PEER-REVIEWED PAPER

A system perspective on industrial energy efficiency

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Abstract

The EU Action Plan for Energy Efficiency states that Europe still waste over 20 % of its use of energy due to inefficiency. The 20-20-20 targets that are established by the EU, has set a series of severe climate and energy targets to be met by 2020. These targets mean that each Member State shall reduce their primary energy use of 20 % by 2020. A special significant potential to reduce energy demand and CO_2 emissions are highlighted within industrial energy systems. In Sweden the use of electricity is among the highest in the world. Rising electricity price will promote further electricity production in Swedish CHP plants. Altering industrial energy use will imply considerable cost-effective possibilities to lower global emissions of CO_2 when considering reduction in electricity consumption to reduce marginal production in coal condensing power plants. The aim of this paper is to analyse how a system perspective can be profitable for both energy suppliers and industrial energy users as well as for the environment. Results show how industrial and energy supply measures will lead to reduced electricity use with about 50 %, increased use of district heating and cost-effective possibilities to lower global emissions of CO_2. Driving forces and barriers to implementation of energy efficient measures, together with a system perspective of how to account for electricity use, are also discussed.

Introduction

Sweden is known as energy dimensioned system with variations of the electricity price over the year. The electricity supply system in the rest of Europe is characterized as power dimensioned with changes in electricity price over the day. Since the Nordic market constitutes only a minor portion of the common European market, it is likely that the conditions on the European continent will be valid for the entire common European market and that electricity prices between Scandinavia and northern Europe will level out [SEA 2006].

Based on this argumentation it is likely that a common European electricity market will imply both higher electricity prices and prices that vary over the day for Swedish electricity users. Swedish industries have higher use of electricity compared to other plants in the EU region, this situation with high electricity use and a high electricity price will lead to an unsustainable situation. To maintain competitiveness with industries in other EU countries, it is vital for Swedish plants to focus on reducing their electricity usage and changing the relation between electricity and fuel by converting from electricity to i.e. district heating.

A raising electricity price also means that energy suppliers will concentrate their production to more electricity production. In combination with an increased demand for DH, which will be a result of industries converting from electricity or fuel to DH, this will make investment in combined heat and power plants (CHP) an extremely interesting option. Since the DH grids in Sweden are among the world's most extensive [Werner, 1989], it will probably prove attractive for Swedish energy suppliers to consider further investment in these power plants, which would consequently increase electricity production in Sweden. Increased production in CHP plants is promoted in the EU directive 2004/8/EC [COM 2004] and according to the Swedish District Heating Association electricity production from Swedish CHP can increase from today's low level of 5 TWh/year to 20 TWh/year [SDHA 2004].

In energy systems with waste incineration there is often a surplus of heat during the summer. Since the demand for cooling is highest during the summer, the surplus of heat can be used for heat driven cooling in the form of absorption cooling. In energy systems with CHP, the increased demand for heat will mean a higher potential for electricity production. Converting from vapour compression cooling to absorption chillers will consequently have a positive impact on the overall energy system, as the production of cooling will lead to an increase in electricity production instead of consuming electricity.

Reduced use of electricity in Sweden will mean freed capacity for the energy supplier that can be sold to other European countries. Since electricity production in Sweden is mainly supplied from hydropower and nuclear power [SEA 2001] it is mostly free from emissions of carbon dioxide. Electricity generated in Sweden but sold in another European country, could then replace electricity produced with higher external costs. When accounting for electricity with marginal production and assuming coal condensing to be the marginal source, reduced industrial electricity use and increased electricity production in Swedish CHP-system will lead to possibilities for cost-efficient measures to reduce global emissions of carbon dioxide. It would thus help the whole EU region to meet its target as regards lower emissions of carbon dioxide.

This argument means that initiatives to redirect energy use towards less use of electricity and increased use of district heating are measures that will shift the energy system towards sustainability. These measures will naturally be more successful and have a greater impact if all actors can derive benefits from the process. This means that both energy users and energy suppliers must see these measures as profitable measures. However, although there are unquestionable strong motives for an industry to consider measures that will only result in environmental improvements, the driving force will most likely be stronger if there is also an economic initiative connected to the measures. In other words, measures that imply both economic and environmental effects will most certainly be the ones that will have the strongest driving force and the ones that will have the greatest impact.

