104.

Science for Sustainable Development

Starting Points and Critical Reflections

Björn Frostell (ed.)

Proceedings of the 1st VHU Conference on Science for Sustainable Development, Västerås, Sweden, 14-16 april 2005

VHU, Uppsala, 2006

Socio-technical Analyses of Energy Supply and Use in Three Swedish Municipalities Striving Towards Sustainability

Dag Henning, Optensys Energianalys, Örngatan 8C, SE-582 37 Linköping, Sweden, dag.henning@telia.com

Louise Trygg, IKP Energy Systems, Linköping University, SE-581 83 Linköping, Sweden

Wiktoria Glad, Tema Technology and Social Change, Linköping University, SE-581 83 Linköping, Sweden

Stig-Inge Gustafsson, IKP Energy Systems, Linköping University, SE-581 83 Linköping, Sweden

Keywords: Energy, energy systems, sustainability, socio-technical analysis

Abstract

Human behavior and action determine energy use and the shaping of energy supply. Combinations of energy systems at the building and city levels may be synergetic or conflicting. Local government has limited resources and co-operation from individuals and companies is required for implementation of energy measures that contribute to sustainability. This project aimed at a comprehensive view of energy supply and use, including socio-technical interaction and relationships between different energy systems. Technical and social analyses of energy systems were performed in the Swedish municipalities Solna, Ulricehamn and Örnsköldsvik. The approach considered a number of ecological, economical and social elements of sustainability.

The performed social-science studies demonstrated that it is possible to implement changes in both behavior and equipment. Resources, such as competence and interest, influence the possibilities to introduce technical measures. Scenarios and techno-economic optimizations pointed at possibilities for an energy supply with lower costs and environmental impact. Decreased electricity consumption in Swedish industry reduces operation of foreign coal-fired condensing power plants with large emissions of carbon dioxide (CO_2). In Ulricehamn, a large part of district heating comes from waste heat. If more industries use district heating, more waste heat can be utilized. In Örnsköldsvik, the municipal utility and private industry co-operate on co-generation of heat, steam and electricity. Office proprietors in Solna with environmental management systems and own operational personnel were able to substantially reduce energy use.

Introduction

Sweden is part of the European electricity market and therefore Swedish electricity prices are likely to adapt to the level in continental Europe, where electricity price is higher and use is lower. The most expensive power generation in northern Europe normally takes place in a coal-fired condensing power plant (SEA, 2002) with low efficiency and large emissions of CO_2, which is the main contributor to the enhanced greenhouse effect. Increased electricity production in other plants and reduced electricity consumption reduce operation of coal-condensing plants. Such measures are here considered to improve sustainability. Electricity consumption for industrial support and manufacturing processes can be reduced, for instance, by shutting off equipment when no production takes place and switching from electricity to fuel or district heating for heat production. Swedish industry is more electricity-intensive than industry in continental Europe. Swedish electricity prices should adapt to the higher European level due to increased cross-border trading. Swedish companies that reduce electricity consumption will have a competitive advantage in a developed market with higher electricity prices. Previous studies showed how Swedish industry can reduce electricity use by one-half, which will lead to economical and environmental benefits (Trygg and Karlsson, 2004).

For buildings supplied with district heating, an energy conservation measure is here considered to promote sustainability when utility *and* building proprietor reduce their costs, including environmental costs. The value of saving district heat depends on how the heat is produced, for example with oil or through combined heat and power (CHP) production.

Technical and social-science analyses of energy supply and use have been performed in three Swedish municipalities. A municipality is an arena for actors with various interests and differing goals. Energy systems are here regarded as socio-technical systems, where technology is intertwined with social, political and institutional factors, which interact in the shaping of technical solutions. Relationships among energy systems within and outside a municipality were considered. Energy conservation possibilities in industries and buildings were investigated. Techno-economic optimization simulations of energy supply were done for different scenarios. A social-science study analyzed organizational possibilities, such as knowledge and incentives, to realize technical measures.

Aim and method

The aim of this paper is to discuss results obtained in our previous research on energy supply and use in three different Swedish municipalities, Solna, Örnsköldsvik and Ulricehamn. The main part of the material presented here has previously been reported in Swedish (Gebremedhin et al, 2004; Henning et al, 2004; Bohlin et al, 2004). Here, we try to integrate and summarize the most important findings of the three studies and put them together into a number of general conclusions. The methods applied include energy systems analysis and energy user studies as described in (Gebremedhin et al, 2004; Henning et al, 2004; Bohlin et al, 2004).

