Electricity Use and Related CO_2 Emissions for Cooker Manufacturing in Denmark, England and Sweden: A Benchmarking Study

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ABSTRACT

The European electricity market became deregulated by the beginning of 1999 and there is now free trade in electricity across the borders. This means that Swedish industry has two incentives to reduce electricity use. The deregulated electricity market means that the problem with CO_2 emissions is common within the European Union. Nationally, Swedish electricity use does not cause high emissions of CO_2, due to electricity production being mainly based on nuclear and hydropower. However, in a European context Swedish electricity use will cause higher global CO_2 emissions, as the production of electricity generated at coal-fired condensing power plants will rise. The other incentive is the electricity price. Due to the lower price compared with other countries in Europe, Swedish electricity is increasingly becoming an export product on the European market. This will most certainly lead to higher electricity prices in Sweden.

Energy statistics and studies imply a clear relation between electricity price and electricity use. For the industrial sector in countries with low electricity prices, electricity is a major energy source. Electricity is the dominant energy source not only for industrial processes, but also for support processes, such as process heating and heating of the premises. The situation is quite different for industry in countries with high electricity prices. Electricity is sparsely used and only for electricity-specific processes.

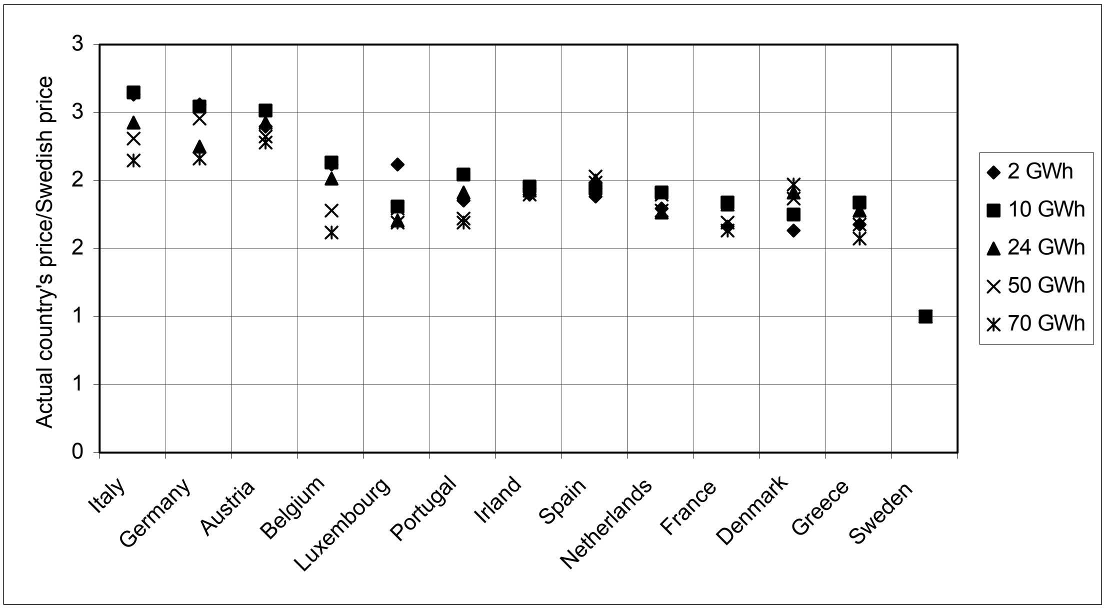
A benchmarking study of the electricity usage pattern for Electrolux cooker manufacturing in three European countries, i.e. Fredericia in Denmark, Spennymoor in England and Motala in Sweden, was conducted in order to identify differences in electricity use among the factories. The results from this study are presented in this paper.

Introduction

Electricity is a major energy source in Sweden, both for the industrial and residential sectors. The oil crisis in the 1970s led to a transition from oil to electricity, where electricity has replaced oil in non-electricity-specific processes as well, for example heating processes. In 1998, Sweden had the second highest electricity use per capita of the OECD countries (IEA 1998). Before the oil crisis, electricity production in Sweden was based on hydro power and conventional thermal power, including cold condensing and CHP plants, and from1970 on there was a massive introduction of nuclear power. Before the oil crisis more than 75 % of the energy used in Sweden was produced by oil (Swedish Energy Agency 1999).

Due to the low running costs for the hydroelectric and nuclear power plants, the electricity price has been low for both the industrial and residential sector, compared to other OECD countries, which mainly have thermal power plants fired with fossil fuels. The electricity price for industries in Continental Europe (CE) has been two or even three times higher than for the Swedish industrial sector, see Figure 1.

Figure 1. Electricity Price for Industries in OECD Countries in Relation to Sweden, 1 Jan. 1999



Source: VIK 1999.

The deregulation of the electricity markets in the EU started in January 1999 and now there is free trade in electricity across the borders. After deregulation electricity prices decreased for many EU countries. In Germany, electricity prices for industry have fallen 23.3% since January 1999 (VIK 1999-2000). In Sweden, electricity prices fell 9.1% for the same period and are now rising again, but they are still lower than in Germany. The deregulation will result in harmonised electricity prices within the EU and consequently a higher electricity price in Sweden in order to match the electricity prices on the continent. The electricity prices will most likely correspond to the price of new condensing power on the continent.