Electricity is one of the few products that are consumed continuously by all customers. It is consumed within a second of its production and less than a tenth of a second of power can be stored as electrical energy. No other product has a delivered cost that changes anywhere near as fast. Electricity is a product that originates from a number of different production plants with different resource costs and environmental costs. It is impossible to distinguish any unit from another and therefore also impossible to calculate the direct and accurate environmental effect of one specific used kWh of electricity. The methods for accounting electricity consumption are diverse; a few of them are briefly discussed and comment in this paper. It is vital to emphasize that none of the methods of accounting electricity can be acknowledged as the absolutely correct method and in the same way none can be identified as completely wrong. What is important, though, is that assumptions made when presenting environmental effects from the use of electricity are stated and explained thoroughly.

In this paper the effects of different way to account for electricity is outlined together with discussions on how a system perspective on energy supply and energy use will lead to a win-win situation for all the parties involved.

How to account for electricity use

According to EU Electricity Directive (96/92/EC) and to the directive, all member state should have at least opened their markets by 30 %. The reason for deregulating the European electricity market was to improve Europe's competitiveness and the welfare of the citizens. Electricity is the most important secondary source of energy in the European Union and the electricity industry is one of the largest sectors of the economy in Europe [COM (2001) 125 final]. The objective of the directive is to open up the electricity market through the gradual introduction of competition, thereby increasing the efficiency of the energy sector and the competitiveness of the European economy as a whole.

According to Stoft [2002] the most common argument for deregulation is the inefficiency of regulation. Deregulation is not equivalent to perfect competition, which is well known to be efficient. Truly competitive markets provide full-powered incentives to hold down the price to marginal cost and to minimize cost. Regulation can do one or the other but not both at the same time. It must always make a trade-off since the suppliers always know the market better than the regulators [Stoft 2002].

There are many different opinions as to how to account for electricity consumption in a deregulated market. The discussion around the environmental value of the electricity used reflects widespread controversies among, for example, scientists, various interest groups, professionals, industrial organizations, public authorities and so on. To decide how to account for electricity consumption is vital when considering the environmental effects of a planned investment in an industry or when considering converting from oil fired boiler to a heat pump. The issue is also central when a company balances the books and wants to account for the electricity used over the previous year. Sjödin and Grönkvist [2004] discuss some different ways to account for changes in greenhouse gas emissions due to changes in the use or supply of electricity. According to Sjödin and Grönkvist, a comprehensive accounting scheme would provide an accurate link between various types of energy measures and their related emissions in order to facilitate cost-effective carbon dioxide mitigation procedures.

ACCOUNTING ACCORDING TO AVERAGE ELECTRICITY PRODUCTION

Average electricity production is sometimes used when analyzing electricity consumption. One of the problems with using average production is to decide which average to use: global production, EU production, Nordic production or Swedish production? Another issue that deserves attention is which time interval to use: a year, a week, a day? If boundary limits are set, it is, though, a method that is easy to apply and easy to communicate. Using average production gives you a view of the production of electricity over the chosen time period, but it will not reflect the impact of changes in electricity use, for example increased electricity use due to conversion from an oil fired boiler to a heat pump or decreased electricity use resulting from energy efficiency measures in an industry. Average emissions do not illustrate the dynamics of the power system.

ACCOUNTING ACCORDING TO EMISSIONS TRADING

Emissions trading is a scheme whereby companies are allocated allowances for their emissions of greenhouse gases according to the overall environmental ambitions of their government. The companies can trade the allowances with each other. The emissions trading system has introduced an upper limit of carbon dioxide emissions and is divided into two periods; the first from 2005 to 2008 and the second from 2008 to 2012 [SEA 2005c]. This means that even if electricity consumption is decreased this will not lead to a decrease in carbon dioxide emissions since the freed allowances can be sold and thus used to increase electricity use and carbon dioxide emissions in another part of the market. The total amount of carbon dioxide emissions can subsequently not decrease below the upper limit of the system. It is therefore often argued that the effect of emissions trading is that measures to decrease electricity use will have no impact on global carbon dioxide emissions at all and such measures are therefore unessential as regards emissions of carbon dioxide. Another effect of the emissions trading system is that conversion from oil to electricity is more favourable since electricity driven systems are included in the system while oil driven systems are not.

