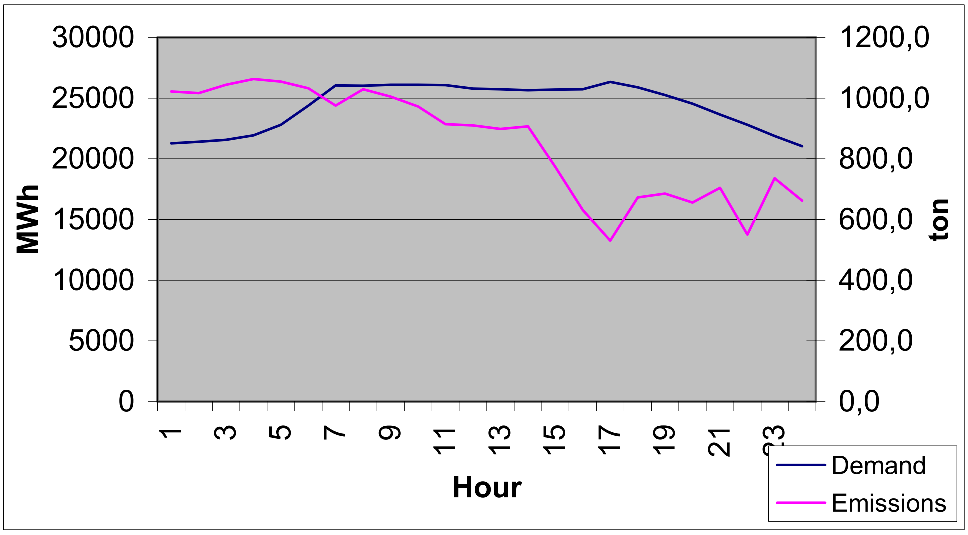

Figure 17. *Demand and CO_2 emissions Feb. 5, 2001*

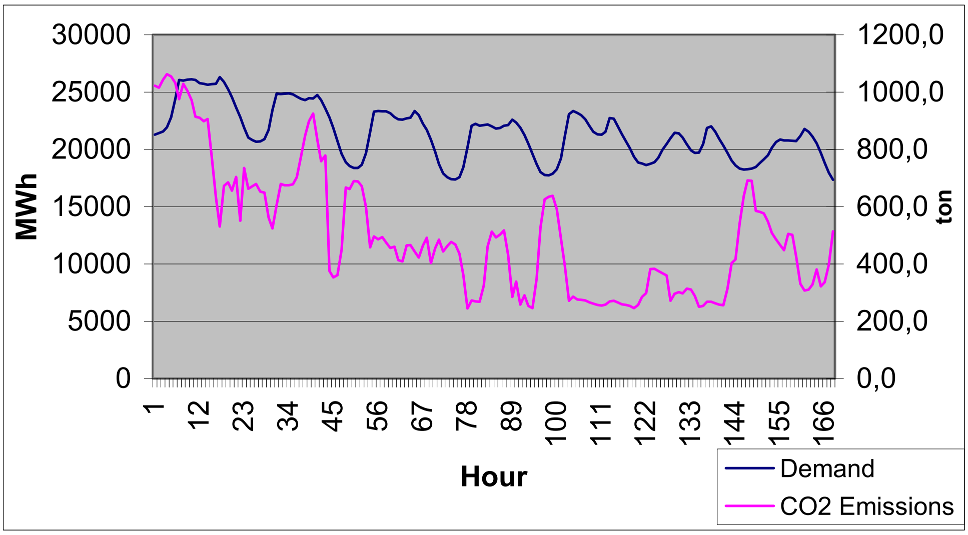

Figure 18. *Demand and CO_2 emissions Monday, Feb. 5, 2001 – Sunday, Feb. 11, 2001*

