Discussion Papers
Statistics Norway
Research department
No. 736
April 2013

Statistics Norway

Statistisk sentralbyrå

Hanne Marit Dalen and Bodil M. Larsen

Residential end-use electricity demand

Development over time

Discussion Papers No. 736, April 2013
Statistics Norway, Research Department

Hanne Marit Dalen and Bodil M. Larsen

Residential end-use electricity demand
Development over time

Abstract:
It is costly and difficult to meter electricity consumption for different end uses, e.g. space heating, lighting and household appliances. We deduce a model for using cross-sectional data for total annual electricity consumption for a sample of households, together with information from energy surveys, to estimate the end uses within an econometric demand model conditional on appliance ownership. By applying a consistent method to Norwegian data for 1990, 2001 and 2006, we compare results over time and detect possible trends. We find that electricity consumption for many end use necessities such as washing, water heating and refrigeration varies somewhat from year to year, but they show no trend. The only clear trend is a steady increase in electricity used for more untraditional end uses and newer types of appliances. Total energy consumption for heating purposes is quite stable over the time period.

Keywords: Energy end-use consumption over time; Econometric conditional demand model.

JEL classification: C51; D12; Q40.

Acknowledgements: We are grateful to Bente Halvorsen and Taran Fæhn for comments on earlier drafts and to the Research Council of Norway for financial support (through the Renergi programme and CREE).

Address: Hanne Marit Dalen, Statistics Norway, Research Department. E-mail: hmd@ssb.no

Bodil M. Larsen, Statistics Norway, Research Department. E-mail: bml@ssb.no

Discussion Papers comprise research papers intended for international journals or books. A preprint of a Discussion Paper may be longer and more elaborate than a standard journal article, as it may include intermediate calculations and background material etc.

Abstracts with downloadable Discussion Papers
in PDF are available on the Internet:
http://www.ssb.no
http://ideas.repec.org/s/ssb/dispap.html

For printed Discussion Papers contact:
Statistics Norway
Telephone: +47 62 88 55 00
E-mail: Salg-abonnement@ssb.no

ISSN 0809-733X
Print: Statistics Norway

Sammendrag

Det er kostbart og vanskelig å måle elektrisitetsforbruk til ulike formål, som oppvarming av bolig og vann, belysning, oppvaskmaskin og andre apparater. Vi utvikler en modell for å benytte tverrsnittsdata for totalt årlig elektrisitetsforbruk for et utvalg av husholdninger sammen med informasjon fra energiundersøkelser for å estimere elektrisitetsforbruk til ulike formål. Vi benytter en økonometrisk etterspørselsmodell som er betinget av eierskap til elektrisk utstyr. Ved å benytte en konsistent metode på norske data for 1990, 2001 og 2006 kan vi sammenligne formålsfordelingen over tid. Vi finner at elektrisitetsforbruk til nødvendighetspregede formål som vasking, kjøling og varmtvann varierer noe fra år til år men vi finner ingen trend for disse formålene. Totalt energiforbruk til oppvarming er relativt stabilt over perioden. Derimot finner vi en klar trend for elektrisitetsforbruk til mer utradisjonelle formål, som har økt over tid.

1. Introduction

In recent years, there has been a great deal of interest in and debate about end-use energy consumption in Norway. One question is to what extent Norwegian residential electricity consumption for different end uses varies over time. Current and future policy measures used to increase energy efficiency and the consumption of renewable energy form the political background to the interest in end-use consumption. A range of instruments have been used: taxes on electricity and fuel oils; government subsidies for investing in more clean-burning wood stoves, pellets stoves, heat pumps and heating control systems; and a variety of softer policy measures, such as information campaigns and energy labelling. The EU has also adopted an integrated energy and climate policy aimed at cutting greenhouse gas emissions, increasing energy efficiency and increasing the renewable share, all by 20 per cent by the year 2020.