One consequence of such arguments might be that efforts to change any energy system towards sustainability by converting from electricity to renewable sources stops. Motivation will also very probably be affected, as the environmental correlation no longer exists. This can have far-reaching consequences. Global warming is the most serious threat to mankind and an effort to achieve sustainability is essential. It is dangerous to let policy instruments undermine our efforts to change our energy systems and use more renewable sources. Even though measures to reduce electricity consumption not will lead to any direct reduction in emissions of carbon dioxide because of the emissions trading system, the measures will demonstrate how to help the member states of the EU lower their emissions of carbon dioxide and thus fulfil their commitments under the Kyoto protocol. If any measures to reduce electricity are proven to be economically profitable, the measures consequently illustrate possible cost-efficient ways to reduce emissions of carbon dioxide and might thus contribute to lowering the upper limit set by the emissions trading system. It will also be a competitive alternative to new production.

ACCOUNTING ACCORDING TO LABELLED ELECTRICITY

In Sweden, the Swedish Society for Nature Conservation (SSNC) operates a system of environmental labelling of electricity delivery contracts since 1996. Labelling is available for suppliers offering electricity from renewable sources of energy such as solar power, wind power, hydropower plants built before 1996, and biofuel plants. Companies may acquire a licence to use the label by proving their ability to deliver such electricity and by agreeing to be audited [SNF 2001].

Kåberger and Karlsson (1998) argue that long-term and regular electricity consumption may be a reason for the electricity producer to invest in more base-load production capacity. This means that whether the consuming process was established or not would not affect the use of electricity production plants as marginal production capacity. Life-time or investments in nuclear reactors, coal fired plants or other base load type plants would instead be affected, for example when an electricity intensive process industry sets up or shuts down. Using labelled electricity means that data from specific contracted electricity production plants should be used when accounting electricity consumption.

ACCOUNTING ACCORDING TO MARGINAL PRODUCTION

It is the plants with the poorest efficiency and the most expensive that supply the margin. Marginal cost is defined as the running cost (RC) of the most expensive generating plant that is needed to supply the immediate demand for electricity. Marginal costs consider future costs either in a short-range perspective (SRMC) or in a long-range perspective (LRMC). SRMC can be described as the sum of RC and SC, where SC is the shortage cost due to the risk of a shortage of power during periods when electricity demand is high and approaches the limits of generating capacity. If there is a need for investment in new power plants due to an increase in power demand, the investment cost must be included in the marginal cost. The criteria for an investment in a new power plant can be described as $RC + SC \geq LRMC$. When the relation is satisfied there is a need for investment.

Using marginal production to account electricity is a way to reflect the changes in electricity consumption as the demand decreases or increases. In continental Europe, as well as in the Nordic electric power system, it is usually coal condensing power plants that have the highest variable cost and thus act as the marginal electricity source. The principal of coal condensing power being on the margin of Swedish electric power system is supported in a report from the Swedish Energy Agency [SEA 2002] where it is claimed that coal-condensing power has been the last dispatched source of power. The same report also states that in the short run (SRMC) coal-condensing power will remain the marginal source and in a longer perspective the marginal source (LRMC) in a European system will be generated in natural gas based power plants. Kågeson [2001] makes the same observation and assumes that in perhaps 20 years, natural gas combined cycle generation will take over as the marginal source of electricity.

When marginal production is used it is important to distinguish short-range changes, as for example turning on and off a lamp, from long-range changes as when converting from an electricity boiler to a biofuel boiler. Marginal production can sometimes be complex to explain for those who are going to use the method, but are nevertheless the method that best reflects increases or decreases in electricity consumption. As the electricity usage alters it will be the most expensive source of power that will be affected. Considering this, marginal production will consequently be the most accurate way to calculate the environmental value of electricity consumption.

It is important to decide whether marginal production is to be used for Swedish production, Nordic production, EU production or global production, though. This means that system boundaries must be set, which is discussed in the next section.

System analyses

System analyses are above all a way of thinking about these total systems and their components, an approach, not a number of methods, and it is only one approach to the way in which humans should respond to reality; but it is a "grand" approach according to Churchman [1968].

The definition of a system and its boundaries are central issues as regards system analyses. Churchman [1968] outlines five basic considerations that must be kept in mind when thinking about the meaning of a system:

- The total system's objectives, and more specifically, the performance measures.
- The system's environment: the fixed constraints.
- The resources of the system.
- The components of the system, their activities, goals and measures of performance.
- The management of the system.

