Energy savings in Scandinavian households: an assessment of 25 years development

Fridtjof Unander
International Energy Agency
9, rue de la Fédération, 75739 PARIS, Cedex 15
fridtjof.unander@iea.org

Ingunn Ettestøl
Enova
Abelsgate 5, N-7030 Trondheim, Norway
ingunn.ettestoel@enova.no

Mike Ting
International Energy Agency
mike.ting@iea.org

Keywords

energy indicators, energy savings, decomposition, residential, Scandinavia

Abstract

This paper uses a decomposition approach based on Laspeyres indices to examine savings in residential energy use in the Scandinavian countries: Denmark, Norway and Sweden, over the period 1973 to 1998. The decomposition approach allows for separating impacts on energy use from changes in residential energy demand structure and end-use intensities. The paper also makes comparisons to other countries that have been analysed in the IEA energy efficiency indicator project. The results show that while Denmark and Sweden achieved significant reductions of residential energy intensities between 1973 and 1990, the reductions in Norway were negligible. After 1990, the picture changed; there was a strong decline in residential energy intensities in Norway and a high rate of energy savings compared most other countries analysed by the IEA, while energy savings in Denmark and Sweden more or less came to a halt.

Introduction

This paper analyses residential energy use in the three Scandinavian countries Denmark, Norway and Sweden from 1973 to 1998, with comparisons to other IEA countries. Most of the results discussed in this paper are based on analysis presented in Unander et al. (2003). References to earlier studies that this work builds on include Schipper et al. (1992, 1993 and 1995), and Unander et al. (1997), and Unander and Schipper (2000).

The purpose of the paper is to explain how residential energy use in the three Scandinavian countries compare through investigating differences in residential energy demand structure and end-use intensities. The paper addresses both differences in absolute levels of energy use and differences over time. An important element of the trend analysis is to estimate the savings that are a result of declining end-use energy intensities.

The paper begins with an overview of the methodology and data used for the analysis. The results of the analysis are then presented in three sections, first a section with aggregate trends in residential energy use followed by a section discussing how structural and intensity components have affected energy use, and finally a section presenting results from the decomposition analysis used to identify energy savings resulting from declining end-use intensities.

Methodology and data

The methodology used to analyse residential energy use is building on the IEA indicator approach, see the Schipper et al. (2001) and Unander (2001). Table 1 illustrates how the indicator approach can be used to break down changes in residential energy use into changes in activity, demand structure and end-use intensities. While *activity* is simply defined as population, the *structure* components are floor area/capita, person/household and appliance ownership/capita. *Energy intensity* is defined as delivered, or final, energy per unit of activity. Energy intensities are related, but not equivalent, to the inverse of energy efficiency. Increases in

Table 1. Measures of activity, structure and end-use energy intensities in the residential sector.

End uses (E_i)	Activity (A)	**Structure (S_i)**	**Intensity (I_i)**
Space Heat	Population	Floor area/capita	Energy/floor area
Water Heat	Population	Person/household	Energy/capita
Cooking	Population	Person/household	Energy/capita
Lighting	Population	Floor area/capita	Energy/floor area
Appliances	Population	Ownership/capita	Energy/appliance

energy efficiency help reduce energy intensities, but changes in other factors (e.g. usage patterns) can either augment or counter-balance the impact of improved efficiencies on energy intensity. For example, a decline in space heating per unit of floor area may actually underestimate improvements in building shell energy efficiency, if average indoor temperatures have increased at the same time. On the other hand, floor area may also be an inadequate activity measure for space heating efficiency as building statistics do not capture the share of building area that is actually heated. However, because of the limitations in data availability and limited information about utilisation of household equipment this paper focuses on analysing the intensities listed in Table 1 as indicative for how much energy savings that have been achieved.

This paper uses Laspeyres indices to analyse changes in the structure and intensity components over time. These indices can be thought of as "all else being equal" indices, describing the evolution of energy use that would have taken place if all but one factor remained constant. This can be summarised by the following equation:

$$\mathbf{E = A * S_i * I_i}$$

Where:

E represents total residential energy use,

A activity (population),

Si the structure component for each residential end-use i, and

Ii the energy intensity of each end-use i.