The work was performed within a programme run by the Swedish energy agency called Sustainable municipality, which aims at promoting co-operation among local actors to attain sustainable growth in Swedish municipalities. Solna is a city with 58000 inhabitants, which is a part of greater Stockholm. Ulricehamn is a small town in southern Sweden with 22000 inhabitants. Örnsköldsvik is situated on the coast in northern Sweden and has 55000 inhabitants. The two latter municipalities include large rural areas.

Sustainable energy conservation measures in buildings

In Solna, almost all buildings are connected to the district heating network and therefore the project aim was saving district heat and here residential, office and commercial buildings were in focus (Gebremedhin et al, 2004). Large conglomerates of offices and residences were studied, e.g. the central shopping mall of Solna, but also one small day care centre for children. Many buildings were coupled to one or more subscriptions of district heat and therefore the buildings could not be studied as separate entities. The heat supply origins from a mix of energy carriers, some of them more sustainable than others and conservation measures will therefore affect the utility supply due to the savings pattern. For instance, solar panels save most energy during summer while attic floor insulation contributes mainly during wintertime (Figure 1).

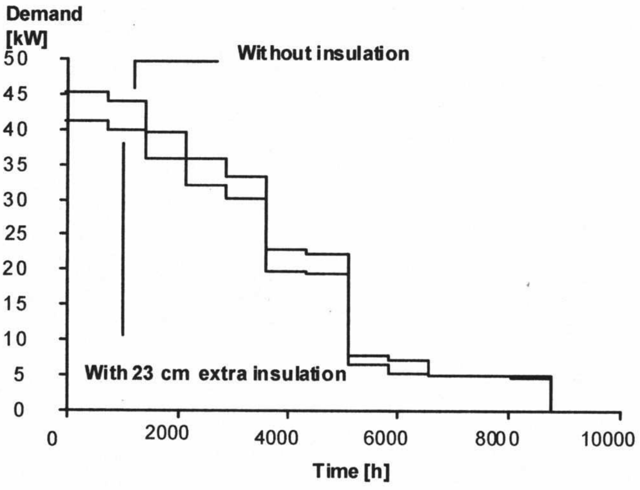


Figure 1. Heat demand during a year for a building in Solna with and without extra attic floor insulation (Gebremedhin et al, 2004).

Even if substantial measures were installed in one building, they would only have minor effect on the total district-heating load. In our calculations, we therefore scaled up the building size, making their loads significant parts of the total district-heating demand. Normally, if an owner of a building finds attic floor insulation profitable, the district heating utility only experiences lower income, a classic conflict. Hence, the utility must ascertain a competitive tariff or customers escape to other heating systems or take energy saving measures. There are, however, time segments where also the utility benefits from such measures, i.e. when the heat production cost is higher than the tariff. All costs, e.g. environmental costs, should be included for the utility as well as for the building proprietor. We define that a sustainable energy conservation measure is found when *both* actors reduce their costs. We used mathematical modelling techniques for finding such measures. Two models were used, the MODEST linear programming model (Henning, 1998) for the utility and OPERA (Gustafsson and Karlsson, 1989) for the buildings. Using a heat load pattern for a test building, we found that the average district heat price was 50 euro/MWh. This price made a number of retrofits profitable according to the OPERA model and we then inserted the savings pattern from them in MODEST. Measures that were profitable both in OPERA and MODEST computations were considered sustainable.

One of the most important facts to consider when profitable energy-saving measures are analyzed, is the shape of the existing building. It is obvious that poorly insulated old buildings (Figure 1) are profitable to refurbish. Even more important is to add plenty of new insulation, e.g. 23 cm in the studied case, in order to reach optimal conditions. Such poor buildings, however, were not among our cases. Instead we had new, or recently refurbished, buildings to deal with, and such buildings cannot be refurbished again until a certain amount of time has passed. This illustrates the lead time in system reconstruction. Nonetheless, we found a number of facts that were of interest (Gebremedhin et al, 2004):

- For many buildings, there were no, or only small, differences in heat demand between day and night. This was surprising, since the demand should be lower during nights and weekends when facilities were not in use.