Of these issues the second aspect; "the system's environment" is perhaps the one that needs most attention since it is tightly connected to the systems boundaries.

SYSTEM DEFINITION

One broad definition of a system is that it is a group of objects that interact [Wallén 1996]. This implies a system as a totality with different qualities than what can be found in the objects. According to Wallén, system thinking starts with a need to follow, understand, and plan for development and changes in complex connections where a number of factors interact with each other. The reason for letting the system consist of a certain number of components and connections is that they constitute a totality. In the same way, Ingelstam [2002] points out that a system consists of two sorts of parameters: some sort of components and the connection between them. According to Churchman [1986] a system is made up of sets of components that work together for the overall objective of the whole.

SYSTEM BOUNDARIES

In many applications, the criteria of what's inside the system is what an actor controls while parts he does not control belong to the environment. Ingelstam [2002] claims that identifying the interactions between the components of the system and the connection between them is an important issue for system analyses as is the elucidation of the system itself. It is easy to argue that everything is connected. System analysis does not deny that there is a connection between practically everything, but it stipulates that the intellectual method to handle the questions must be to distinguish a system and a subsystem and to draw a borderline between this and the environment. It is often natural to look upon a system as compounded of several subsystems. The larger system will be the environment to the subsystems. The subsystems can then be divided into subsystems that will result in a hieratic of systems logically related to each other like Russian dolls [Ingelstam 2002]. Wallén [1996] points out that the first assignment for a system analysis is to find suitable delimitation: what is inside and what is outside the system. Some of the main points in system theoretical analyses are, in addition to system delimitation, the construction of a system and studies of, for example, energy flows inside the system and between the system and the surrounding, interactions between the different parts of the system and how the system changes over time [Wallén 1996]. The environment is something that is outside the system's control and also something that determines in part how the system performs. Churchman [1968] gives one example on how to look upon the environment. If the system is operating in a very cold climate so that its equipment must be designed to withstand various kinds of severe temperature change, then the temperature changes are in the environment, because these indicate the given possibilities of the system's performance and yet the system can do nothing about the temperature changes. This means that if we can answer *No* to the question: "Can I do anything about it" and answer *Yes* to the question "Does it matter relative to my objectives?" then "its" is the environment, according to Churchman [1968].

Previous studies of industrial energy efficiency

Previous studies of industrial energy efficiency of industries in Oskarshamn, Ulricehamn, Örnsköldsvik and Skövde have been performed. Örnsköldsvik is a municipality in the north of Sweden while Ulricehamn, Skövde and Oskarshamn are municipalities situated in the south and southwest of Sweden. The studies have been performed during 2002–2003 and comply of about 30 industries. The industries have been analysed using a top-down approach focused upon finding system changes in the use of energy, and not the traditional way of making existing energy utilization slightly more efficient. The industries have been analysed within above all the following areas [Trygg 2005]:

- More efficient use of electricity.
- Reduced use of electricity when no production is taking place.
- Connection to a local district heating grid.
- Conversion of non-electricity specific processes.
- Use of surplus heat.

The results of these studies have shown a possibility to reduce the use of electricity with about 50 %. The results also showed that the industries could increase their use of district heating with about 110 GWh a year by converting hot tap water, heating of goods, space heating, heating, drying from electricity to district heating and by converting from compression chillers to absorption chillers supplied by district heating. Some industries could also use waste heat from the industrial processes to reduce the energy used for space heating and/or hot water [Trygg 2004, Trygg et al 2005, Trygg et al 2006].

System perspective on industrial energy efficiency

Considering the above discussion about system perspective, this altered use of energy will have an impact on the whole energy system. For example, when an industry, situated in an energy system with combined heat and power (CHP) plants, alters its energy use towards less electricity dependence and increased use of district heating, this will consequently affect the local energy supplier. Figure 1 illustrates an example of how the demand for district heating increases as one of the studied industry situated in the municipality of Skövde altered its energy use and converted the processes hot tap water and space heating to district heating and also converted from compression chillers to absorption chillers supplied by district heating. When changing the system boundaries from just looking at the industry, to instead comprise the whole energy system of energy user and energy supplier, the effects are obvious. This new situation with increased use of district heating leads to changed load duration curves for the local energy utility which consequently leads to potential for further electricity generation in the local CHP-system [Trygg et al. 2005]. The increased production of electricity can substitute marginal fossil-fuelled electricity, according the argumentation in the introduction section, which in the case of Skövde means possibility to lower the global emissions of CO_2 from the studied energy systems with about 350 %. It also led to decreased production cost by about 50 % [Trygg et al. 2005].