Energy savings are defined as the difference between actual energy use and the amount of energy that would have been used in a given year, *t*, if energy intensities in each end-use were frozen at a base year level, while the activity and structure had evolved as they actually did. This can be measured as:

$$\%E\ savings = (A_t \sum_{i=1}^{n} S_{it}(I_{i0} - I_{it}) \ / \ E_0$$

The data used in this paper draw on data developed for previous studies of Danish, Norwegian and Swedish energy use. For Sweden, Energy use in Sweden: An international perspective (Schipper et al., 1993) and Efficient energy use and well-being: The Swedish example after 20 years (Schipper et al., 1994) are used. For Norway the main references are Trends in Norwegian Stationary Energy Use (Unander and Schipper, 2000) and Energy Use in Norway: An International Perspective (1997). For Denmark, we draw from the recent study Energy Efficiency in Denmark (Dal and Jenssen, 2000) in addition to Energy Use in Denmark and other OECD Countries: Comparisons of Trends through the early 1990's. (1995). Date for energy prices are taken from IEA's quarterly publication on Energy Prices and Taxes. For other countries data were primarily developed through Lawrence Berkeley National Laboratory's long-standing analysis of each country's official housing, equipment, household, and energy statistics, and updated for recent years by the IEA, who has also extended the analysis to more countries, refer to Schipper (1997).

Trends in residential energy use

Figure 1 shows per capita residential energy use by end-use for the three Scandinavian countries and selected IEA countries, with space heating adjusted to 2 700 degree days (Base 18°C) to correct for differences in climate among the countries. Denmark's residential consumption in 1973 was high compared to most other IEA countries, while Norway was the lowest after Japan. By 1998, however, Danish consumption had fallen significantly and dropped slightly under the level of Sweden, who saw a more modest reduction between 1973 and 1998. In Norway, on the other hand, per capita household energy use rose significantly over this period. Still, despite the reductions experienced in Sweden and Denmark, Norway still consumed marginally less energy per capita than its two neighbouring countries in 1998.

Outside of Scandinavia energy use rose in the United Kingdom and France as central heating became more widespread and appliance ownership expanded. More residential appliances also drove up energy use in all the other countries, most significantly in countries where ownership levels were low to start with in the 1970's. As a result, the residential per capita energy use shown in Figure 1 differs less among the countries in 1998 than in 1973.

As Table 2 shows, Danish and Swedish residential energy demand fell between 1973 and 1990, a period when energy prices generally rose, while Norway, on the other hand, saw a significant increase in demand during the same period. Increased use of electricity for space heating was the dominant factor behind the growth in Norway. In Norway the 1973 share of homes with electric heating was 42 percent, which rose to a staggering 65 percent in 1998. No other country studied by the IEA comes close to this penetration of electricity as a heating alternative, Unander et al. (2003).

The high share of electricity in space heating can explain why electricity accounts for almost 80 percent of residential