- Buildings used both district heating *and* district cooling simultaneously even during winter, see Table 1, where the cooling system was used during the coldest day of the year.
- A number of buildings were heavily ventilated, even when no people used the premises, see Table 1, where the district heating demand was doubled during morning hours, even if the outdoor temperature was almost constant.
- Several buildings were refurbished with measures that were not optimal from an energy viewpoint.
- Some buildings, where no retrofits have been made, showed good profitability for energy-conserving measures.
- Load management of district heating was of interest, which calls upon communication, perhaps via the Internet, between consumer and utility. (The utility uses oil-fired boilers to cover the peak demand.)
- Some buildings were equipped with sophisticated measurement equipment, but the systems were so complex that fast, trustworthy analyses were impossible to obtain.
- Energy conservation has low priority compared to selling products and making customers satisfied.

Insulation (Figure 1) and better windows showed sustainability in poor buildings. Solar panels and exhaust-air heat pumps were not sustainable according to our criterion.

Table 1. Outdoor temperature and district heating and cooling demand for one of the studied buildings in Solna for New Years Eve, 2000, during 10 hours (Gebremedhin et al, 2004).

Time	Temp	Heating	Cooling
hour	**°C**	**kW**	**kW**
0000	-15.6	310	0
0100	-16.1	300	0
0200	-16.2	310	0
0300	-16.4	310	0
0400	-16.6	290	0
0500	-16.4	330	100
0600	-16.3	390	0
0700	-16.5	610	0
0800	-16.6	750	0
0900	-16.3	850	0

Socio-technical energy competence among building proprietors

A prerequisite for changes in an energy system is competence (Kaijser and Summerton, 1983). Since technology is always embedded in a social context, together forming a socio-technical system, skills concerning social issues are as important as technical knowledge. The competence surrounding the buildings in Solna could mainly be characterized as technical skills embodied in real estate managers, engineers and technicians. However, the number of people endowed with this competence varied between the different organizations under study. In one organization, the work group dealing with energy issues, which consisted of managers and engineers, had increased, while in another organization the number of people working with energy-related issues had decreased. This influenced the energy management of the buildings.

In several buildings, the office spaces were over-ventilated. However, in some buildings personnel worked around the clock, e.g. researchers, making a decent indoor climate necessary. Organizations with clear energy objectives had incentives to lower energy demand. But in this study, we found only one organization with enough competence to work continuously with high-aiming technical energy objectives. As an organization introduces environmental management, it is necessary to consider the human beings interacting with the technical system as well. Environmental management implies that personnel get educated in environmental issues and how to implement appropriate measures that decrease energy demand. In some organizations, however, education did not enhance environmental concern to a measurable extent.

Other measures to motivate end-users might be different types of incentives. For instance, feedback on how much energy has been saved during the last month can be presented to the personnel regularly (Gebremedhin et al, 2004).

Swedish industrial energy use towards sustainability

To analyze the possibilities to alter energy use towards sustainability, the energy use in 12 industries in Örnsköldsvik and 10 in Ulricehamn were analyzed (Bohlin et al, 2004, Henning et al, 2004). The specific industries studied, were selected among industries that applied to participate in the project according to two criteria: (i) the industries should represent different intensities of electricity and energy use and (ii) management should have shown an interest in energy efficiency issues. The use of electricity at the selected industries varied from 300 MWh to 16,000 MWh a year and the use of energy from 300 MWh to 26,000 MWh a year. The industries were analyzed according to a generalized method for analyzing industrial energy use towards sustainability (Trygg, 2004).

The results of the analysis showed that electricity use for lighting could be reduced by 70%, that for compressed air by 60% and that for ventilation by 52% (Figure 2). The reduction for lighting is, for example, due to more efficient equipment and turning off light when no people are present. Converting the non-electricity-specific processes, such as space heating, hot tap water and heating processes, increases the use of district heating by about 8,500 MWh a year for the 22 industries. The study also showed that the total *electricity* use for the industries could be reduced by 55% and the total *energy* use by 32% of the original level. Assuming that coal condensing power is the marginal electricity production in the European market, the altered electricity use in the industries leads to reduced CO_2 emissions by 47,000 tons a year (assuming also that district heating is produced with bio-fuel with no discharge of CO_2.)