The expected rise in electricity prices is one incentive for Swedish industry to reduce its electricity dependency. A clear trend towards higher electricity use with a lower electricity price has been shown in different studies (Dag 1999; Trygg 2002). One explanation is that for industries with a low electricity price, it is profitable to use electricity as the energy source for non-electricity-specific processes. At Volvo the electricity use per manufactured car was 560 kWh/car at the Gent plant and 1220 kWh/car at the Torslanda plant (Dag 1999). The electricity price at Gent was 1.8 times higher than at Torslanda. Also the electricity use during non-production time was higher at the Torslanda plant, 43% of maximum electricity use and 35% at the Gent plant.

Another incentive for Swedish industry to reduce its electricity dependency is increasing global environmental problems, for example global warming related to rising CO_2 emissions caused by electricity production. Sweden's electricity production causes low amounts of CO_2 emissions. However, with the common electricity market and electricity exchange between the countries, the marginal electricity production is made by coal-fired condensing power plants. Marginal electricity is defined as the electricity generated to cover the last used units of electricity on the market. In a functioning market it is the production units with highest running costs that generates the marginal electricity, and those are often the power plants with the poorest efficiencies. In the Nordic power market it is coal-fired condensing units that provide the marginal electricity and they have efficiencies down of 33% less. As a consequence these units have high emissions of CO_2.

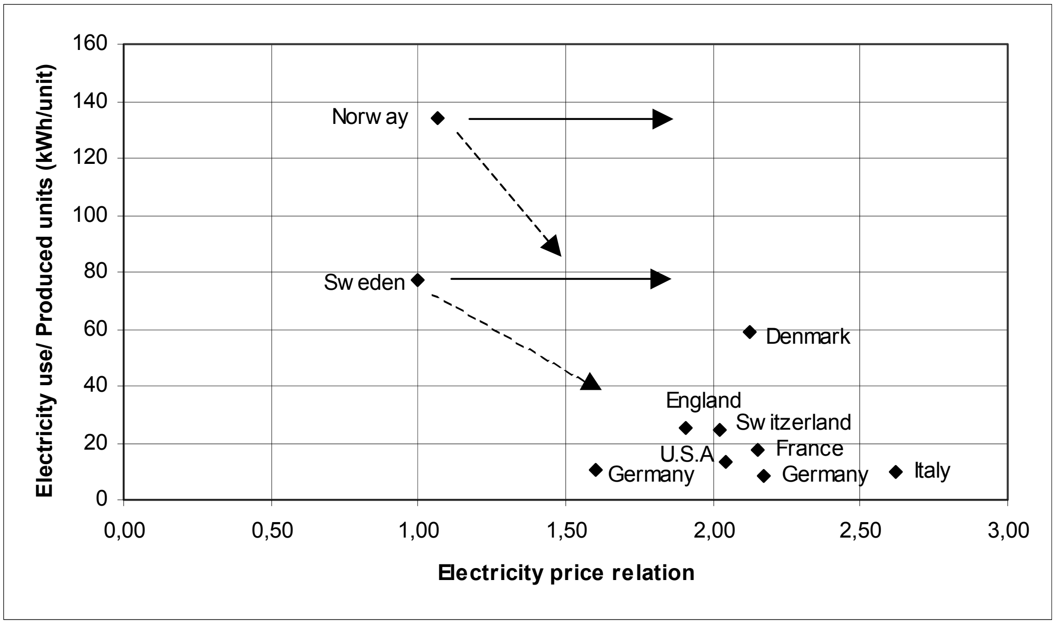
As climate effects due to CO_2 emissions and other greenhouse gas emissions are global in nature, it is important to look at the effects of a change in electricity use in one nation from an international perspective. Electricity savings in Sweden do not lead to any noticeable reduction of CO_2 emissions nationally, but considering the whole north European electricity market the CO_2 emissions will decrease due to less coal-fired condensing power. This has been shown in a study made by the Swedish Energy Agency (Swedish Energy Agency 2002).

The results in this study are based on marginal electricity production. This means that the CO_2 emissions are based on electricity generated at coal-condensing power plants, as it is these production units that will run less due to electricity reductions in a fully integrated electricity market.

The Case Studies

To investigate the validity of the electricity use and price connection for other manufacturing industries, a benchmarking study was conducted for cooker manufacturing in three European countries. It was three Electrolux factories: Fredericia in Denmark, Spennymoor in England and Motala in Sweden, which manufactures household cookers. The factories were chosen after an overview pre-study, in which the energy and electricity use at factories from different European countries and the U.S.A. was illustrated by diagrams. Figure 2 represents one of the diagrams, which shows the electricity used for producing one unit related to the electricity price. The electricity price relation is defined as the actual country's price divided by the Swedish electricity price. The price relation is 1 for Sweden.

Figure 2. Electricity Use per Produced Unit for Electrolux Cooker Factories



This diagram shows a clear difference in electricity prices and use. Sweden and Norway have high electricity use and a low electricity price, while the other countries have low electricity use and a high electricity price. The electricity price for example in Germany is 0.0648 EUR/kWh, which is nearly double the Swedish electricity price. A harmonisation of the electricity prices due to the deregulation of the electricity markets within the EU can lead to different consequences; see the horizontal arrows in Figure 2. This will happen if Sweden and Norway gets a higher electricity price and maintain their electricity use. The other consequence, shown by the dotted arrows, will happen if changes in the electricity price lead to a change in electricity use.