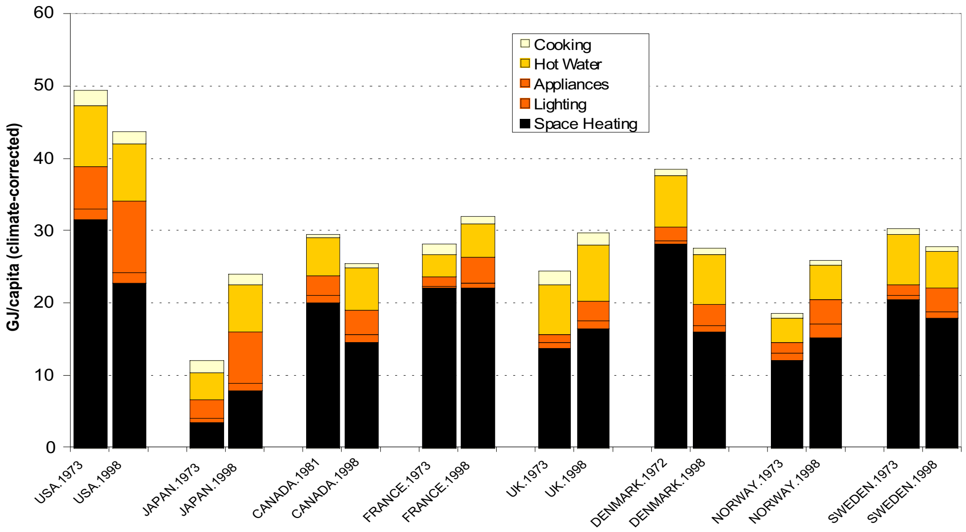

Figure 1. *Residential final energy use per capita by end-use (adjusted for climate differences), 1973 vs. 1998.*

energy use in Norway. In no other country studied by the IEA is the share of electricity more than 50 percent with the exception of Canada (see Unander and Schipper, 2000). Electricity share of residential energy demand in Sweden is a bit more than 40 percent and around 20 percent in Denmark.

Residential structure and intensity

The most important structural component driving residential energy demand is the size of homes occupied. Figure 2 shows house area per capita versus private consumption expenditures (a measure of private income) for Denmark, Norway and Sweden and for some selected IEA countries. Note that each data point represents the combination of expenditures and area for a given year. If expenditures fall temporarily, successive values will move to the left. To illustrate the time development, a line is drawn through the data points year by year.

Despite having relatively low income levels in the early 1970's, Norwegians had above IEA-average per capita floor space (see Unander and Schipper, 2000). However, Norwegian homes were smaller than those in Sweden and Denmark, where income levels were higher. As income rose for Norwegians, house sizes grew bigger. Today Norwegians have the same size residences per capita as in Denmark. Interestingly, the two countries also had the same per capita personal expenditure levels in 1995. Swedish houses are larger than those in Norway though income levels now are lower than in Denmark and Norway. From Figure 2 it can be seen that Sweden has undergone a recession during the 1990's. The income levels have stagnated and so has house area per capita.

Another important structural component of residential energy use is household occupancy, measured as persons per household. Energy use tends to rise with falling household occupancy, all else being equal. The primary reason is that space heating demand, and to some extent lighting levels, in a given residence are relatively independent of how many people occupy the dwelling. Thus, if household occupancy

Table 2. Residential energy demand and end-use shares in Denmark, Norway, and Sweden (space heating is corrected for year-to-year variations in climate).

	1973	1990	1998
Denmark*			
Total (PJ)	**225.6**	**165.1**	**171.4**
Space heating electricity (%)	*0%*	*3%*	*2%*
Space heating other (%)	*73%*	*57%*	*57%*
Water heating (%)	*19%*	*24%*	*25%*
Cooking (%)	*2%*	*3%*	*3%*
Lighting (%)	*1%*	*4%*	*3%*
Appliances (%)	*5%*	*9%*	*10%*
Norway			
Total (PJ)	**106.3**	**161.9**	**166.1**
Space heating electricity (%)	*21%*	*34%*	*36%*
Space heating other (%)	*44%*	*28%*	*23%*
Water heating (%)	*18%*	*17%*	*18%*
Cooking (%)	*4%*	*3%*	*3%*
Lighting (%)	*6%*	*7%*	*8%*
Appliances (%)	*8%*	*11%*	*13%*
Sweden			
Total (PJ)	**362.3**	**347.0**	**361.7**
Space heating electricity (%)	*4%*	*18%*	*19%*
Space heating other (%)	*64%*	*47%*	*46%*
Water heating (%)	*23%*	*19%*	*18%*
Cooking (%)	*2%*	*2%*	*2%*
Lighting (%)	*2%*	*3%*	*3%*
Appliances (%)	*5%*	*11%*	*13%*

** Beginning year for Denmark is 1972.*

declines, space-heating demand per household declines at a much slower rate (or not at all), which pushes up space heating demand per capita. In Denmark, Sweden and Norway, as in most other countries, household occupancy has steadily declined since the 1970's.