The altered energy use will also give economical benefits for the industries. Changing the energy use as outlined in this paper, leads to a reduction in variable energy cost of 1,900,000 Euro a year for the 22 industries together (no investments included and assuming an electricity price of 45 Euro/MWh and a price for district heating of 40 Euro/MWh.) If the electricity price level in Sweden was adjusted to a higher European level of 80 Euro/MWh (Melkersson and Söderberg, 2004), the change in energy use would lead to a reduction in variable energy cost for the industries of more than 3,600,000 Euro per year.

District heating as a means of improving sustainability

District heating has the advantage of utilizing resources that are difficult to make use of in other ways, such as waste heat that is derived from industries, waste incineration or CHP. National and international policy instruments, such as taxes, green electricity certificates and emission allowances, have significant influence on investment decisions and operational strategy for local utilities (e.g. Sundberg and Henning, 2002). The studied district-heating companies are owned by each municipality.

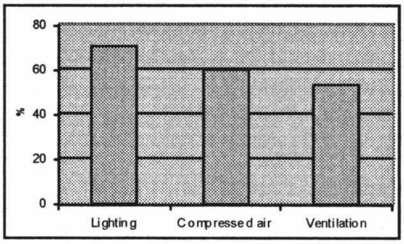


Figure 2. Possible reduction of electricity use for three support processes in 22 investigated industries (cf. Trygg, 2004).

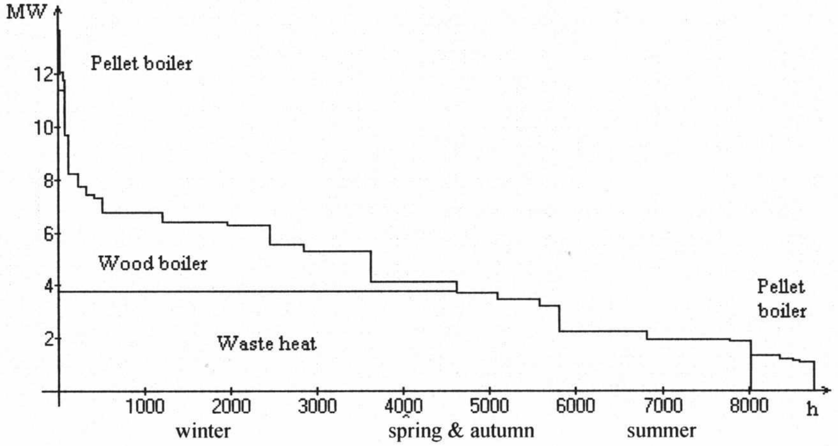
A local utility can also have a district-cooling system, which supplies office blocks, shops, industries, etc. with cooling. In Örnsköldsvik, seawater from the bottom of the city bay is used. In Ulricehamn, cooling might be derived from the adjacent lake or from absorption refrigeration driven by district heating.

In many industries, electricity and oil used for heat production could be replaced by district heating. The industrial heat demand is partly due to space heating and tap water and partly due to the demand for process heat, which is mainly needed during the working hours of weekdays throughout the year except during the summer holiday. The seasonal variations of industrial heat demand are therefore normally smaller than for other customers. In Ulricehamn, the main source for district heating is surplus heat from a wood pellet manufacturer, which is sold to the local utility according to a long-term agreement. The factory also has wood and oil fired boilers that produce district heating. Only when pellet manufacturing is standing still in summer or during very cold days with high heat demand, the utility uses pellets or even oil and electricity in its own boilers (Figure 3). A connection of industries to the district-heating grid would mean that in autumn, winter and spring, more biomass would be fired. During summer, there is now surplus heat that has to be wasted because it has no outlet but with more industrial district-heating customers it could be utilized to a larger extent (Figure 3, Bohlin et al, 2004).