From these figures the best-fitting plants to study were chosen. The criteria for the different plants were different electricity prices, similar products, comparable production capacity, insubstantial differences in size and not very different climate conditions. This means that at least two plants in northern Europe were best suited. As shown in the diagrams, Sweden has a low electricity price and high electricity use. England has a high electricity price and low electricity use. Even Denmark has a high electricity price, but not that low electricity use. It is of great interest to find an explanation for this.

The hypothesis is that Swedish industry must be prepared to decide necessary arrangements to make electricity use more efficient due to the deregulation of the European electricity market.

Method

In this work the results from a benchmarking study is used to explain differences in electricity and other energy use. In order to investigate possible electricity reduction and connected CO_2 emissions for the Motala factory, an optimization tool was used.

Collecting Data

All data was collected by energy mappings of each factory. The goal in mapping was to get a total picture of the electricity and energy use. This picture was broken down into more detailed information, by collecting and summarizing information about energy use at different levels. The total energy use and energy costs were of interest for the total picture. Then data were summarised to cover different departments and processes.

The data were collected through company statistics, meter readings, measurements, informal discussions with employees and impressions from the production areas. From company statistics, information about total energy use, energy cost, material use and energy use for some of the larger processes was gathered. For some of the departments and larger processes electricity meters had been installed, but other processes that were found interesting had to be measured.

Mainly larger manufacturing processes and smaller processes of special interest were measured. For measuring electricity use, two kinds of tools were used: for momentary values, a clip-on ammeter, Fluke 41B, and for the logging of electricity, Orion Mini tags. The Fluke 41B has the following measuring accuracies: ±0.5% for current, ±1.0% for power and ±0.02% for cos φ. The Orion Mini tags are clip-on ammeters equipped with data loggers. Each ammeter has one data logger. Logged data are transferred to a measure treatment program, ISIMU, where the measured data can be visualised in diagrams. The measuring tolerance for the Orion Mini tags is 1.5-2.0%.

The Orion Mini tags register a mean value every minute. There is a mean value every second, building a mean value every minute. This mean value is the measured value plotted.

From the measured data, the minimum and maximum power use and the working time and hours were determined. The energy is calculated from the measured data as $E = \sum \frac{P \cdot t}{60}$ (kWh) and a mean power demand is calculated as $P_m = \frac{\sum P}{n}$ (kW), where P is the power demand in kW, t is the time in minutes and n is the number of timesteps. A mean power demand in relation to the installed power, *PR*, is calculated with the expression $PR = \frac{P_m}{P_i} \cdot 100$ (%), where P_i is the installed power.

Ventilation, lighting and compressed air. From drawings and observations at the ventilated areas, a picture of the ventilation was constructed. Most ventilation is running all working hours with an almost constant load. Therefore, to calculate the electricity use for most of the ventilation units, a momentarily measured value was used. Some special ventilation units were also logged.

In addition to measuring the electricity use for lighting, the light fittings were counted and the energy use was derived. Brightness is important for evaluating light quality. Brightness was measured with a Hagner lux meter. Values were taken at evenly spaced points in the manufacturing area. The Swedish guideline says sufficient brightness is 300 lux for manufacturing at an engineering industry.

The energy use for the compressors was either taken from meters on site or measured. In addition, air load diagrams were analysed. From these diagrams the base loads, leakage and process-related loads were identified. All three factories were examined in order to find air leakage into the process areas. For this purpose an ultrasonic probe was used.

Non-production inspection. From the power utility's electricity figures of the factories, a base load during non-production time can be identified. To investigate this load, non-production inspections were made. During non-production time inspections in the production areas were made on one or two occasions. During the inspections, everything running was noted, for example, lighting or machines. Remarks about the status of the processes were recorded, whether they were supposed to be running or not. These notes were summarised and in this way the energy use due to non-production losses could be estimated.

Energy distribution for cooker manufacturing at Motala. The Motala factory not only manufactures cookers, but also cooker hoods and adsorbent refrigerators. As the main idea was to compare different cooker manufacturers, the manufacture of cookers had to be isolated.

The factory was divided into different departments. In most of the departments the production is mixed, but in the enamel department, only cooker parts are processed. For the departments with mixed production, distribution keys allocated the energy use according to the processes. The keys are built on the amount of details for each processed product; i.e.

there are different distribution keys at different departments (Nord-Ågren 2002). Energy use for lighting, ventilation, compressed air and heating was also allocated with distribution keys.

Benchmarking

To compare the energy use of the factories, the unit process method was used. The method is a way of structuring industrial energy use, where the manufacturing processes are divided into new processes according to their main tasks, e.g. heating a product, transporting or mixing materials. These new processes build the unit processes (Nord-Ågren 2002). Unit processes are general; i.e. they are the same for all different lines of industry. Industries can be benchmarked both in the same trade and in different trades.

In order to create the unit processes, the following information was collected for the manufacturing processes: installed power, the kind of energy carrier, operation hours, energy use and material flows. For the manufacturing processes, the proper unit process was identified.