To determine the effect and potential of policies aimed at changing the composition or intensity of different energy uses, it is important to know both the proportion and amount of electricity used for different purposes. Heating is often provided by different energy sources, and in order to predict the effect of changing the composition of these sources, it is important to have information about the amount of energy and, specifically, the amount of electricity used for heating. Furthermore, to determine the effect of future and past policies aimed at increasing energy efficiency, it is important to know the amount of electricity used for different purposes (including behavioural and technical aspects that influence actual consumption). To analyse the energy saving potential of efficiency measures, it is also important to know how electricity use for relevant purposes has developed. In this context, electricity consumption for space heating and other purposes is important, and it is also important whether changes have taken place over time and, if so, why.

A large proportion of household energy consumption is used for stationary purposes such as heating, washing, lighting, cooking and other household uses. For heating households may use several different energy sources; they can use electricity, firewood, fuel oil, paraffin, gas, district heating, pellets etc., or any combination of these. A large share of Norwegian households (70 per cent) use more than one energy source to heat their home, and a combination of electricity and firewood is the most common. Thus, there are extensive substitution possibilities for space heating in Norwegian households, which in turn have a substantial effect on behavioural responses to environmental and energy policies targeting household stationary energy consumption. Residential electricity consumption is very heterogeneous, and several variables are important in relation to explaining both total electricity consumption and the different end uses. These explanatory variables vary both between households and over time. Explanatory variables for electricity consumption and electricity for different end uses include electricity prices, prices of other energy goods, outdoor temperature, technology, income, policy measures, efficiency, appliance ownership and other household characteristics. In this paper, we study the importance of different explanatory variables to households' electricity consumption for different end uses over time, with particular focus on electrical appliances.

The most common econometric approach to end-use estimation used in the literature is conditional demand analysis (CDA). CDA is a multivariate econometric technique combining information of households' total electricity consumption, household specific information regarding prices and weather and detailed household survey data on energy appliance stock and background data. The technique yields robust end-use estimates for energy consumption of different appliances. Early studies include Parti and Parti (1980), Aigner et al. (1984) and Lafrance and Perron (1994). Later studies have used data for directly metered electricity consumption for specific appliances in some households to improve the results from traditional CDA. Metering data are used in, for example, Bartels and Fiebig (1990), Aigner and Shönfeld (1990), Bauwens et al. (1994), Hsiao et al. (1995) and Bartels and Fiebig (2000). Several of these studies focus on end-use consumption over time in the form of load profiles. However, few studies of electricity consumption for different end uses focus on changes in end-use consumption over a period of years. Larsen and Nesbakken (2004) compare engineering and econometric models and study one year only (1990). We use a traditional econometric CDA as our initial approach, but we deduce the model for explicit use on annual cross-sectional samples of households. The data are taken from the Norwegian Survey of Consumer Expenditure expanded by questions on energy use. In these data, we also see variation in energy prices over households, which is not very common. In addition to data for 1990, we use more up-to-date data, i.e. data for 2001 and 2006. Based on data for 1990, 2001 and 2006, we have estimated end-use consumption for each of these years. Using the same econometric method together with annual cross-sectional data enables us to analyse end-use consumption consistently over a period of time.

2. The econometric model

In the conditional demand (CDA) model for total electricity consumption, dummies for ownership of different appliances are included as explanatory variables, i.e. electricity consumption is conditional on having (or not having) an appliance. The coefficients of the appliance variables provide estimates of electricity consumption for the different appliances and form the basis for the end-use estimates. The main idea of the econometric model is that the estimated difference in electricity consumption between households with and without a particular appliance is interpreted as the mean electricity consumption for this appliance. Estimates of mean electricity consumption for each appliance, given possession of that specific appliance, are multiplied by the proportions of households possessing the appliances. This yields estimates of the mean electricity consumption for different appliances. Electricity consumption for each end use divided by total electricity consumption gives end-use shares. Details of the model are presented below.