Figure 1 indicated relatively big differences in both levels and time development of end-use energy demand across countries. To what extent is this due to differences in energy efficiency developments and to what extent is it a result of structural differences? Consider the most important end-use, space heating. Obviously, levels of space heating are dependent on climate and house area, but also on the type of

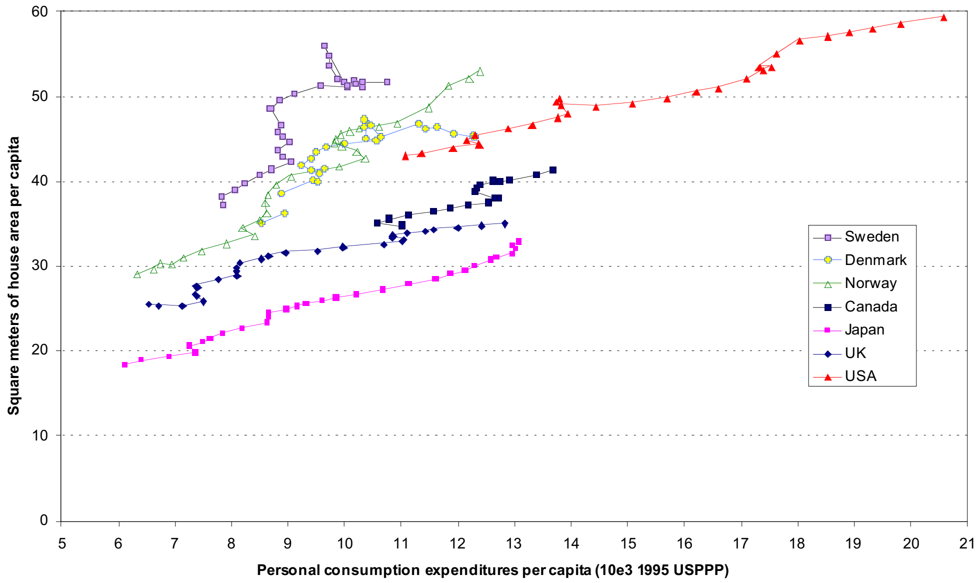

Figure 2. *Personal consumption expenditures and house area, 1970-1998.*

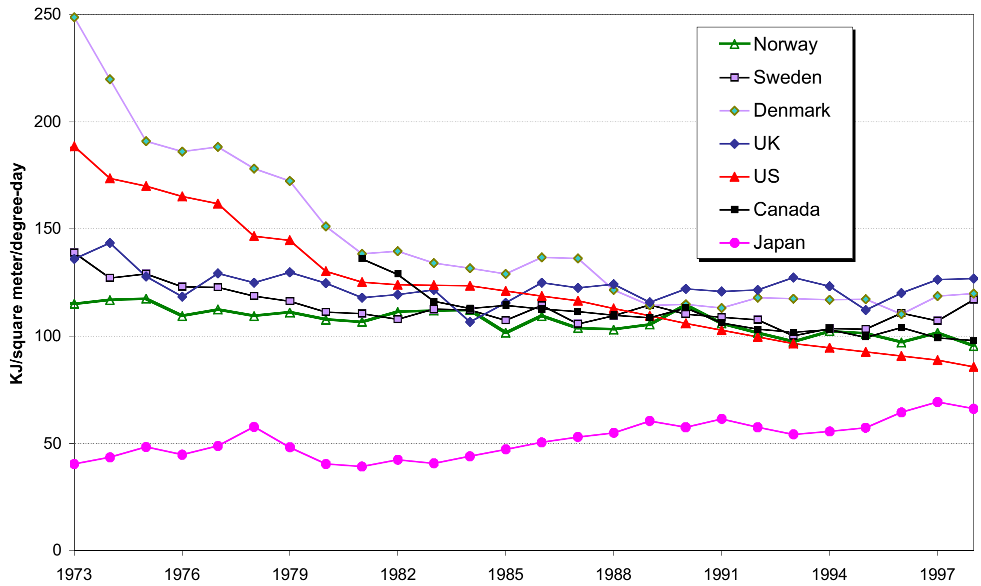

Figure 3. *Useful space heating intensity, 1973-1998.*

heating system. To correct for differences among the major heating systems, space-heating demand can be expressed as useful energy. This approach allows a reasonable comparison among countries with different space heating fuel shares by calculating useful energy with solids counted at 55 percent conversion efficiency, oil and gas counted at 66 percent and electricity and district heat counted at 100 percent efficiency[1]. A normalisation for climate variations is obtained by dividing by each country's yearly degree-days. The differences among countries and over time are depicted by showing space intensity expressed as useful energy per square metre of floor area per degree-day (base 18°C) in Figure 3.

Useful space heating intensity in Denmark was among the highest observed during the early 1970's but then declined significantly through the 1970's and 1980's. Space heating intensity in Sweden was considerably lower than in Denmark in the early 1970's and declined steadily throughout the whole period albeit at a slower rate. Space heating intensity in Norway has been among the lowest of the countries shown in Figure 3 since 1973. Since heat is expressed in terms of useful energy, the high penetration of electric re-