For easier handling of collected and measured data, a relational database was developed in File Maker Pro 5.0. It is a relational database where data can be put together in different report registers according to certain criteria. In the report registers data is put together according to departments, unit processes, transformers and unit processes within the same department. Data gathered in the report registers are total energy use, energy carriers, total installed power and material flows (Nord-Ågren 2002).

Estimation of CO_2 Emissions

The CO_2 emissions related to energy and electricity use were calculated with the following method in this study. Estimation of the CO_2 emissions due to the electricity use was made with the marginal electricity method. This means that the amount of CO_2 is based on the power plants covering the last used unit of electricity, as it is those production units that will be reduced when there is a reduction in electricity use. In the northern European electricity market it is coal-fired cold condensing plants that generates the marginal electricity, which means that the CO_2 emissions due to electricity use are taken from this type of power plant.

The CO_2 emissions are calculated as $m_{CO_2} = \frac{E \cdot c}{\eta}$ (kg/year), where E is the energy demand in kWh, c is the amount of CO_2 per energy unit in kg/kWh and η is the efficiency. The values of c and η are shown in Table 1.

Table 1. Values of c and η

Energy carrier	c (kg/kWh)	η (%)
Electricity	0.837	100
Oil	0.2736	90
Natural gas	0.2052	80
LPG	0.2157	90
District heating	0.2736[1]	416[2]
Coal	0.3348	80

The Optimisation Tool

To investigate different electricity saving actions at the Motala factory an optimisation tool, reMind, was used. ReMind is a MILP (mixed integer linear programming) program, developed at the University of Linköping, Sweden. ReMind is a new version of the optimisation tool MIND and is written in JAVA code with a user-friendly interface. These optimisation tools are intended for optimisation of industrial energy systems where the objective is to minimise the system cost. The MIND tool was developed by a former PhD-student, Katarina Nilsson, at the division of Energy Systems, University of Linköping (Nilsson 1993).

The features of reMind and MIND include a flexible time division, representation of both energy and material flows, representation of non-linear relationships and the possibility of choosing different levels of accuracy in parts of the energy system. To make an optimisation, a model of the industrial energy system is made in reMind and the equation matrixes are generated. The model is then optimised with a mathematical optimisation tool such as ZOOM or C-plex.

In the model the industry's energy system is described with different nodes and branches. The nodes can represent energy conversion units, power generation, manufacturing and support processes. The branches represent different energy and material flows within the industry. For the nodes different relations and time divisions are identified. The relations describe how the process or energy conversion works or depends on energy. The time division describes working hours and different cost periods.

Results and Discussion

Total Energy Use

At both Motala and Fredericia the major energy source is electricity, see Figure 3. At Fredericia the other large energy source is oil, used for steam production both for industrial processes and heating of the premises. Electricity is the most expensive energy source at Fredericia. Oil is the second largest, but not that expensive. The electricity price is double the oil price; i.e. the largest economic savings with unchanged energy prices can be obtained by reducing electricity use. Electricity use is most sensitive to price changes; there can either be

[1] The amount of CO_2 per energy unit is valid for the district heating fuel mix, i.e. 76% bio-fuel and 24% oil, in Motala Energy AB.

[2] The efficiency is valid for the district heating fuel mix mentioned above, in Motala Energy AB.

large reductions or rises in electricity cost. One alternative is district heating, but today the price is too high.

Motala is using district heating for heating the premises and hot water. At Motala the electricity price is equal to the district-heating price.

At Spennymoor the major energy source is natural gas and then coal. During the study Spennymoor's coal-fired boilers were decentralised. Today all coal is replaced by natural gas. At Spennymoor electricity is expensive compared to natural gas, i.e. gas-fired processes are chosen instead of electricity, as far as possible. If the energy prices remain constant, electricity savings are most profitable. Gas is the most cost-sensitive energy as the main energy supply, where a gas price rise leads to a large rise in energy costs. If electricity prices become lower, energy costs will be greatly affected, for example if the electricity price is equal to the Swedish electricity price, which is half of that in England, the cost is reduced by 330 000 EUR.