2.1 Econometric model

If we assume, as a base line, that annual electricity consumption for end use j for household i (x_{ij} , i=1,..., *N*) is observed through direct metering, the following end-use equation can be estimated:

$$(1) \qquad x_{ij} = \gamma_j + \sum_{m=1}^{M} \rho_{jm} \left(C_{im} - \overline{C}_{jm} \right) + \varepsilon_{ij} \quad ,$$

where C_{im} (m=1, 2,..., M) are economic and demographic variables; household and dwelling characteristics, electricity prices, heating degree days etc., and $\overline{C}_{jm}$ is the mean value of these variables for households possessing appliance j. ε_{ij} is a stochastic error term. The parameter γ_j represents the mean value of electricity for end use j given that household characteristics (C_{im}) relevant to end use j are equal for all households or given that no economic or demographic variables are relevant to the electricity consumption for end use j (i.e. $\rho_{jm} = 0$ for all m). Household characteristics vary across households, however. Thus, the second term of equation (1) represents an adjustment of end-use consumption due to the impact of economic and demographic variables.

We do not have data for electricity consumption for different end uses, and equation (1) cannot therefore be estimated. However, the total electricity consumption of each household is observed. By summarising electricity consumption over all end uses in equation (1), we arrive at the total electricity consumption of household i (x_i). In this connection, we have to take into account that not all households possess all types of appliances and that not all end uses can be specified. D_{ij} is a dummy variable with value one if household i possesses appliance j and value zero if the household does not possess appliance j. Of a total of J possible end uses, we define S as electricity end uses that can be estimated separately, i.e. j=1, 2,.., S,.., J and S<J. The total electricity consumption of household i is then:

(2) $$x_i \equiv \sum_{j=1}^{J} x_{ij} D_{ij} \equiv \sum_{j=1}^{S} x_{ij} D_{ij} + \sum_{j=S+1}^{J} x_{ij} D_{ij} = \sum_{j=S+1}^{J} \gamma_j D_{ij} + \sum_{j=1}^{S} \gamma_j D_{ij} + \sum_{j=1}^{J} \sum_{m=1}^{M} \rho_{jm} (C_{im} - \overline{C}_{jm}) D_{ij} + u_i ,$$

where u_i is a stochastic error term with the form:

(3) $$\sum_{j=1}^{J} \varepsilon_{ij} D_{ij} = u_i ,$$

with expectation zero and constant variance.[1] The economic and demographic variables are included so that they adjust electricity consumption for end use j, i.e. they are interactions with the appliance variables. For example, an interaction between dishwasher (j=dishwasher) and household size (m=number of household members) will capture the effect that electricity consumption by dishwashers varies with household size. The interactions are calculated as deviations from mean values for the different household characteristic variables for the H_j households possessing the appliance in question, i.e. $\overline{C}_{jm} = \frac{1}{H_j} \sum_{i=1}^{N} C_{im} D_{ij}$. This means that the term $\sum_{m=1}^{M} \rho_{jm} (C_{im} - \overline{C}_{jm}) D_{ij}$ is an adjustment of electricity consumption for end use j due to deviations from mean values for the different economic and demographic variables.

In equation (2), the term $\sum_{j=S+1}^{J} \gamma_j D_{ij}$ is unspecified electricity consumption. The interactions apply to all J because the unspecified electricity consumption can also depend on economic and demographic variables in the same way as the specified electricity consumption. We assume that the coefficients for the appliance dummies and interactions are constant (not varying between households). We also assume that the unspecified electricity consumption does not vary between households, i.e. $\sum_{j=S+1}^{J} \gamma_j D_{ij} = x_0$. For the specified appliances, the dummies indicate whether or not the household possesses the appliance, and they do not vary with size, capacity or number. However, such variations are included through the interaction variables.

