Chapter 2

European Industries on a Deregulated Energy Market
The Volvo Case

Karlsson, B. – Dag, S.

2.1 Executive Summary

The member countries within the European Union (EU) has agreed to open all national electricity markets for competition, starting January 1, 1999. The electricity market in Sweden is deregulated since January 1, 1996. The deregulation of the electricity markets will gradually shift the electricity price levels in different countries towards an equal price level, which will most likely be close to the levels on the Continental Europe (CE), which are not at all equal today of table 2:1.

A deregulated European electricity market may change the competition situation for Swedish industries dramatically. The capacity in electric generation with low operating costs in Sweden has led to very low electricity prices and high usage level compared to other EU countries. The consumption level of electric energy per capita is nearly three times higher in Sweden than the average per capita EU usage. The high level of electricity consumption is typical also of industrial customers in Sweden.

Studies of Volvo Car Corporation[8] have shown that the Volvo car plant in Torslanda, Sweden utilizes substantially more electric energy per manufactured car than the Volvo car plant in Gent, Belgium.

A method is developed to transform the Torslanda plant from a low energy efficiency state to a higher energy efficiency state by modeling. The method is based on the Life Cycle Cost (LCC) concept and includes optimization models of the two plants with mixed integer linear programming (MILP).

To be able to act efficient on the new deregulated and competitive electricity market industries must have access to tools and routines enabling them to integrate the energy system with other subsystems, e.g. the control system and the material- and productionplanning system, within the company. This efficiency can be secured by systems development leading to a good and detailed knowledge of the electricity use at different locations within the company.

2.2 Introduction

2.2.1 Background

The oil crisis in the 1970's contributed to major changes in the Swedish energy system. The use of oil decreased by 50 percent between 1970 and 1990. Heating processes in the industrial sector and heating of premises in the housing sector were converted to the use of electricity instead of oil as heating source, which has turned both sectors very electricity-intensive.

A massive introduction of nuclear energy in the 1970's and 1980's handled the increased electricity demand[1,2]. Today, most of the electricity production in Sweden is based on hydroelectric power and nuclear power. From the Swedish point of view electricity and oil are therefore substitutes when used for heating processes. In 1995 the hydroelectric and nuclear power plants generated together 93 percent of the total electricity production. The rest was generated in cogeneration power plants, mainly with biomass as fuel. Oil-fired condensing power plants are only used as reserve plants.

The situation is different on the CE, where the electricity generation is mainly based on fossil fuels. The efficiency factor for power plants using fossil fuels for electricity generation is around 35 per cent. It is therefore not reasonable, and consequently not common, to use electricity, generated with fossil fuels, to replace fossil fuels used in heating processes.

Between the second world war and 1970 there was a very fast increase of the oil use in Sweden. Compared to electricity the increase was about five times higher. From 1970 to 1990 the electricity use was increased by 100 percent, while the use of oil decreased by 50 percent. Since almost no fossil fuels are used for electricity generation in Sweden the curve in figure 2:1 describes the actual relation between electricity and oil.