Figure 3. The Total Energy and Energy Cost Distribution for All Three Factories

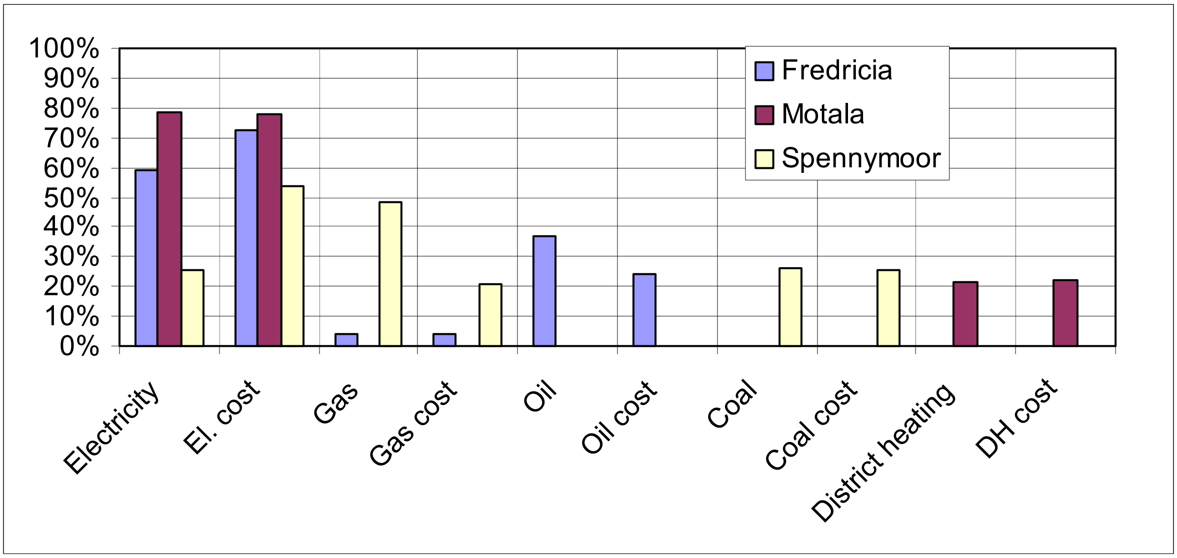


Table 2 shows the total primary energy use, including electricity, and cost for manufacturing one cooker at each factory.

Table 2. The Total Energy Use and Cost per Manufactured Cooker

Plant	Total energy use (kWh/unit)	Energy cost (EUR/unit)
Fredericia	98.7	5.04
Motala	88.1	2.60
Spennymoor	143.6	4.51

According to Table 2, Motala uses less total energy per cooker than Fredericia and Spennymoor. Motala can have some advantage as the energy has been distributed among the different products in different ways. Another reason is that Motala uses more electricity, which has high efficiency in heating processes, nearly one. Gas has an efficiency of about 0.8 and this is not considered in the figures. Also oil has a lower efficiency, when fired in a boiler, than electricity heating. Spennymoor also has a high gas use, partly depending on the enamel process at Spennymoor.

The energy cost for manufacturing one cooker is higher for Fredericia and Spennymoor. One reason is that the electricity price at Motala is about half the price at Fredericia and Spennymoor and the district-heating price is also low. It is 90% of the oil price at Fredericia. Gas and coal have low prices. The gas price is half the district-heating price and coal is the same as the district-heating price. The low gas price is the reason that Spennymoor doesn't have higher costs.

If we convert the electricity into oil equivalents instead, the total energy use per manufactured cooker is as given in Table 3. In this case Motala uses more energy than Fredericia and the difference between Spennymoor and the two other factories is smaller. The reason for this is that Motala uses most electricity and Fredericia also uses a high percentage of electricity in relation to the total energy use.

Table 3. Total Energy Use per Unit in Oil Equivalents

Plant	Total energy use (kWh/unit)
Fredericia	186.7
Motala	191.8
Spennymoor	199.3

CO_2 Emissions Due to the Total Energy Use

The CO_2 emissions due to the total energy use for all factories are presented in Table 4.

Table 4. Total CO_2 Emissions for the Factories

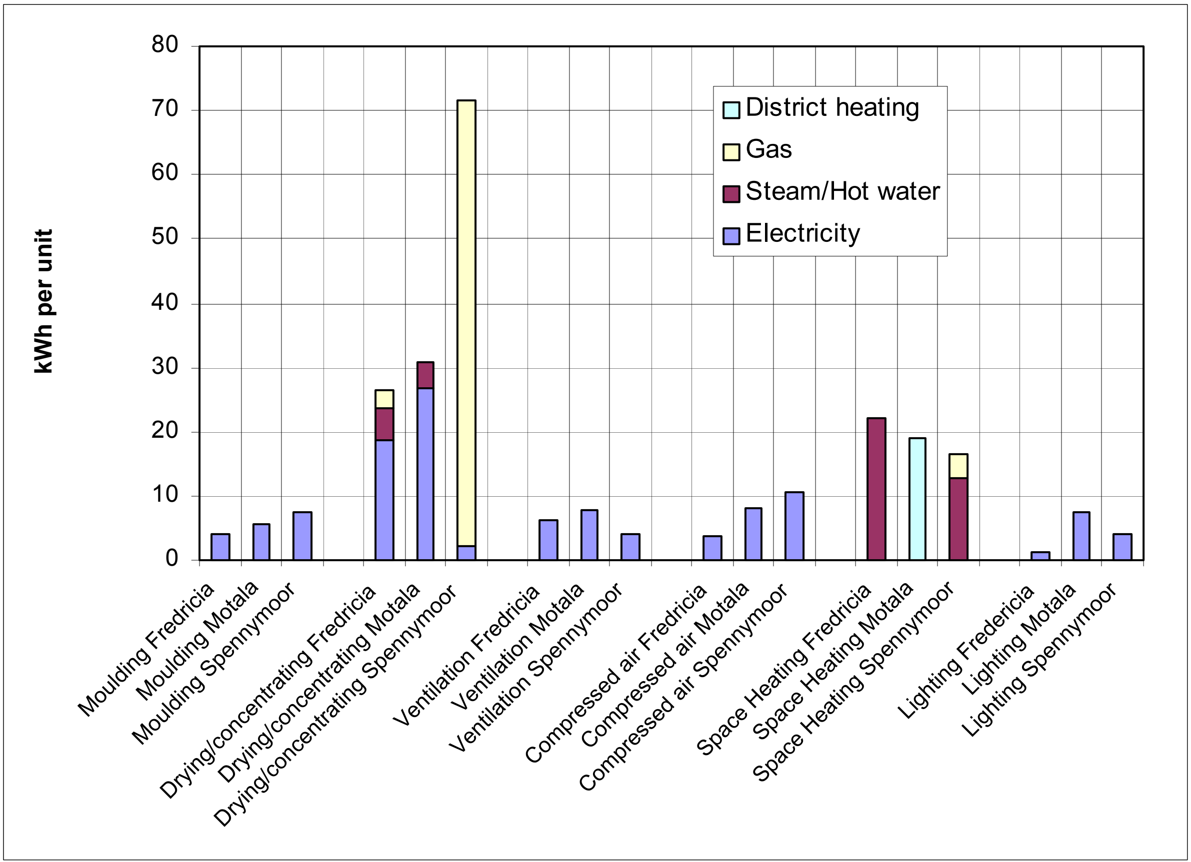
Plant	CO_2 emissions (kg/unit)
Fredericia	61.0
Motala	59.0
Spennymoor	64.5