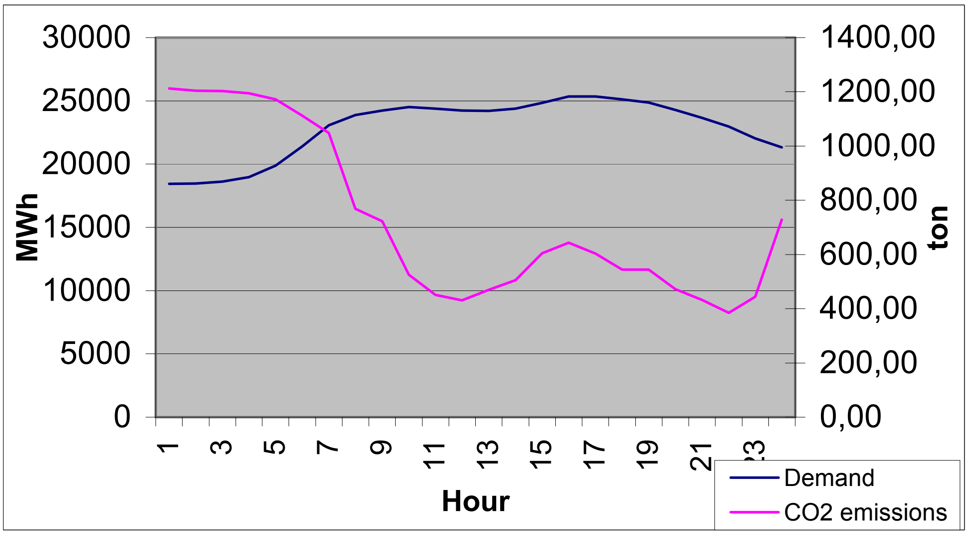

Figure 19. *Demand and CO_2 emissions Wednesday, Jan. 2, 2002*

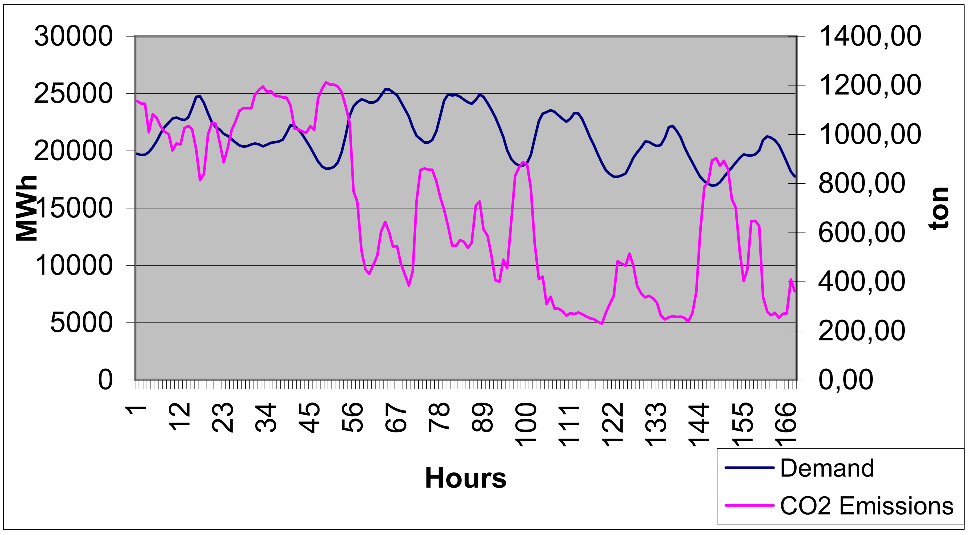

Figure 20. *Demand and CO_2 emissions Monday, Dec. 31, 2001 – Sunday Jan. 6, 2002*

CO_2 emissions from the power consumed in Sweden originate in principle from the imported electricity. In Denmark, Poland and Germany, a great part of power is produced in coal condensing power plants. It means that when the import from these countries increases, the CO_2 emissions increases as well (Swedish Energy Agency, 2002).

The main source of CO_2 emissions in Swedish system is from the power imported from Denmark, one of the major exporters of electricity to Sweden. While comparing Figures 10, 12, 14 and 16 with 17, 18, 19 and 20, it could be seen that CO_2 emissions curves in every case follow the curves of import from Denmark. An obvious way to decrease the emissions seems to be the decrease of import from Denmark.

As the graphs show, there is no direct relation between load demand and emissions. The reasons for that most probably are economic, and the import sources are selected according to the best economic decision. The cheapest power on the market is purchased. During the morning and evening peaks the hydropower is used, which is most flexible technology and at the same time results in no emissions. That is why the emissions are higher during off-peak periods (nights) when more power is imported.

3.3 Load management and emissions in Sweden

3.3.1 Load management techniques

Can load management decrease the emissions in Sweden? This question is quite complex to answer. It depends on many factors already mentioned and, of course, on a kind of load management measures that are implemented.

Peak clipping

Peak clipping means reduction of load during peak periods to get the load profile as desired by the supply side. This is a direct load control measure, primarily used to reduce capacity requirements, operating costs and dependence on peak units. Since the predominant power source to meet the peaks in Swedish system is hydropower, the reduction in emissions would not be significant. However, the share of import from Denmark and Germany prevails during the analysed peak periods (see Figures. 10 and 14), therefore, assuming that this share is decreased by load control measures, the decrease in emissions could be achieved.