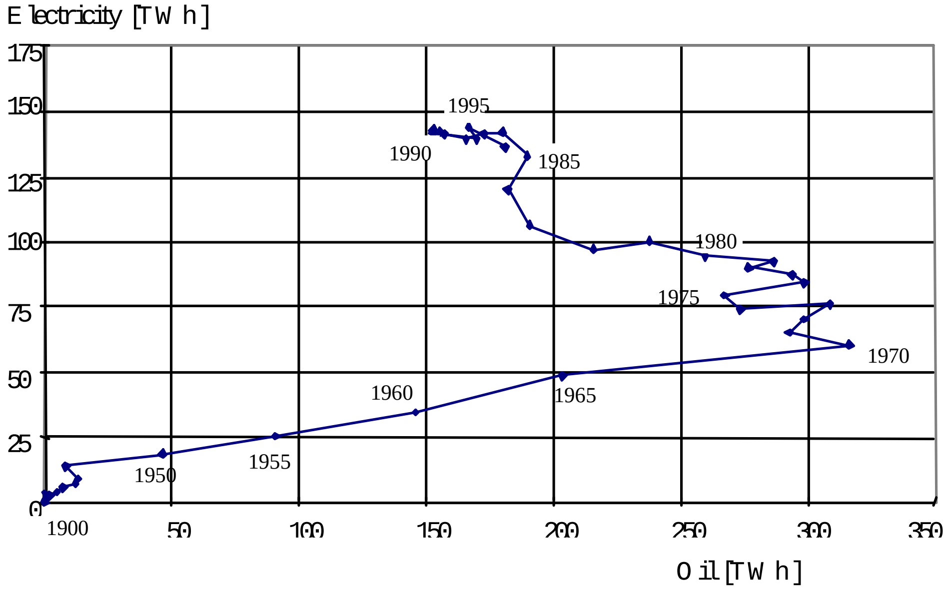

Figure 2:1. The relation between total use of electricity and oil from 1900 to 1996 in Sweden[a].

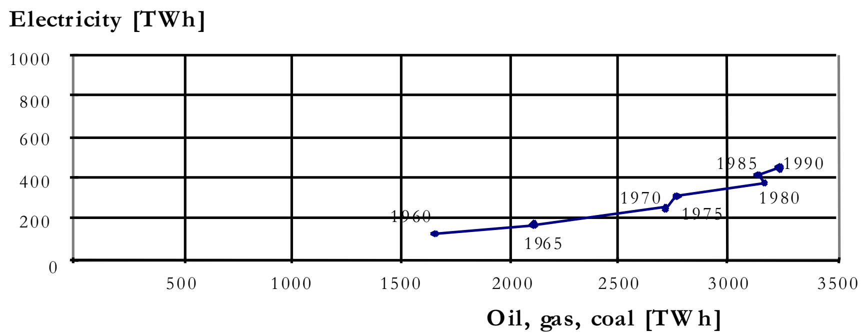

Figure 2:2. The relation between total use of electricity and fossil fuels from 1960 to 1990 in the former West Germany[b].

The relation between total electricity production and total supply of fossil fuels in former West Germany is shown in figure 2:2. Fossil fuels used for electricity generation are included in the figures on the x-axis.

A comparison between figure 2:1 and figure 2:2 show that no conversion from oil (fossil fuels) to electricity of the kind that has occured in Sweden has occurred in West Germany.

A deregulated European electricity market will cause higher electricity prices in Sweden, which means that a ”re-conversion” from the use of electricity to fossil fuels or biomass as energy source in heating processes will take place, which will create an excess capacity.

Instead of oil replacement in Sweden, where 1 kWh of electricity replaces 1 kWh of oil in heating processes, electricity should be exported to the CE, e.g. Germany, and be used for specific electricity purposes and thereby replace nearly 3 kWh of fossil fuels.

2.2.2 Electricity Pricing

Electricity pricing based on short range marginal cost (SRMC) reflects the real cost for electricity and therefore leads to an efficient allocation of resources[4,5]. SRMC is the cost of producing one additional kWh of electricity in the existing system. The marginal cost based pricing method considers future costs, which can be divided into two time perspectives, namely SRMC and long range marginal cost, LRMC. Both SRMC and LRMC describe the balance between supply and demand, but with a different time perspective[3].

In a short time perspective only running cost, RC, and a shortage cost, SC, need to be considered. If the power demand is lower than the maximum capacity in an electricity generating system, SC will be zero. If, however, the demand approaches the maximum capacity there will soon be a risk for shortage of power and consequently an increase in SC. Demand-side measures may in that situation be a cost-effective way to reduce the power demand. In the long run perspective, capital costs for new plants have to be included since there might be a need for an expansion of the generating capacity due to an increase in power demand.

The relation between SRMC, RC and SC is

SRMC = RC + SC (1)

If SRMC, at any time, is equal to or larger than LRMC, i.e. SRMC = LRMC, there is a need for investment in new power plants. LRMC can thus be regarded as an investment criterion[3]. To a certain degree, introduction of end-use measures can

postpone investment in new power plants.

2.2.3 Electricity Prices for Industries in Europe

The consumption of electric energy per person is approximately three times higher in Sweden than in the rest of the EU[11]. For example, the usage is about 2.5 times larger in Sweden than in the former West Germany. In the industrial sector and the household sector, electric energy is not used for heating purposes to the same extent on the CE as in Sweden.