[1] Heteroskedasticity follows from the model specification, and whether heteroskedasticity is a problem is an empirical question. Even though parameter values are not affected, we have tested for potential problems with non-constant variance. The results show that the significance of the parameter estimates are somewhat affected (in both directions). However, the same appliance variables are significant in both models. The reason why we do not report the estimations corrected for heteroskedasticity is that the software SAS does not enable both sample weighting and heteroskedasticity correction.

Combining these properties, our econometric conditional demand specification of household electricity consumption is given by:

$$(4)\qquad x_i = x_0 + \sum_{j=1}^{S} \gamma_j D_{ij} + \sum_{j=1}^{J} \sum_{m=1}^{M} \rho_{jm} (C_{im} - \overline{C}_{jm}) D_{ij} + u_i \ ,$$

where x_0, γ_j and ρ_{jm} are parameters to be estimated. The first term of equation (4) is the constant term in the estimation, and it is interpreted as unspecified electricity consumption. The second term of equation (4) contains mean electricity consumption (γ_j) for the different appliances j that household i possesses, i.e. for appliances for which the dummy variable D_{ij} has a value of 1.

All explanatory variables in the demand function (4) are assumed to be exogenous. Over time, the households may change their stock of energy-using equipment (as well as other characteristics). We use cross-sectional annual data, however, and our model is estimated on a yearly basis. We assume that there is no change in the stock of electricity-using equipment (or other right-hand side variables) during the year.

When estimating electricity consumption associated with different appliances, we compare households with a particular appliance to households that do not posses this appliance. As a result, the estimated coefficients include behavioural differences associated with the use of an electrical appliance. Therefore, consumption of electricity end use, as estimated by the above model, is the use of electricity for different *activities* (such as watching TV, washing clothes and keeping food refrigerated) and it will not necessarily correspond to the electricity consumption of a specific appliance measured technically.

2.2 Calculation of end-use electricity consumption

From equation (4) it follows that the expected electricity consumption for appliance k for household i equals:

$$(5)\qquad x_{ik} = \gamma_k D_{ik} + \sum_{m=1}^{M} \rho_{km} (C_{im} - \overline{C}_{km}) D_{ik} \ ,$$

i.e. zero for households that do not have the appliance ($D_{ik} = 0$) and $\gamma_k + \sum_{m=1}^{M} \rho_{km}(C_{im} - \overline{C}_{km})$ for households that have the appliance ($D_{ik} = 1$). The predicted expected electricity consumption for appliance k for a household with average characteristics (x_k^P) is then:

(6) $$x_k^P = \hat{\gamma}_k \overline{D}_k + \sum_{m=1}^{M} \hat{\rho}_{km} \overline{(C_m - \overline{C}_{km}) D_k} \quad ,$$

where parameters with the symbol ˆ indicate an estimated parameter and $\overline{D}_k = \frac{1}{N} \sum_{i=1}^{N} D_{ik}$, i.e. the mean value of the dummy variable D_{ik} for the households (N). Correspondingly, $\overline{(C_m - \overline{C}_{km}) D_k}$ is the mean value of $(C_{im} - \overline{C}_{km}) D_{ik}$ over all households. In equation (6), the estimates for the parameters ($\hat{\gamma}_k$ and $\hat{\rho}_{km}$) are for a household with average characteristics. We also use mean values for the dummy and interaction variables where the interactions are calculated as deviations from mean values. As a result, the term $\sum_{m=1}^{M} \hat{\rho}_{km} \overline{(C_m - \overline{C}_{km}) D_k}$ in equation (6) equals zero. The predicted expected electricity consumption for appliance k for the average household can then be calculated as mean electricity consumption for appliance k for households possessing appliance k multiplied by the proportion of households possessing appliance k:

(7) $$x_k^P = \hat{\gamma}_k \overline{D}_k \, .$$

The coefficient γ_k is interpreted as the difference in electricity consumption (in kWh per year) between a household with average characteristics possessing appliance k and an identical household not possessing this appliance k. In other words, γ_k is electricity consumption for a typical household possessing appliance k. To obtain an estimate of mean electricity consumption for appliance k for all households (whether or not they possess the appliance), we multiply by the mean value of the dummy variable ($\overline{D}_k$).