Implementation and communication of industrial energy efficiency measures

The industrial measures demonstrate how to reach a situation where industrial electricity and energy use is at an absolute minimum and is therefore to be seen as an optimal situation. The results must consequently be understood as indicators of processes or parts of processes where electricity use is high and can be reduced. On the basis of the presented measures some processes that can be altered at once can be prioritized and measures with a long-term goal can be included in a long-term action list.

As a suggestion, industry can begin with measures that do not involve any cost at all, for example reduction of electricity when there no production is active and proceed with other measures step-by-step. As argued earlier, the measures will have a knock-on effect: profitability will increase as the electricity price rises.

The above mentioned energy systems analyses were performed during 2002–2003 and showed a potential of about halved the use of electricity, as described earlier. Up to eight years after the energy system analyses were performed the industry were studied again with both interviews and a questionnaire. The aim of these studies were to analyze driving forces and barriers to implementation of cost-efficient industrial energy efficiency measures [Trygg et al 2010, Thollander et al. 2007]. The result showed that 41 % of the purposed measures from the energy audits had been implemented. Result also showed that energy efficiency above all is a management issue and that the strongest driving forces for energy efficiency measures are reduced energy costs, the presence of engaged people and the threat of rising energy prices, while the largest barriers to implementation are lack of time, other priorities, other priorities for capital investments and long decision-chains [Trygg et al. 2010].

Concluding discussion

The European Union is consuming more and more energy and will not be able to free itself from its increasing energy dependence without an active energy policy. At the same time humanity is facing its greatest challenge ever – to transition society towards sustainability and the entire global human civilization is now threatened. Our current use of energy is a major part of the sustainability problem and to rapidly develop sustainable energy systems is crucial for the whole society's transition towards sustainability. When considering coal condensing as the marginal source of electricity in a European perspective, reducing the use of electricity by more efficient use of electricity and by converting to district heating are important measures in the transition towards more sustainable society.

The results of this study show how a system perspective on energy use and electricity production gives major economic and environmental benefits. Energy measures such as energy efficiency, conversion from electricity to district heating, cooperation on heat between industry and energy supplier, are important for industry and energy suppliers to take as they will reduce system cost and lead to possibilities to lower global emissions of CO_2. The measures will in other words lead to lead to a win-win situation for both energy supplier and industrial energy user with reduced system cost and possibilities to lower global emissions of CO_2.

Electricity produced in Sweden but sold in another European country can replace marginal coal-based power production

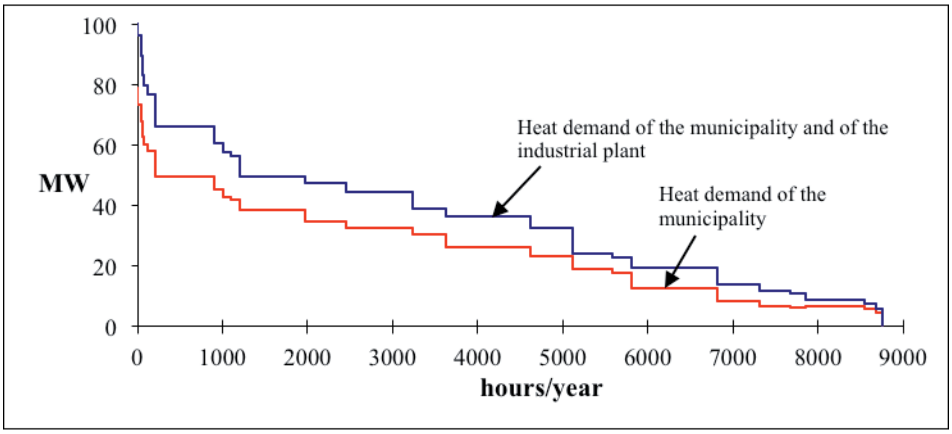

Figure 1. Load duration curves for DH before and after conversion of hot tap water, space heating and cooling to DH. [Trygg et al. 2005.]

and as consequence lower the total environmental cost in Europe. These are outstanding favorable conditions especially for Sweden where, for example district heating is well established, the potential for electricity reduction is huge and electricity is generated with very low environmental costs.

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