Different systems regarding electricity generation in Sweden and in the countries on the CE mean different marginal cost for electricity generation, which is the reason for the variation in electricity price between the countries in table 2:1. For instance, the electricity generation in Denmark and Germany is mainly based on thermal power plants with coal as fuel. The electricity generation system in Sweden, which is based on hydroelectric and nuclear power plants, is characterized by low operating costs. Electricity costs are higher on the CE because new combined cycle plants fuelled by natural gas define the marginal cost for electricity generation.

Country	**Small industries**[e]	**Medium-sized industries**[f]	**Large industries**[g]
Sweden[d]	*40*[h]	*35*[i]	*29*[j]
Belgium	*96*	*78*	*48*
Western Germany	130	106	78
Portugal	118	105	78
Italy	114	89	54
Spain	109	91	74
Luxembourg	95	63	48
The Netherlands	94	65	46
Ireland	91	70	55
France	85	70	49
Great Britain	84	63	-
Greece	74	69	49

Table 2:1. Electricity prices for industries in Sweden and some other countries within the EU, 1993 [US$/MWh]*[c] *(1 US$ ~ 8 SEK)

[a] *Statistisk Årsbok/Vattenfall, NUTEK*
[b] *IEA Statistics*
[c] *NUTEK (1993)*
[d] *SOU (1995)*
[e] *1,25 GWh/year, 500 kW*
[f] *10 GWh/year, 2500 kW*
[g] *70 GWh/year, 10 MW*
[h] *2 GWh/year*
[i] *50 GWh/year, 10 MW*
[j] *140 GWh/year, 20 MW*

2.2.4 Deregulated European Electricity Market

A deregulated European electricity market, starting January 1, 1999, combined with big differences in electricity prices between the countries in Europe should be an incentive for increased international electricity trade. The impact of this on Swedish electricity prices will be considerable in a long perspective.
The electricity markets of Sweden, Norway and Finland constitute in principal a common Nordic market. As the Nordic electricity market is deregulated, customers within the market can freely buy electricity through a common bourse. This market is highly dependent on hydroelectric power. The Norwegian electricity supply system is mainly based on hydroelectric power plants with very low operating cost. The Norwegian system is energy dimensioned, which means that it is designed for meeting the energy demand also during years with low water affluence. Hence, during years with normal or good affluence, electricity can be exported to neighboring countries. The electricity price has decreased in Sweden since the Nordic electricity market was realized. The increased trade with Norway in combination with good affluence in the rivers has reduced the price. A probable scenario for the progress of electricity prices in Sweden facing a deregulated European electricity market is shown in figure 2:3.

A deregulated European electricity market means that the Nordic market will face another condition, i.e. the European boundary condition. With a deregulated European market, large industrial electricity customers and large distributors within EU will freely choose electricity producers and distributors. Higher marginal cost for electricity generation on the CE will mean increased trade between the Nordic countries and the countries on the CE. The transmission capacity between the Nordic countries, primarily Norway and Sweden, and the CE is continuously extended and will be so to a higher extent as the trade increases[2]. In a deregulated market, German producers would of course be willing to buy electricity for a price lower than their own production cost. The average price level in Sweden should therefore in a 5 to 10 year outlook approach the German electricity price levels. Electricity export to the CE will cause an increase in electricity prices in Sweden.

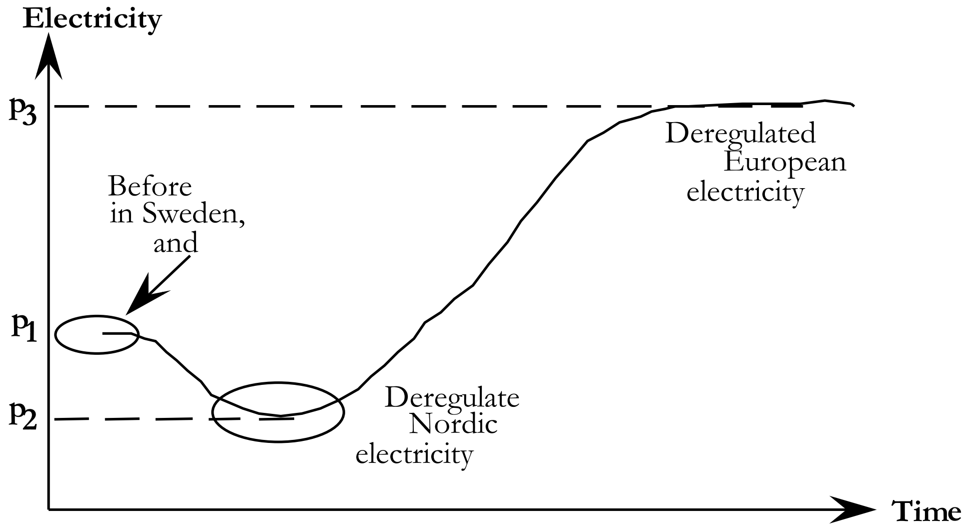

Figure 2:3. A probable scenario for the progress of electricity prices in Sweden.