1. These conversion efficiencies are estimated average efficiencies for space heating equipment among several countries and over a long time span. Although the efficiencies of space heating equipment can be expected to change over time and although there may be differences from country to country that affect the efficiencies, the figures used here give a reasonable basis for comparing how useful space heating has developed across a large number of countries.

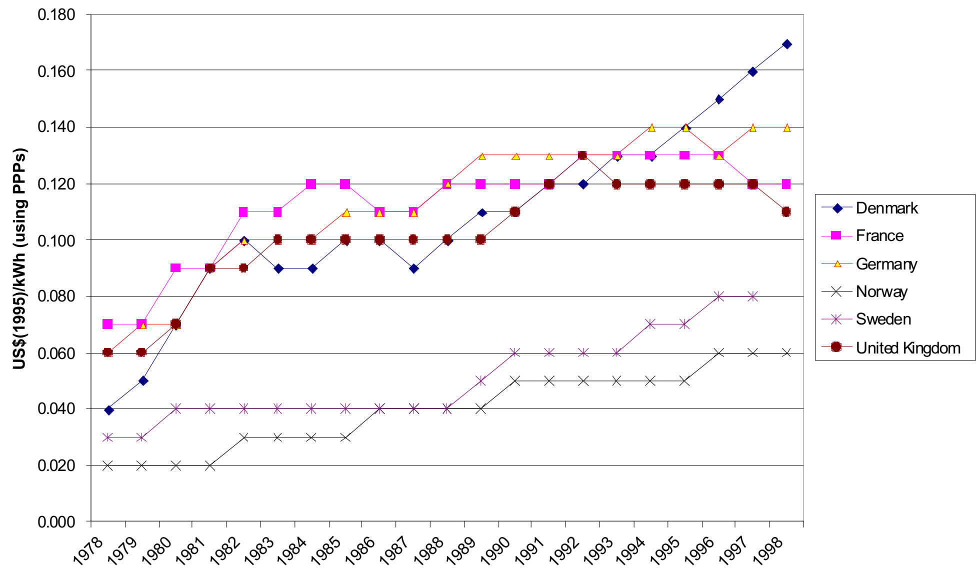

Figure 4. *Residential Electricity Prices(US$ 1995 (PPP) per kWh) (from IEA Energy Prices and Taxes).*

sistance heaters in Norway does not explain the low intensity. Lower heating levels (heating comfort) in Norwegian homes in the early years shown in the figure may be an important reason for the low intensity. Throughout the 1970's and early 1980's the heating comfort in Norwegian households expanded with a rise in indoor temperatures and the heating of more of the total house area (Grinden, 1988). This increase in heating comfort levelled out savings from higher insulation levels as new homes built with stricter energy codes replaced older residences. This helps to explain why the space heating energy intensity in Norway did not decline as much as in other countries in this period. After Norway reached similar income levels as in other "cold" countries in the mid 1980's, heating intensity has fallen at about the same rate as Sweden and Denmark.