In addition to the electricity consumption estimated for the appliances explicitly included in the econometric model (equation 4), we have the unspecified electricity consumption (electricity for all other appliances). This consumption is represented by the constant term x_0, and the interpretation is the mean electricity consumption for all J-S appliances not included explicitly in the econometric model. For several appliances, we do not have data to include them explicitly in the model. Moreover, it is difficult to estimate significantly appliances that very few or most households possess. The estimate of electricity consumption for unspecified appliances is given by:

(8) $$x^P_{misc} = \hat{x}_0 .$$

The calculation of end-use consumption for mean values of all variables ensures that the estimated electricity consumption for the different appliances specified and for the unspecified appliances summarises to the mean electricity consumption of the households (this is because the expectation of the error term equals zero and the expectation of the interaction terms equals zero). Based on this and using equation (7), we arrive at the following summarising condition for electricity consumption:

(9) $$x^P = \hat{x}_0 + \sum_{j=1}^{S} x^P_j = \hat{x}_0 + \sum_{j=1}^{S} \hat{\gamma}_j \overline{D}_j = \overline{x} ,$$

where x^P is predicted expected total electricity consumption, and the mean observed electricity consumption $\overline{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$ is calculated for all households in our sample.

From equations (7) and (8), we find the mean electricity consumption for the specified appliances as well as the unspecified electricity consumption, all in kWh per year. We also want to calculate the different appliances' percentage share of mean (total) electricity consumption. The share of electricity consumption for appliance k is calculated as the mean electricity consumption for appliance k divided by the mean total electricity consumption:

(10) $$a^P_k = \frac{x^P_k}{\overline{x}}$$ and

(11) $$a_{misc} = \frac{\hat{x}_0}{\overline{x}} .$$

Since the decomposed consumption summarises to total consumption (for the 'mean' household), the shares in equation (10) and (11) will summarise to 1.

3. The data

We use micro data for the years 1990, 2001 and 2006 to study residential electricity consumption for different end uses over time. Our data is from Statistics Norway's 1990 Energy Survey and the 2001 and 2006 Survey of Consumer Expenditure (SCE). For these years these surveys include specific questions regarding type of heating equipment and energy consumption, which, in addition to the general high level of detail in these surveys, makes it possible to estimate end use consumption. For the 1990 survey, the net sample was 2107 households (the gross sample was 4004). Due to missing values for important variables, our econometric study for 1990 is based on 1453 households. The 2001 econometric study is based on 987 households (a gross sample of 2200 households), and the 2006 study is based on 1005 households (a gross sample of 2200 households). Single person households are highly under-represented in our samples compared to the population. This is because the gross samples are drawn using a register of persons and not households, and because of lower response probability for single person households. All data are therefore weighted using the number of households in the population divided by the number in our sample for each category of household members.

The surveys provide information about each household's energy consumption, stock of heating equipment and electrical appliances, as well as income and household and dwelling characteristics. The power supplier used by each household is known, as are electricity tariffs for each of about 250 power suppliers in Norway. We thus have electricity prices for each household. Household electricity consumption is mainly obtained from the power suppliers. For households where information from the power supplier is missing, electricity consumption is calculated based on the electricity expenses stated in the survey and electricity prices.