2.3 MODELING OF THE CAR PLANTS

2.3.1 Industrial Energy System Modeling

When designing industrial energy system models for optimization purposes there are some criteria that have to be fulfilled. It is important to include all factors which may influence the energy system. The electricity and heat demand is not always a linear function of the industrial production or material flow. On an equipment level very often non-linear relations appear, which means that the model must represent non-linear relationships. Non-linearities can be modeled by using 0/1 binary variables in mixed integer linear programming (MILP)[10]. Binary integers can also be used to represent logical restrictions in the energy system. Variations in the boundary conditions, e.g. electricity prices and outside temperature or demand, as well as processes must be represented in the model. This dynamic of the energy system can be modeled in the optimization with a time division reflecting the variations with sufficient accuracy. The length of each time step and the number of time steps should be flexible since industrial systems differ from case to case.

The structure of the industrial energy system is normally represented as a network of nodes and branches. The nodes represent e.g. conversion of energy, distribution of energy and material flows and processes with energy conversion. The branches represent energy and material flows. Formulation of the MILP equations for process selection, i.e. when a product can be manufactured with two processes that are exclusive (both should not be installed at the same time), can be done as Const. is

$Pa + Pb = P$ (2)
$Ia + Ib = 1$ (3)
$Pa - Const. * Ia = 0$ (4)
$Pb - Const. * Ib = 0$ (5)

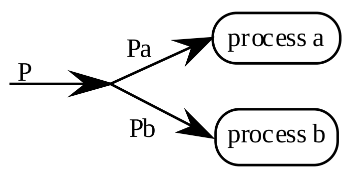

Figure 2:4. Either of the processes can be used for manufacturing.

a large number that should be greater than the maximum values of Pa and Pb. Ia and Ib are 0/1 binary integers assigned to process a and b respectively. P, Pa and Pb are material flows. If for example process a is chosen in the optimization and hence Ia = 1, the binary integer Ib must be equal to zero according to (3), which means that the only way for condition (5) to be satisfied is when Pb = 0. The same discussion is applicable when process b is chosen.

The MILP formulation of a process equipment unit having an electricity demand like a linear function beginning with a step may be written as

$$E - E0 * Int. - slope * M = 0 \qquad (6)$$
$$Const. * Int. - M = 0 \qquad (7)$$

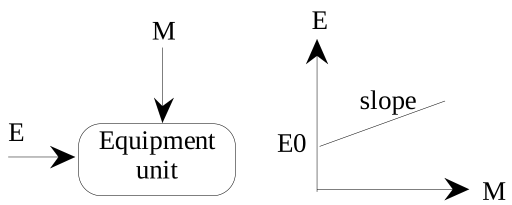

Figure 2:5. A process equipment unit with its electricity demand function.

The constant Const. in (7) should be a number greater than the maximum value M can be assigned, E is the total electricity use, the integer Int. is a 0/1 binary variable indicating the existence of the equipment, E0 is the initial energy value at no material load, M is the material flow through the unit.

The objective of the optimization is often to minimize the system cost for the industrial energy system during the analyzed period of time. The system cost is normally the sum of costs for electricity, fuels, raw material and investments. Other costs, e.g. environmental costs and maintenance costs that may be of importance for a particular system can be included in the optimization.

2.3.2 Life Cycle Cost

The life cycle cost (LCC) is a total cost analysis method. The LCC is calculated as the sum of all internal and external costs that can be related to a product or a production system during its entire life cycle[6].

The above definition of LCC is in accordance with the definition of the system cost for an industrial energy system for the chosen time period. All costs can be regarded as either fixed costs or running costs. LCC can thus be defined as the sum of all fixed and running costs.

$$LCC^T = \sum_T (FC) + \sum_T (RC) = \sum_T (FC + RC) \qquad (8)$$

where T is the time period for the analysis, FC are the fixed costs and RC are the running costs.