As Figure 3 indicates, Norway and Sweden still have among the lowest space heating intensities. At the same time, Swedish and Norwegian consumers are endowed with significantly lower electricity prices (including taxes) than in most other countries (Figure 4). Danish consumers, pay on the order 2.5 to 3 times more for their electricity. Given the high share of electricity in space heating in Norway, electricity price is a good indicator for what Norwegian consumers pay to heat their homes. It is however misleading to compare incentives for improving space-heating efficiency based on electricity prices as most other countries rely on other fuels for heating. Unander et al. (2003) instead compares a fuel-weighted price index for useful heat[2]. This price index was in 1998 around the same level in the three Scandinavian countries. It is thus reasonable to conclude that there were real improvements in space heating efficiency in Norway between 1973 and 1990, and that higher indoor heating comfort levels ate up these savings as income grew. On the other hand, the comparatively low Norwegian electricity prices do not stimulate improved efficiency of non-heating uses of electricity, thus it is likely that little savings were achieved in these end-uses.

Table 3. Impact of changes in activity, structure and end-use intensities. Average percentage change per year.

	1973-90	1990-95	1995-98
Norway			
Actual Energy	2.5%	-0.6%	1.6%
Activity	0.4%	0.6%	0.6%
Structure	2.0%	0.7%	2.4%
Intensity	0.0%	-1.9%	-1.2%
Sweden			
Actual Energy	-0.3%	-0.1%	1.5%
Activity	0.3%	0.6%	0.1%
Structure	1.7%	0.8%	-0.7%
Intensity	-2.3%	-1.5%	2.2%
Denmark*			
Actual Energy	-1.8%	0.5%	0.4%
Activity	0.2%	0.4%	0.4%
Structure	1.5%	0.2%	-0.1%
Intensity	-3.6%	-0.1%	0.1%

** Beginning year for Denmark is 1972*

Decomposition of residential energy use

Table 3 shows the results of decomposing changes in residential energy into changes in activity, structure and end-use energy intensities for the three Scandinavian countries. Recall from Table 1 that while the activity variable is simply population growth, structural changes include:

- home area per capita (for space heating and lighting);
- appliance ownership per capita;

2. For Denmark the district heat price data are taken from the Danish Competition Authority's (*Konkurrenceraadet* in Danish) publication "*Energiprisorientering – Statistikk 1998*" (in Danish). Data for Sweden are from the Swedish Energy Agency's (*Energimyndigheten* in Swedish) publication "*Prisblad för biobränslen, torv m.m", Nr. 2/2002* (in Swedish).

- household size (for water heating and cooking).

These are measured as the impacts of changes in residential energy use with intensities for the same end-uses fixed at 1990 base-year values. Hence the structure component illustrates what residential energy use would have been in any given year if only these measures changed, (i.e. space heating and lighting per area, water heat and cooking per capita and electricity used in major appliances all remained constant). Conversely, the intensity effect illustrates the impact changes in all these intensities would have on energy use if the various structure components had been constant at 1990-levels[3].

In order to isolate recent trends, the results are expressed as average annual rates of change over the periods 1973-1990, 1990-1995, and 1995-1998. Over the period 1973-1990, structural changes pushed up energy use in all three countries, driven by increases in house area and appliance ownership and decreases in household occupancy. Before 1990 falling intensities lead to significant savings in both Denmark and Sweden. The same trend can be seen for most other OECD countries studied by the IEA (Unander and Schipper, 2000). In Norway, however, the net change in energy use from changes in energy intensities was close to nil. As mentioned in the discussion of space heating intensity this development can be partly explained by increasing heating comfort levels as Norwegian incomes grew.