Spennymoor's emissions are higher than at Fredericia and Motala. This is true for the time the investigation took place. Today, as the coal-fired boilers are decentralised and the coal is replaced by natural gas, the emissions should be 58.3 kg/unit at Spennymoor. One reason that Fredericia gets higher amount of CO_2 emissions than Motala is that oil is used for heating purposes. At Motala, district-heating is used for space heating and tap water, and the district heating is produced with a fuel mix of 76% bio-fuel and 24% oil.

Unit Processes

In order to find and explain differences between the factories, the unit process method was used. As all factories are different with respect to size, the energy per unit was used. Six of the most energy-intensive and in other ways interesting unit processes are described in Figure 5. It is the primary energy use that is represented in Figure 4.

Figure 4. The Specific Energy Use for Unit Processes



The unit process moulding includes all metal-forming processes, thus all presses are included. The presses have large installed power but on average only 20–30% of the installed power is used. In the start up and at the instant of pressing there is a power peak. Thus the electricity use for moulding is not as high as expected from the total installed power. For this unit process, Spennymoor uses more electricity than Fredericia and Motala. One reason is the cavity line, Kuhn line, which is more electricity intensive than at Motala and Fredericia. In the cavity line the cavities for the cookers are manufactured.

The most energy-intensive unit process for all factories is drying/concentrating, where all furnaces are included. This unit process has the largest difference in electricity use, where Fredericia and Motala use between eight and twelve times more electricity than Spennymoor. This has to do with the way the furnaces are heated. At Fredericia and Motala the enamel furnaces are heated by electricity and at Spennymoor they are gas-fired. Fredericia uses less electricity than Motala, because only the enamel furnaces are heated by electricity; all the other furnaces are gas-fired. Spennymoor has the largest total energy use for drying/concentrating, where a lot of gas is used. This is due to the thermal efficiency of about 0.8 and a different enamelling process. Fredericia and Motala have the same enamelling method, 'two coats – one fire', which means that the enamelled parts are baked once in the enamelling furnace. At Spennymoor they use a method called 'direct-on', which means that the majority of the cooker parts are baked twice in the enamelling furnace. It is also interesting to see the differences in CO_2 emissions due to the energy use for this unit process, as all factories use different energy carriers. The energy use for drying/concentrating at

Fredericia corresponds to an emission of 17.8 kg CO_2/cooker, at Motala 25.7 kg CO_2/cooker and at Spennymoor 19.6 kg CO_2/cooker. This shows that even if Spennymoor uses the most energy for this unit process, they do not get the highest amount of CO_2 emissions. Motala gets the highest amount of CO_2 emissions due to the electricity-heated furnaces.

In ventilation all ventilation systems, extraction and input fans and other air treatment units are included. Both Motala and Spennymoor have ventilation systems, Fredericia has mainly point ventilation where there are heat loads or contaminated air. Motala uses more electricity for ventilation per manufactured cooker than Fredericia and Spennymoor do. Also, the electricity use for ventilation per m^2 of floor area shows the same result, where Motala uses 118.3 kWh/m^2, Fredericia uses 54.1 kWh/m^2 and Spennymoor 30.8 kWh/m^2.

Both Motala and Spennymoor use more electricity for compressed air than Fredericia. The main reason is that there is practically no air leakage at Fredericia. Another reason is that Fredericia has no paint department and compressed air is used for applying the paint. At Motala and Spennymoor there was a lot of air leakage and at Motala one of the three compressors is used to keep the air pressure in the system due to the leakage. Another reason that Spennymoor uses more compressed air is the Kuhn line, where a lot of compressed air is used to mould the cavities. Even if Fredericia uses less electricity for compressed air than Motala does, the energy cost is nearly the same due to the higher electricity price. This applies as well to Spennymoor, which uses slightly more electricity than Motala, but has double the energy cost.