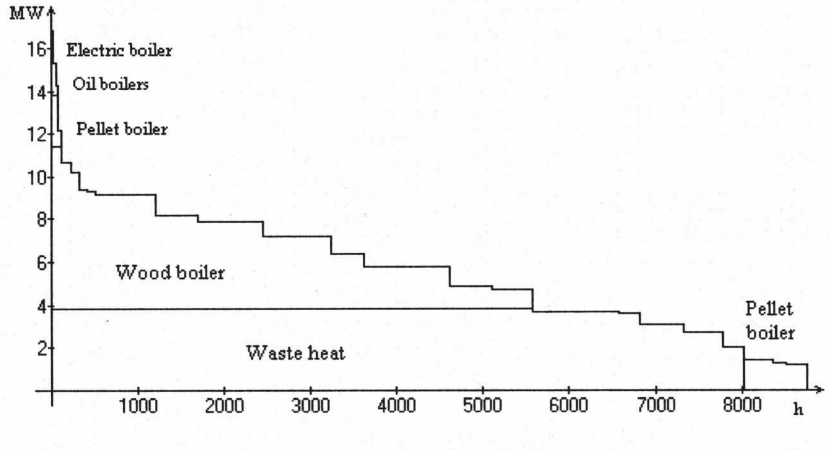
To cover a substantially increased district-heating demand in Ulricehamn, a new supply unit is required. Because the base load is covered by low-cost waste heat, it is less suitable with large investments that require long annual running times to be profitable, such as waste incineration or CHP plants (cf. Danestig and Henning, 2004). They would here only serve as a complement to waste heat. Local resources, such as waste heat, can only be used at their locations and should mostly be used before regional resources that can be transported, such as waste or biomass. A new plant would primarily be used in winter and a wood-fired heat-only boiler should be preferable.

In Örnsköldsvik, the local utility has purchased boilers and a turbine from an industry, which it now supplies with steam. A CHP plant, which can produce electricity, district heating and industrial steam, is planned. The concept illustrates a promising co-operation between public and private organizations (Henning et al, 2004). The private company might in this case not have afforded the investment in a new plant, but can carry steam purchase costs. A techno-economic energy system optimization showed that the planned CHP plant is a preferable solution due to synergies between steam and heat production. The investment can be carried by heat *and* steam sales and the steam supply enables the generation of additional power that can be sold in the market. The electricity can displace coal-condensing power and reduce CO_2 emissions.

The Örnsköldsvik utility considers an introduction of waste incineration, which would serve as base load, because it generates a net running income since costs for other types of waste management are avoided. Waste incineration would therefore reduce the heat demand that can be used as heat sink for a CHP plant. It would reduce local power generation and decrease the displacement of coal-fired condensing plants and their CO_2 emissions (Danestig and Henning, 2004).



a)



b)

Figure 3. District-heating supply during a year in Ulricehamn a) now and b) with 12 GWh additional industrial heat load (Bohlin et al, 2004).

Besides industries, there are several detached houses that could be supplied by district heating. A district-heating grid is normally expanded to new areas stepwise. It is important for potential customers to know when they will be offered district-heating supply. If many houses install new individual equipment, the district heating market vanishes (cf. Danestig & Westerberg, 2005). To secure future markets for a district-heating utility and to secure the shaping of more sustainable local energy systems, utilities may need to initiate new ways of customer communication. One-way presentations of tariffs and time schedules should be replaced by dialogue on cost structures and customer desires for when duties should begin, supply quality etc. (cf. Bohlin et al, 2004).

Discussion

A sustainable society should be ecologically, economically and socially sustainable. This may include, among other things, a significantly lower consumption of finite resources, production and distribution of goods and services in a long-term affordable manner and stable forms for popular participation in society development. We have tried to show ways to reduce fossil-fuel consumption and to keep energy costs for services premises and manufacturing affordable. We have also considered energy management in buildings.

In this paper, we have assumed that increased local power generation and decreased electricity use reduce global CO_2 emissions, because it reduces power production in coal-fired condensing plants. But the recently introduced European emission trading system determines the total CO_2 emissions from energy and manufacturing industries in the EU to a fixed level and total CO_2 emissions will not be influenced if the system functions as intended. The operation of coal condensing plants and their emissions are still reduced by increased generation in other plants and reduced electricity use, but it does not influence the total CO_2 emissions. The reduced demand for emission quotas from coal-fired plants would rather reduce the allowance price and make it cheaper to emit CO_2 from other energy or industrial plants.