2.3.3 The MIND Optimization Method

The MIND[7] method has been developed for optimization of dynamic industrial energy systems. The optimization is carried out by mixed integer linear programming in order to minimize the system cost. The system cost may include investment cost for the time period chosen in the optimization, energy costs, raw material costs, etc. Binary integers are used in the optimization procedure for example to represent non-linear relationships as piecewise linear segments or as step functions and logical restrictions in the energy system.

The structure of the energy system is represented as a network of nodes and branches. The branches represent energy or material flows. The branches and the nodes of the network are specified with information about the nodes and the flows in the network, e.g. type of flow, limitations, alfa-values, energy demands and energy functions. The optimal energy and material flow path through the system is determined from a structure which includes all competitive options.

2.3.4 Energy System Network of the Volvo Plants in Gent and Torslanda

The MIND method is used to model the energy system at both car plants[8]. The structures of the plants are similar to each other, which means that the schematic energy system network in figure 3:6 is valid for the two plants in Gent and Torslanda except for three deviations in the Gent plant, there is no press shop, natural gas is not used in the welding shop and there are no waste-heat deliveries to the plant.

The electricity demand and the natural gas demand at both car plants is fully satisfied by external electricity and natural gas suppliers. Well distributed hot water networks exist within the plants. Almost 100 percent of the heating demand is covered by deliveries through the network. Compressed air is also distributed via central network systems.

The time division in the models is based on the electricity tariff, the production pattern at the different subplants and the variation in electricity and heat demand over the year.

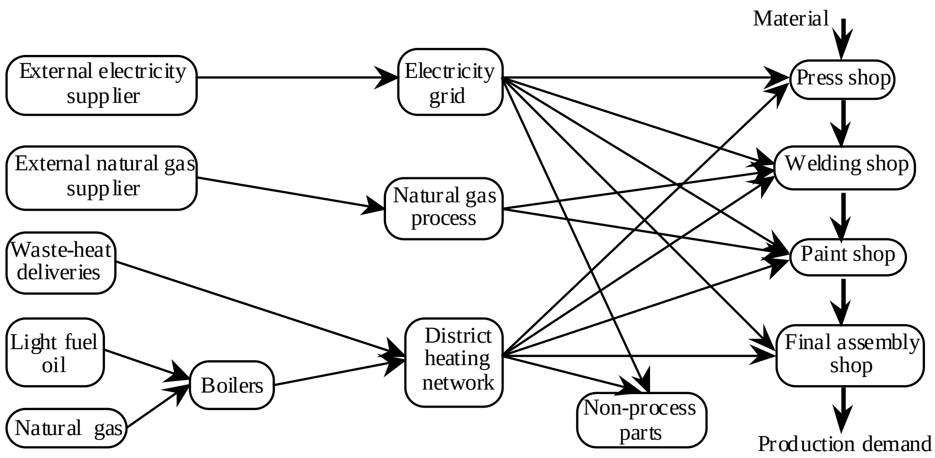

Figure 2:6. A schematic node network of the energy systems in Gent and Torslanda.

2.4 Transition of the Volvo Plant in Sweden

2.4.1 Electricity Use in Gent and Torslanda

Studies of the Volvo car plant at Torslanda in Sweden and the Volvo car plant at Gent in Belgium show that the Swedish plant utilizes more electric energy per manufactured car. This fact remains also in comparison with other car producers. Different price levels on electric energy between the two plants is probably the main reason for this difference. Lower prices lead to higher usage level. Higher prices, on the other hand, lead to a higher cost awareness, which reduces the usage.

An energy bench-marking among some car producing companies in Belgium in 1993 indicate very clearly that the price level is indeed an important factor for the usage. In fig. 2:7 the electricity price is plotted against the electricity use per car for the companies participating in the energy bench-marking study. In the same graph the figures for Torslanda are included, showing how much more electric energy the company uses compared to the others. Only the total of electric energy used in the welding, painting and final assembly subplants is compared since these activities exist in all plants involved in the study.