Space heating includes all energy for heating of premises and tap water. At Fredericia steam produced in oil-boilers is used for the heating and at Motala district heating. At Spennymoor the heating systems were changed during the study. When the study started the areas were heated by steam from coal-boilers, by gas-fired radiant tubes or by hot water from local gas-fired boilers. During the study the coal-fired boilers were decentralised and two gas-fired boilers and unit heaters in one department replaced them. According to the summary, Fredericia uses more energy per manufactured cooker for heating than Motala and Spennymoor do. The result is different when the energy per m^2 floor area is used. Then Motala uses more energy for heating the premises than Fredricia and Spennymoor do. Motala uses 330.4 kWh/m^2, Fredericia uses 189.5 kWh/m^2 and Spennymoor uses 121.9 kWh/m^2. The space heating is degree-day compensated.

The unit process lighting is smallest at Fredericia. Two reasons are that Fredericia has new fluorescent lighting and guidelines that say that 7%/m^2 of the lighting at full-time work has to be daylight, thus the manufacturing areas have a lot of windows. At Motala, for main lighting in the ceiling there are either mercury light bulbs or fluorescent lamps. All mercury lighting was being replaced by fluorescent lamps during the study. The lighting at Spennymoor consists of fluorescent light fittings and high-pressure sodium light fittings for general lighting. There are fluorescent lamps for work place lighting at all three factories. There is a big difference in power use for different fluorescent lamps. At Motala and Spennymoor, the power use for the fluorescent lighting is between 7 and 12 W/m^2. At Fredericia the power use is about 4-6 W/m^2, because the new fluorescent lamps have very good reflectors.

Non-Production Inspections

Figures on incoming electricity show that the base load (900kW) during non-production time is 13% of the full production load (7000 kW) at Motala. At Fredericia the base load is approximately 200 kW during non-production times and about 1600 kW during full production, i.e. the base load is 12.5% of the full production load. The base load consists mainly of lighting, ventilation, hydraulic and other process pumps, computers, transformer losses and circulation pumps. Some water circulation pumps have to be running all the time.

Table 5 shows the results from the non-production inspections at Motala, where the power use of processes that are not supposed to be running is described.

Table 5. Total Power Use and Non-Essential Power Use at Motala

	Total power use (kW)	**Non-essential power use (kW)**
Inspection one	779	80
Inspection two	827	56

The table shows that during the first inspection 10% of the total power could be switched off. Out of these 80 kW, 21% was lighting, 66% was for other process equipment and 13% was ventilation or fans. The second time, the non-essential power use was less than the first time, i.e. 7% of the total power use. Out of the 56 kW that could be turned off, 48% was lighting, 4.5% was for other process equipment and 48% was ventilation or fans.

According to Table 6, 9% of the total power use could be switched off at Fredericia; out of these 27 kW, 39% was lighting, 33% was other process equipment and 28% was ventilation and fans.

Table 6. Total Power Use and Non-Essential Power Use at Fredericia

	Total power use (kW)	**Non-essential power use (kW)**
Inspection	300	27

The conclusion drawn from these results is that there are no large non-production losses. There is only about 20 kW to save on the base load at Fredericia and about 50 kW at Motala.

At Spennymoor there was no opportunity for a non-production inspection due to continuous production at both visits. Also, information about the total incoming electricity every hour or 15 minutes cannot easily be derived, since another industry also gets its electricity from the same feeding point. Instead meter readings from a week when there was a planned production stop for maintenance were used. Due to the maintenance work, some lighting, ventilation and compressed air were on. The mean non-production power use was 700 kW and full production mean power use was 3500 kW, i.e. the base load is 20% of production mean power. No identification of the 700 kW was possible. Also, the 700 kW is probably unusually high due to the maintenance work going on during that week.

Optimisation Results for Motala

Three different optimisations have been made for Motala, and the CO_2 emissions were also estimated. First a model of the energy use and costs for cooker manufacturing at Motala was made, where the unit process division is used to describe the manufacturing and support processes. In the model the amount of manufactured cookers constitutes the material flow. The optimisation is made for one year, which is divided into 48 time steps. In order to describe the energy use related to the material flow at different time steps, the information from the energy mapping and electricity measuring was used.

The first optimisation, called Motala99comp, was done in order to see the electricity cost reduction potential for the unit process called compressed air at Motala, i.e. electricity used for running the compressors. The aim was to see the reduction possibilities of electricity and CO_2 emissions due to different efficiency actions at Motala so that the electricity use for compressed air per cooker becomes the same as at Fredericia. Comparing the three factories, Fredericia has the lowest electricity use per cooker for the compressed air and one reason for this is no air leakage. Examples of efficiency actions at Motala are to seal air leakages and to make sure that the compressors are off when there is no production.

The second optimisation, called Motala99compDK, is the same as the first optimisation but Fredericia's electricity price was used instead of Motala's. This optimisation shows the electricity cost reduction potential if electricity efficiency actions for the compressed air are taken at Motala and the electricity price is equal to the electricity price at Fredericia. Due to the deregulation of the European electricity market and harmonised electricity prices this is a possible scenario. The cost saving is calculated as the difference between the system cost for compressed air with Fredericia's electricity price for Motala before and after efficiency actions are taken.