However, the conclusions concerning what should be done may be the same. The EU emission trading system aims at fulfilling the Union's Kyoto obligations to the lowest possible cost. Measures have to be taken to achieve this goal. Reduced electricity use and increased electricity generation in efficient CHP plants with renewable fuels should be ingredients in required solutions. This issue also leads to a wider question. Should research adapt to prevailing policy measures that have a substantial influence on the studied arena or should science look above and beyond such disturbing factors?

Sustainability is a difficult concept for making trade-offs between its ecological, economic and social dimensions or to judge among current local action alternatives (cf. Henning et al, 2004). Can there, as an example, really be a sustainable growth?

Local governments have limited resources. Sustainability goals can be reached only if inhabitants, companies, etc. are willing to help. Municipal bodies should initiate and stimulate co-operation among local actors. An industry's core business is the manufacturing of products. Energy supply is seen as a means of production that should be readily available (cf. Sandberg and Söderström, 2003). Municipal energy advisors could help companies pay attention to energy conservation. Municipal personnel could arrange seminars for dissemination of knowledge and ideas and with dialogue on energy supply and conservation among utilities, industries and house owners. Such events could be a starting point for networks among actors with similar interests where experiences could be exchanged and common action may be initiated. It would also promote economical and social sustainability. Industries that are pioneers in introducing ecologically sustainable energy supply and use should have better economic prospects (Bohlin et al, 2004). Such a development may now take place in Ulricehamn and Örnsköldsvik.

Conclusions

There are measures that can be taken to lower the energy demand in the buildings studied in Solna, though the selected buildings were not traditional objects for refurbishment. Some results from the mathematical modelling suggested that there was a waste of energy in several buildings. Free energy from people and appliances was not recovered even if recovery equipment was present. For some offices, ventilation during night was necessary due to the working hours of the personnel. For others, such electricity waste could be caused by a lack of technical competence. To introduce socio-technical efficiency improvements in the operations of these organizations, we suggest environmental management training or the introduction of different incentives for the end users.

A reduction in electricity use by Swedish industry will mean lower CO_2 emissions. It also implies freed generation capacity for Swedish power suppliers and as a result, better possibilities for a Swedish supplier to sell electricity to customers on the European market. Because Swedish electricity production is mainly free from CO_2 emissions, electricity produced in Swedish power plants will be promoted by international trading in CO_2 emission quotas. Hence, energy conservation supporting a more sustainable electricity use helps EU meet its target with respect to lower emissions of greenhouse gases.

Many industries can be connected to district-heating grids and can, together with other heat consumers, become heat sinks for waste heat, CHP plants or waste incineration during large parts of the year. Waste heat is a local resource that normally should be used in the first place, whereas wood and waste are regional resources that can be transported and should be used in the second place. Cogeneration of electricity, steam and district heating can be advantageous if industrial steam demand is present.

Acknowledgement

The work has been carried out under the auspices of the programmes *Sustainable municipality* and *Energy systems*, which are financed by the Swedish Energy Agency.

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Science for Sustainable Development

Starting Points and Critical Reflections

Sustainable development as a political goal and as a research field challenges the compartmentalisation that characterizes society as a whole and that characterizes research. There is a need to promote an improved dialogue between actors representing different societal sectors and between different research disciplines. The Swedish association VHU (Science for Sustainable Development) was formally started in February 2002. The main aim of VHU is to create and maintain a national arena for those who work with sustainable development within research and higher education. VHU promotes the multi-, cross-, inter- and transdisciplinary interaction and cooperation between different fields of science, but also between science and actors outside the research- and education community. On 14–16 April 2004 in Västerås, VHU in co-operation with the Mälardalen University organized its first national conference called: Science for Sustainable Development – starting points, dialogue and critical reflection. The focus of the conference was to promote critical reflection on different assumptions made in sustainable development oriented research. Another goal of the conference was to provide an opportunity for PhD students and young researchers to present and discuss their sustainable development research. These proceedings bring together a number of the papers presented at the conference. They include a wide range of ideas, approaches and reflections and we believe they offer an interesting overview of the range of issues that are being dealt with in sustainable development research in Sweden. The picture of ongoing work presented in this book is not complete, but we hope it will provide a starting point for a constructive, critical and respectful dialogue across disciplinary boundaries and thus hopefully promote further research, reflection and debate on and for sustainable development.

VETENSKAP FÖR HÅLLBAR UTVECKLING

MÄLARDALENS HÖGSKOLA