Summary statistics for heating equipment, electrical appliance ownership and household characteristics for the three years 1990, 2001 and 2006 are shown in Table 1. We see that electric heating is common in Norway, and the proportion of households that have electric ovens and/or electric floor heating has increased from 92 per cent in 1990 to 98 and 94 per cent in 2001 and 2006. Average electricity consumption was relatively stable over these years, and it was lowest in 2006. The figure for heating degree days was lowest in 1990 (mild winter) and highest in 2001 (cold winter). Electricity prices were far higher in 2006 than in 1990 and 2001. An increasing proportion of households own electric appliances such as tumble dryers and washing machines, and especially dishwashers, which have increased by 12 percentage points in five years and by 30 percentage points compared to 1990. There has also been an enormous increase for microwave ovens. Average dwelling size increased by 7 m^2 from 2001 to 2006, and by 11 m^2 from 1990 to 2006. The proportion of households living in a block of flats decreased by 5 percentage points in 2006 compared to 2001, and 15 percentage points fewer households had an oil/paraffin oven in 2001 than in 1990. Household income increased by 12 per cent from 2001 to 2006 (for 1990 we do not have income data).

Table 1. Summary statistics, Energy survey 1990 (N=1453), SCE 2001 (N=987) and 2006 (N=1005), weighted average

Variable	1990	2001	2006
Electricity consumption (kWh per year)	16923	17382	15852
Electrical appliance variables (0 or 1)			
Electric heaters and/or electric floor heating	0.92	0.98	0.94
Individual central electric heating, incl. combinations	0.02	0.01	0.03
Electric water heater	0.88	0.86	0.87
Number of lighting points > 10	0.94	0.89	0.92
Tumble dryer or drying cabinet	0.40	0.41	0.46
Washing machine	0.91	0.91	0.95
Dishwasher	0.43	0.61	0.73
Refrigerator	0.90	0.51	0.71*
Combined refrigerator/freezer	0.31	0.54	0.70*
Outdoor electric ground heating	0.02	0.03	0.05**
PC at home		0.59	0.81
TV and video (both)	0.39	0.74	0.74***
Sauna	0.05	0.04	n/a
Electric stove	0.99	0.96	0.97*
Microwave oven	0.35	0.65	0.74***
Deep freezer	0.81	0.70	0.78*
Refrigerator room	0.07	0.06	n/a
Sunbed	0.04	0.01	n/a
Other variables (interactions)			
Heating degree days	3141	4180	3688
Electricity price (2001-prices, øre/kWh)	47.7	55.9	76.8
Dwelling size (m^2)	111	115	122
Farmhouse (0 or 1)	0.08	0.06	0.08
Detached house with basement flat (0 or 1)	0.05	0.03	n/a
Block of flats (0 or 1)	0.19	0.20	0.15
Number of household members	2.40	2.28	2.26
Single person household (0 or 1)	0.34	0.38	0.39
Age main income contributor	47.8	47.5	47.7
At least 1 person over age 60 (0 or 1)	0.29	0.25	0.26
Number of lighting points	29	34.1	n/a
Number of showers per week	7.96	10.0	n/a
Number of baths per week	2.49	1.15	n/a
Energy economising household (0 or 1)	0.50	0.69	n/a
Oil/paraffin oven (0 or 1)	0.30	0.15	0.16
Wood-burning oven (0 or 1)	0.70	0.68	0.72
Shared central heating with other apartments (0 or 1)	0.04	0.05	0.05
District heating (0 or 1)	0.01	0.00	n/a
Individual central heating based on oil (0 or 1)	0.03	0.02	0.04
Individual central heating based on wood (0 or 1)	0.01	0.00	0.01
Household income (2001-kroner per year)	n/a	337 835	379 104

* Own and/or use. ** Use. *** Own.

4. Econometric estimation results

Based on the data described in section 3, electricity consumption for the years 1990, 2001 and 2006 is estimated using the CDA model described in section 2 and the ordinary least square method. The estimations of equation (4) for have generally resulted in significant results for several appliances and the estimated models also have good explanatory power. Tables 2, 3 and 4 show the results of the estimation of equation (4) for the years 1990, 2001 and 2006. The tables show the estimated electricity use for different appliance variables. Only equipment that is significant on at least a 15 per cent level is included in the estimations.[2] The second columns show the variables' estimated effect on electricity consumption, the third columns show the standard errors and the last columns show the p-values from the estimations.