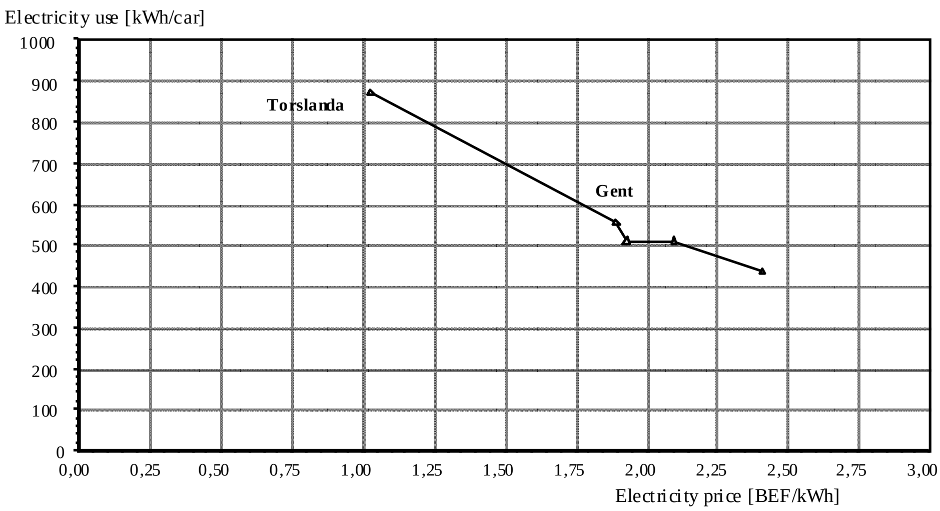

Figure 2:7. The electricity use per manufactured car as a function of the price level for five plants. All plants, except Torslanda, are situated in Belgium.

2.4.2 The LCC for Electricity Use in Gent and Torslanda

The total cost for electricity, i.e. electric energy and power, per manufactured car shows a minimal difference between the Gent plant and the Torslanda plant, which could be expected since the electricity cost is lower at Torslanda while Gent is more efficient regarding electricity use per car. Other factors, besides the electricity price level, contributing to the different usage levels of electricity might be the composition of the manufacturing process used at each plant and the total volume of cars being produced. However, both plants produce the same kind of cars with quite identical manufacturing processes and about the same amount of cars annually. Furthermore, assume that when investing in other equipment, e.g. lighting and ventilation, the optimal choices for each plant were made considering boundary conditions, such as the electricity price.

The total cost for electricity use, which is here defined as the sum of electric energy cost, power cost, maintenance cost and investment cost for electricity monitoring and controlling devices, can be regarded as the LCC for electricity use. The cost for electric energy and power counts for the major part of the total cost.

The knowledge of the total cost for electricity, i.e. electric energy and power, per manufactured car together with the optimality assumptions made earlier provide enough information to design the schematic LCC for electricity use as a function of the electricity price at each plant, see figure 2:8.

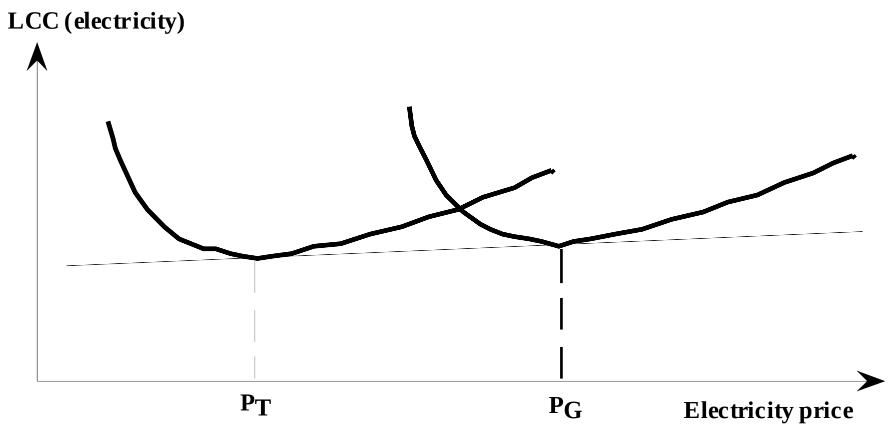

Figure 2:8. LCC for electricity use as a function of the electricity price for Gent (P_G) and Torslanda (P_T).

The two plants are running at an optimum regarding the total cost for electricity use with today's electricity prices:

$$\frac{\partial LCC}{\partial P_G} = 0 \quad \text{and} \quad \frac{\partial LCC}{\partial P_T} = 0 \qquad (9)$$

Almost the same total cost for electricity at the two plants, independent of the price level, means that the lower electricity prices at Torslanda is of no advantage regarding competition.