Since 1990, the structure effect continued to increase energy use but at a significantly lower rate as growth in house area slowed down and appliance ownership began to saturate. In Norway, however, strong growth in new housing construction rates since 1995 has pushed the structure effect up to nearly the same levels experienced during the 1970's and 1980's. On the other hand, Norway has since 1990 experienced significant declines in energy intensities. This development may indicate continued improvements in space heating, but this time without loosing the savings through increases in heating comfort. In Sweden and Denmark the development went the other direction, the strong declines in intensities seen before 1990 slowed significantly. After 1995 the intensity effect in Sweden even led to increased residential energy use. Danish residential energy intensities remained remarkably constant both between 1990 and 1995 and between 1995 and 1998.

If the savings from declining intensities are calculated according to the formula described in the methodology section above, the decline in the Danish intensities between 1973 and 1990 reduced residential energy by 47 percent and the intensity decline in Sweden reduced energy use by 32 percent from what it would have been if intensities had not changed over the 1973-1990 period. Norway did not achieve any savings in this period due to the near zero net change in intensities between 1973 and 1990.

Between 1990 and 1998, the situation reversed, both Denmark and Sweden saw no net change in intensities over this period and did thus not achieve any savings, while the intensity decline in Norway reduced energy use by 12 percent compared to a situation where intensities had not changed since 1990.

Conclusions

Differences in climate-adjusted per capita residential energy use among the three Scandinavian countries are today relatively small. This is in contrast to the early 1970's when Danish per capita energy use was more than twice as high as in Norway, and the Swedish around two-thirds higher. One reason for this development is that while homes in Norway in the early 1970s were smaller, and consequently required less energy than in its Scandinavian neighbours, their area grew much faster throughout 1970's and 1980's and thus drove up energy use compared to the development in Denmark and Sweden.

However, our analysis shows that the most important reason for the convergence in the level of residential energy use among the three countries is the significantly higher energy savings achieved in Denmark and Sweden compared to Norway. The main driver behind these savings were the strong reduction in space heating intensities up to the mid-1980's seen especially in Denmark, but also in Sweden. Between 1973 and 1990 energy savings were negligible in Norway, which can be partly explained by increasing heating comfort levels during this period. Another important explanation is that the access to inexpensive hydropower in Norway reduced the incentive for *electricity* savings, and gave room for an expansion of electricity as the main heating source. After 1990, the picture changed; there was a strong decline in energy intensities in Norway and a high rate of energy savings compared to most other countries analysed by the IEA, while energy savings in Denmark and Sweden more or less came to a halt. Although these results are affected by many sources of uncertainties due to data limitations, the tendency during the 1990's is clear. Energy savings have been accelerating in Norway and slowing down in Denmark and Sweden. The positive development in Norway may indicate that increasing attention to energy costs and opportunities to save energy has made an impact.

Still, in Norway as well as in Sweden and Denmark efforts to save energy and especially electricity is more important than ever: The three countries today share a common electricity market, a market that during the winter of 2003 was very strained due to lower than normal precipitation and high demand. This resulted in significant increases in prices, especially in Norway, and fear that supplies would not be sufficient to meet demand as the water levels hydro reservoirs in Norway and Sweden fell way below levels normal for the season. The Scandinavian market, and in particular Norway with its high share of electricity for space heating, thus faces a difficult challenges to reduce future growth in electricity demand. The challenge is augmented by Sweden's ambitious plan to phase out nuclear generation capacity. Indeed, significant expansion of the Nordic electricity supply will either be expensive or result in increasing CO_2 emissions, highlighting the importance of focussing on measures that improve energy efficiency.

3. In this calculation the energy intensity of space heating is linearly corrected for variations in degree-days.

References

Bøeng, A. C. and Nesbakken R., 1999, Energibruk til stasjonaere og mobile formål per husholdning 1993, 1994 of 1995. Gjennomsnittstall basert på forbruksundersøkelsen, Rapporter, Statistics Norway (in Norwegian).

Dal, P. and Jensen, S. J., 2000, Energy Efficiency in Denmark: An Analysis Based on the ODYSSEE Data Base from the SAVE project "Cross Country Comparison on Energy Efficiency Indicators, Phase 6", Energistyrelsen, ISBN: 87-7844-207-9.