Load shifting on the daily basis

If load management would be used as a shifting from peak to off-peak use it is hardly to expect clear changes in emissions. The curves in Figures 17-20 show that the emissions do not follow the demand. Load following power source is the hydropower. Import (the principal cause of emissions) structure varies more due to economic (or other) reasons rather than demand and the environmental performance. The results show that the emissions are even higher during off-peak periods. The reason for that is that the cheaper Danish condensing power is purchased during off-peak (night) period and the hydropower is preserved for the peak consumption.

Load shifting on the weekly basis

Load demand could also be shifted from weekdays to weekends. As the curves show, the consumption patterns slightly differ in weekdays and weekends (Fig 15 and 17). As it could be observed, the morning peaks are lower during Saturday and Sunday. Looking at the emissions curves, however the same tendency, as discussed above, could be observed – the emissions are higher during the off-peak period.

3.3.2 Other measures

As discussed in chapter 2.4, energy efficiency measures contribute to load optimisation and could be implemented due to that reason. Energy efficiency decreases the energy consumption, consequently reducing the emissions.

Another important case in Sweden could be the switching from electricity to other heating source. The Swedish use of electricity is greatly dependent on the climate and the highest peaks usually occur when the outdoor temperature drops. This is due to the fact that electric space heating currently accounts for over 30% of the total electricity consumption in the residential, commercial and service sector (Swedish Energy Agency 2003). The alternatives to electrical heating and sanitary hot water preparation, such as natural gas, biofuel, district heating etc. are widely discussed.

3.3.3. Considering the environment when meeting the load demand

The economic factor plays the greater role than the environment when purchasing the electricity. This conclusion could be drawn from the analysis above. Having a lower load demand, the cheaper Danish power is being purchased instead of continuously using the hydropower plants. The latter is preserved for the peak periods when the prices go up.

All Nordic countries levy taxes on electricity at consumer level. The taxes are differentiated for domestic and industrial consumers (Swedish Energy Agency, 2003). However, the taxes are not differentiated according to the power source, i.e. the customer pays for kWh used, without distinguishing the production source.

3.3.4 Swedish case in European perspective

The situation on the Swedish and Nordic electricity market differs in several aspects from the situation prevailing in the rest of Europe. Huge resources of hydropower make the system less sensitive to load fluctuations, since hydropower is the load following technology in the Swedish system. In a system with less hydro resources it would most probably be gas turbines that would meet the short-term peaks. That technology is the most expensive and polluting one. If that one is used as a peak following technology, the need and results of load management would have been much more important and would have played much more significant role in improving the environmental performance.

Liberalization of electricity markets in Europe creates the possibilities for the consumers to choose their electricity supplier. This choice is usually based on price, but there is a new initiative – environmental labelling which would enable people to decide using the environmental criteria as well (Lane, 2003). Can environmental labelling of the electricity improve the situation? Of course, it greatly depends on the awareness and willingness of the user. If customers purchasing the electricity would see that a significant part of electricity comes from polluting sources they would probably not buy it. This would create a higher demand for renewable energy and could gradually cause a need of load management measures in order to meet the load with a highest possible renewable share. When connecting the issue to load questions it is essential that such information is available on an hourly basis. It is also very important to make this information visible and easily readable for customers. Nowadays, there are the technical possibilities to inform the customer about the usage and price of electricity on an hourly basis. However, the hourly information on what kind of energy is used is not available so far. This kind of information is even difficult to get on a national level, since the producers are not obliged to report it on an hourly basis (Svenska Kraftnät, 2003).

Two other factors that would obviously increase the concerns for load issues are the Swedish strategy to phase out nuclear power and to increase the share of renewable energy. A system of electricity certificates was introduced in Sweden on May 2003 (Swedish Energy Agency 2003). The system determines a certain quotas for the renewable energy (it should be mentioned as well that there are special restrictions for hydropower units to be considered as a renewable energy units and only a very small share meets these restrictions). In year 2003 the renewable electricity quota was 7,4% from the total electricity consumed. In year 2010 this quota will reach 16.9 % (Swedish Energy Agency, 2003). Renewable energy units, such as bio-fuel and wind power normally do not operate as a demand following power sources. This means that during the peak demand hours the dependence on import could increase.

Furthermore, the previously mentioned study on marginal power and CO_2 emissions by Swedish Energy Agency concludes that **in a long term**, natural gas based power production in Norway is considered to be a marginal capacity. It is seen as the cheapest technology while considering the full costs. Due to low natural gas costs in Norway and sufficient power transmission capacities between Norway and other Nordic countries, it should be more economical to import power from Norway than to build natural gas power plants in other countries.