2.4.3 The Volvo Plant in Torslanda Towards Higher Energy Efficiency

Because of higher electricity price at the Gent plant there is a greater awareness of electricity costs compared to the Torslanda plant. The higher awareness is brought to light e.g. when comparing the electricity monitoring and controlling equipment at the two plants. The Gent plant has invested in a more sophisticated system enabling them to control the electricity flows better within the factory. To measure is to know. The Gent plant also has a higher degree of automation regarding the electricity use, e.g. electricity for lighting and ventilation are shut off automatically after working hours. A load management program of the electricity demand at the Gent plant is active throughout the year reducing electric peak loads[9], which in turn means reduced power costs. Such a system does not exist at the Torslanda plant.

Due to less control of the electricity use at the Torslanda plant there is an electricity demand of 40 percent of the top demand during non-production time[8]. This is far more than the 25 percent for the Gent plant. The Torslanda plant should adapt the energy management philosophy applied at the Gent plant.

The Torslanda plant is more electricity intensive regarding lighting. For instance, at the final assembly subplants there is an electricity output to lighting per production area of 11.7 W / m2 at the Torslanda plant, while the figure is only 8.1 W / m2 for the Gent plant. Comparing the two plants with respect to various needs shows that major improvement can be made at the Torslanda plant.

The system development should include among other things a decision model for optimal operation in real time, a communication interface to the power market, a model for predicting the power demand, e.g. based on artificial neural networks, per hour, day and week, see figure 2:9. The present systems for monitoring and control of the power and energy demand should also be further developed.

The proposed system development will create enormous information flows which must be handled in an efficient way.

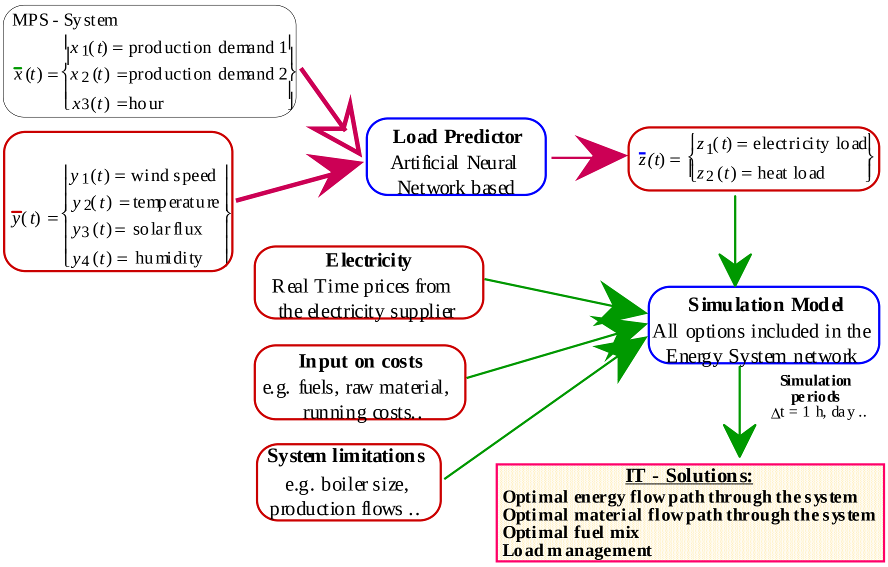

Figure 2:9. System architecture of an energy system integrated with other sub-systems within a company.

2.5 Conclusion

With a deregulated European electricity market the electricity price levels in different countries will gradually equalize, as the market economy in combination with the linking of the electricity network between countries will lead to more or less uniform electricity prices based on the total demand and capacity.

Within a few years the car plant in Torslanda will pay the same for electricity as the plant in Gent. This is not to say that the price level will be the same as in Gent today. The deregulation in Belgium and its neighboring countries may also lead to a lower price level. The final price is not important as the knowledge that both Torslanda and Gent soon will pay the same electricity price.

As a consequence of this, it will be of outmost importance for the car plant in Torslanda to start the transition towards higher energy efficiency, before the higher electricity prices are a fact.

The situation described in this paper is not specific of Volvo as similar situation exists for Electrolux, a global Swedish white-goods producer, and several other companies in Sweden.

2.6 References

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