Energistyrelsen, 1995, Energiforbruk –livsstil og adferd, Danmarks Energifremtider, Miljø- og Energiministeriet (in Danish).

Grinden, Bjørn, 1988, Analyse av energiforbruket 1976-1986 i boligsektor. ENØK og reelle forklaringsvariable.: EFI TR A3534, Trondheim, Norway (in Norwegian).

IEA, 1997, Indicators of Energy Use and Efficiency: Understanding the link between energy and human activity, OECD/IEA.

IEA (International Energy Agency), 1997, The link between Energy and Human Activity, OECD, Paris, France.

IEA (International Energy Agency), 2001, Energy Policies of IEA Countries: Norway 2001 Review, OECD/IEA.

IEA (International Energy Agency), 1998, Energy Policies of IEA Countries: Denmark 1998 Review, OECD/IEA.

IEA (International Energy Agency), 2000, Energy Policies of IEA Countries: Sweden 2000 Review, OECD/IEA.

Norges Offentlige Utredninger, 1998, Energi- og kraftbalansen i Norge mot 2020, NOU 1998:11 (in Norwegian).

Schipper, L., Howarth, R. B., Carlesarle, E., 1992. Energy intensity, sectoral activity, and structural change in the Norwegian economy. Energy–The International Journal 17(3), 215-233.

Schipper, L., Johnson, F., Howarth, R. B., Andersson, B.G., Andersson, B.A., Price, L., 1993. Energy use in Sweden: An international perspective. Berkeley, CA: Lawrence Berkeley Laboratory, LBL-33819.

Schipper, L., and Price, L., 1994. Efficient energy use and well being: The Swedish example after 20 years. Natural Resources Forum 18(2), 125-142.

Schipper, L., Khrushch, M., Unander, F., Ting, M., Szegen, O., Scholl, L., Goldman, T., 1995. Energy Use in Denmark and other OECD Countries: Comparison of Trends through the early 1990's. Danish Energy Agency, Copenhagen.

Schipper, L., Peraelae, L., Johnson, F., Khrushch, M., Ting, M., Unander, F., 1995. Energy use in Finland: An international perspective. Berkeley, CA: Lawrence Berkeley Laboratory, LBL-37510.

Schipper, L., Ting, M., Khrushch, M., Monahan, P., Unander, F., Golove, W., 1997. The Evolution of Carbon Dioxide Emissions from Energy Use in Industrialized Countries: An End-Use Analysis. Energy Policy 25(7-9), 651-672.

Schipper, L.J. and Grubb, M, 2000, On the rebound? Feedback between energy intensities and energy uses in IEA Countries, Energy Policy 28, 367-388.

Schipper, L.J., Unander, F., Marie-Lilliu, C., Walker, I., Gorham, R., Murtishaw, S.G., Ting, M., Khrushch, M., and Krackeler, T., 2000, Energy Use in Australia in an International Perspective: Comparisons of trends through the mid 1990's, IEA, ISR, Australia.

Schipper, L., Unander, F., Murtishaw, S. and Ting, M., 2001, Indicators of Energy Use and Carbon Emissions: Explaining the Energy Economy Link, Annual Review of Energy and the Environment, 26, 49-81.

Statistics Norway Report, 1993, The Evolution of Norwegian Energy Use, from 1950 to 1991, Statistics Norway, 93/21.

Unander, F., Alm,L., Schipper, L., 1997. Energy Use in Norway: An International Perspective. Institute for Energy Technology, Kjeller, Norway. IFE/KR/E -96/003.

Unander, F. and Schipper, L., 2000, Trends in Norwegian Stationary Energy Use: An International Perspective, NVE report.

Unander, F., 2001, Energy indicators and sustainable development, IEA paper published for UNFCC-COP7, Marrakesh.

Unander, F., Ettestøl, I, Ting, M., and Schipper, L., 2003, Residential Energy Use: An International Perspective on Long-Term Trends in Denmark, Norway and Sweden, Energy Policy (forthcoming).