3.4 Case at a local/utility level - Skånska Energi

3.4.1 The utility

Skånska Energi AB[1] is an electricity utility, located in the south of Sweden, Skåne. The utility has 16 000 customers, of which 99 % are residential customers (about 53% of the electricity sale). Skånska Energi also serves industrial companies, agricultural properties and schools (about 47% of the electricity use). About 800 customers (5%) belonging to this grid area purchase their electricity from other energy utilities.

[1] Information used at this chapter was obtained during the interviews at "*Skånska Energi*"

Skånska Energi AB consists of two subsidiary companies - the grid company Skånska Energi Nät AB and the trading company Skånska Energi Marknad AB. They are legally bound to be two different legal entities.

Advanced metering system "CustCom" is installed to all Skånska's residential customers. The system provides automatic hourly measurements (it can even measure with shorter periods - down to 1 minute), as well as electricity control and information services.

Skånska Energi has adopted a minimal risk policy – it means that the company tries to secure its costs by contracts with fixed prices. Therfore, they choose not to buy electricity on the spot market.

3.4.2 Electricity purchases

Historically, Skånska Energi has always had **one** electricity supplier – Sydkraft. But by the turn of the year (2003-01-01), the contracts with Sydkraft are gradually being phased out (finished by year 2006) and new contracts are signed with Vattenfall. The different contracts with Sydkraft have different validity, which means that over some period of time, Skånska Energi will have two distributors.

Earlier contracts with Sydkraft have included a fixed price, often based on a season pricing (winter 1, winter 2, summer and so forth – the same as on the spot market). The earlier contracts have worked with a "rubber band" principle; if the electricity demand is larger than the contracted volume, the price for the exceeding part is still the same. If the demand is below the contracted level, the price for the used electricity is also the same.

The reason why Skånska Energi wants to change its distributor is that Sydkraft no longer wants to sign contracts with the "rubber band" principle. Instead, the exceeding amount of electricity would be purchased at the spot market. Vattenfall has nevertheless agreed to sign a contract that guarantees stable, and therefore predictable, electricity prices (“rubber band”).

As Skånska Energi does not purchase power from the spot market, there is no link between spot price and load management. As the Skånska Energi’s power supply contract looks like today, there is no interest for load management from the **electricity trading perspective**. The price of electricity would be the same no matter what the demand is.

3.4.3 Grid contracts

Skånska Energi has to pay high load demand subscription fees to Sydkraft, that owns the regional grid in the area. The contracted load for year 2002 was 76 500 kW. There are two tariffs – one for weekdays (265 SEK/kW) and for weekends (127 SEK/kW). Hence, from the **grid cost perspective,** there is an obvious interest in load management for the company - to be able to guarantee not to exceed the contracted load level.

3.4.4 Load problem in the utility

Load problem occurs during peaks in winter time. Load demand is especially sensitive for weather changes, as the majority of Skånska Energi’s customers have electrical heating. Daily peak demands (during morning and evening hours) together with higher heat demand due to outdoor temperature drop, cause risk to exceed the subscribed load for the company.