The third optimisation, called Motala99gas, was made to compare with the situation at Spennymoor, where all furnaces are gas-fired. This scenario is hypothetical and shows the results if the furnaces at Motala, were to be converted to gas-fired or dual heated furnaces that are fired with gas. This could be possible if the gas network were expanded to Motala and the furnaces were replaced due to age. In this optimisation all electricity for the furnaces are exchanged to natural gas. The natural gas price used is 0.0365 EUR/kWh, which was the natural gas price for industry customers in Malmö, Sweden in January 2002 (VIK 2002). Today there is no opportunity to buy natural gas in Motala, but in the future it might be an alternative. An equal optimisation as Motala99gas was made with the electricity and gas prices at Spennymoor. This in order to investigate the effect of using gas-fired furnaces instead of electricity heated together with higher electricity prices and a low gas price.

The results of the optimisations for the three different scenarios are shown in Table 7.

Table 7. Optimisations of the Energy Use for Cooker Manufacturing at Motala

No	Optimisation case	Savings (EUR)	CO_2 emissions (tonnes)
1	Motala99 – base model	0	10935
2	Motala99comp	16 900	10256
3	Motala99compDK	51 720	10256
4	Motala99gas	-72 760	7559
5	Motala99UKgas	173 520	7559

The results for the first optimisation, Motala99comp, are that the economic savings are 16900 EUR and the CO_2 emissions are reduced by 679 tonnes per year. If Motala gets the same electricity price as Fredericia, the economic savings for compressed air would be 51720 EUR per year. For the third optimisation, where the furnaces are fired with natural gas, the CO_2 emissions would be reduced by 3,376 tonnes per year but there would not be any economic savings for drying/concentrating, due to a higher gas price than electricity. But with the same electricity and gas prices as Spennymoor the economic saving would be 173520 EUR. With a totally deregulated electricity market in northern Europe and harmonised electricity prices and consequently higher electricity prices in Sweden, this optimisation is of grate interest. In the future with deregulated electricity and gas markets the boundary conditions for the European countries will be more harmonised.

Conclusions

The Relationship Between Electricity Use and Price

Earlier studies implied higher electricity use if the electricity price were low and vice versa. The Electrolux study shows that this applies to Motala and Spennymoor. Motala has a low electricity price and high electricity use, in Spennymoor the conditions are reversed. Fredericia does not follow the pattern, as the electricity price is high, but the electricity use is not that low.

The total energy use per cooker does not differ very much between Motala and Fredericia, but Spennymoor has higher energy use, see Table 2. This implies that there are different energy carriers for the same processes in the factories. If electricity is cheap, that is preferable to other energy in non-electricity-specific processes. At Spennymoor gas is the cheapest and also their major energy source. At Fredericia the situation is different. They use gas or oil to a large extent for non-electricity-specific processes, but for the enamelling furnaces they use electricity. This is the reason why electricity is their major energy source, even if it is the most expensive.

At Volvo the electricity use during non-production time was double at Torslanda factory, Göteborg, Sweden compared to Gent, Belgium. The situation was not the same for Electrolux. All factories had low electricity load during non-production time compared to the load during production. There was little electricity use that was due to non-production losses.

Optimisations

The conclusion is that the possibilities for economical savings and reductions in CO_2 emissions are high and are important. It is important to change the prevailing attitude towards heating with electricity and not use this high quality energy source for non-electricity-specific processes. This is shown in the scenario where gas-fired furnaces are used instead of electricity-heated furnaces. The energy use is slightly larger due to the lower thermal efficiency compared to electricity-heated furnaces, but the CO_2 emissions were reduced by 31% compared to today's emissions related to the energy use for the heating of the furnaces. Therefore it is important for the global environment to only use electricity in electricity-specific processes even if the economic benefits are not that large.

Differences Among the Factories

In the press shops most of the machines are of the same kind in all three factories. The differences are in their own specific manufacturing lines. The cavity line is very different at all three factories. At Fredericia, which is limited for space, the cavity line is very compact and energy efficient. At Spennymoor the cavity line is very large, with many cavities moulded at the same time. This cavity line is not very energy efficient, due to its construction. The cavity line at Motala is ordinary; neither very small nor large, and moderate in energy use. The specific electricity use for the unit process moulding shows this difference. Within the unit process moulding there are only electricity-specific processes included.

Within the enamel department the largest differences are found. The enamel baking furnaces are heated in different ways. At Fredericia and Motala they are electrically heated and at Spennymoor they are gas-heated. Other drying and curing furnaces are gas-heated at Fredericia, but at Motala all furnaces are electrically heated. The unit process drying and concentrating shows this. Since the enamel process differs among the factories, the energy use differs. Spennymoor uses less electricity than Motala and Fredericia, but they use the most energy, natural gas. This is because the enamelled parts are baked twice, compared to the single baking at Fredericia and Motala.

None of the factories uses electricity for heating the premises. This is interesting as it is a non-electricity-specific process. At Motala they buy district heating, at Fredericia they have oil boilers and at Spennymoor they use natural gas. At Motala the district-heating price is equal to the electricity price. Even if the district-heating price were low, Motala has the highest cost for heating the premises per m^2, 8.84 EUR/m^2. The lowest cost for heating per m^2 is at Spennymoor, 2.73 EUR/m^2 and Fredericia's energy cost is 5.70 EUR/m^2.

For lighting Motala uses the most electricity, then Spennymoor and the least Fredericia. This is also recognised by the load per square meter. Motala uses in average 11.7 W/m^2, Fredericia 6.4 W/m^2 and Spennymoor 9.7 W/m^2. One reason for the difference among the factories is the kind of lamps used.

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