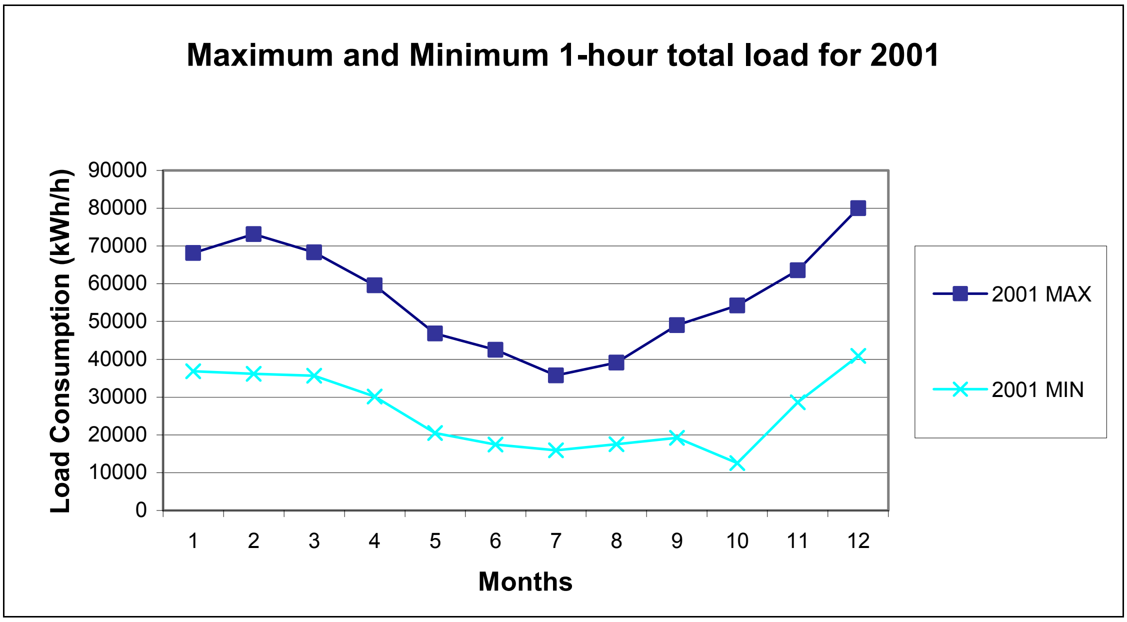

Figure 21. *Skånska Energi's load curves - example for year 2001*

In case of exceeding the contracted load, Skånska Energi has to pay high penalties to Sydkraft, which is the double tariff for every exceeded kW (530 SEK/kW during weekdays and 254 SEK/kW during weekends).

3.4.5 Two alternatives – load management or peak diesel power plant

There is a clear economic interest in Skånska Energi to decrease grid costs, or at least avoid possible penalties. The utility considers two alternatives:

1. To install peak diesel power plant

Skånska Energi considers the installation of 2-3 generators with a capacity of 4 MW each. The used diesel engines from ships are being considered to drive the generators. The plant has to be located closely to the users. The power plant is planned to be used during peak hours, when a risk to exceed the contracted load occurs. In addition, the utility is going to reduce the contracted load by 6 MW and thus save money.

2. To apply load management

Within this alternative there are two possible solutions:

a) Indirect load management. *Skånska Energi* has considered introducing an electricity tariff with load demand component. A comparative study was done in order to see what the effects would have been if the tariff with load demand component from another utility would be applied at Skånska Energi (Perez Mies, 2002). The results showed that it could be a way to improve the customers' consumption patterns and some of the customers would have had a better load profile, however, for the utility in general it would not have been a financially beneficial tariff. Higher benefits would have the customers received. Another disadvantage of this measure is that the utility still cannot be sure that the customer would improve the consumption pattern. It still depends on customers will. Therefore Skånska Energi considers the introduction of direct load control measures as more reliable ones.

b) Direct load control. Advanced metering system "CustCom" is installed to all Skånska's customers. The system can provide automatic hourly measurements (it can even measure with shorter periods - down to 1 minute), as well as **electricity control** and information services.

The CustCom system provides several technical possibilities to control load, such as cyclic control of devices, "object" control, manual "broadcast" control (for more information see North, 2001).

3.4.6 The two alternatives from the environmental perspective

Load demand peaks create significant economic problems for the utility. Both alternative1 and 2 are the solutions, however, with completely different environmental effects. If choosing load management, the increase in CO_2 emissions, as well as other negative environmental effects are avoided.

The construction of the peak plant would have negative environmental impacts both on local and global levels. First of all, the plant has to be located close to the users. This might create significant problems in local environment, as the quality of the environment would be decreased both by emissions and possible noise level increases. From the global perspective, the production of electricity using diesel generators would mean high CO_2 emissions. The efficiency of such a technology is low and the resulting emissions are high. Diesel generation normally has the lowest generation efficiency, reaching only around 25% and also one of the highest emissions factors per fuel, reaching 288 kg C/MWh (1056 kg CO_2/MWh) (see Table 2). For the comparison – the average CO_2 emissions from electricity production in Sweden is 12 kg CO_2/MWh (see Table 1).

As mentioned above Skånska Energi is aiming to decrease the contracted load by 6 MW, from 76.5 to 70.5 MW. From the analysis of hourly load data for Skånska Energi year 2002, it was found out that there were 25 hours when the load demand was higher than 70.5 MW. 47.3 MWh of electricity was consumed during these hours. This resulted in about **0.6** tons of CO_2 emissions. If this electricity was produced by the diesel power plant around **50** tons of CO_2 would have been emitted.

4. Concluding remarks

The analysis of the environmental effects of load management provides different results on different levels. The results, therefore, are different when looking at national situation an analysing the case at a local (utility) case.

National level

Load management measures, such as peak clipping and load shifting can hardly decrease the emissions, as the load following supply source in Swedish system is hydropower.

Energy efficiency measures have a potential to decrease emissions and, at the same time, could contribute to the solution of load problem.

One of the key complications for good estimation of the environmental effects is unavailability of the hourly data, divided according electricity production source.

Local level

As the case of Skånska Energi shows, load management could be an environmentally sound solution to economic problems caused by peak load demand.

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