The first part of Tables 2, 3 and 4 show the estimation results for the intercept from equation (4). The second part shows the results for the appliances included in the models. These estimated coefficients ($\hat{\gamma}_j$ in equation 4) for the different appliances are to be interpreted as an estimate of expected electricity consumption associated with the use of the different appliances for a household with mean values for the economic and demographic variables, given that the household owns the specific appliance.[3] Since the proportion of households owning the different appliances varies greatly (see Table 1), the estimation results in the tables below say little about the importance of the different appliances in relation to total household electricity consumption. We will return to this in section 5. When estimating electricity consumption associated with different appliances, we compare households with a particular appliance to households that do not possess this appliance. The estimated coefficients therefore include behavioural differences associated with the use of an electrical appliance. Consumption as shown in Tables 2, 3 and 4 is the use of electricity for different *activities* (such as watching TV, washing clothes and keeping food refrigerated).

The results for the interaction variables are shown in Appendix A, i.e. variables represented by $(C_{im} - \overline{C}_{jm})D_{ij}$ in equation (4). These variables are included to identify variation in electricity consumption between households due to other explanatory variables than electrical appliances (economic and demographic variables, such as the number of people in the household, income and prices).

---

[2] Dishwashers are included in the 2001 estimation despite the significance level being only 17 per cent. This is because of the relatively stable parameter values for this appliance, i.e. models with alternative explanatory variables included have yielded higher significance for dishwashers, while the parameter value did not change substantially.

[3] For some appliances, the data are for ownership while for other appliances they are for use (see details in Table 3.1).

Table 2. Estimated household electricity consumption, kWh per year, 1990. Weighted sample

Variables	Coefficient	Standard error	p-value
Intercept (β)	2998	1122	0.01
Appliance variables (γ_j)			
Electric heaters and/or floor heating	3521	715	0.00
Individual central electric heater (possibly also oil, wood)	5003	1358	0.00
Electric water heater	3839	594	0.00
Lighting, number of spots > 10	2416	830	0.00
Tumble dryer	1811	398	0.00
Washing machine	1789	681	0.01
Dishwasher	2249	434	0.00
Refrigerator	1001	604	0.10
Outdoor electric ground heating	3606	1204	0.00
TV and VCR	1466	397	0.00
Sauna	1737	869	0.05
R^2	0.53		

Table 3. Estimated household electricity consumption, kWh per year, 2001. Weighted sample

Variables	Coefficient	Standard error	p-value
Intercept (β)	2812	1450	0.05
Appliance variables (γ_j)			
Electric heaters	3663	1197	0.00
Electric floor heating	2566	457	0.00
Individual central electric heater (possibly also oil, wood)	11024	1880	0.00
Electric water heater	2033	737	0.01
Lightning, number of spots > 10	2046	839	0.01
Washing machine	2026	874	0.02
Tumble dryer or drying cabinet	792	443	0.07
Dishwasher	751	542	0.17
Refrigerator	1259	618	0.04
Fridge-freezer	1539	574	0.01
Refrigeration room	1785	835	0.03
Deep freezer (box)	869	479	0.07
Deep freezer (cabinet)	1016	431	0.02
PC	742	446	0.10
Various electrical tools	6787	1774	0.00
R^2	0.594		

Table 4. Estimated household electricity consumption, kWh per year, 2006. Weighted sample

Variables	Coefficient	Standard error	p-value
Intercept (β)	3110	1285	0.02
Appliance variables (γ_j)			
Electric heaters	2387	847	0.00
Electric floor heating	1268	461	0.01
Individual central electric heater (possibly also oil, wood)	3304	1197	0.01
Electric water heater	2955	691	0.00
Lighting, number of spots > 20	1289	625	0.04
Refrigerator	1076	554	0.05
Fridge-freezer	1093	458	0.02
Freezer	1509	646	0.02
Tumble dryer	890	443	0.04
Washing machine	1575	988	0.11
PC	1626	539	0.00
Swimming pool etc.	5967	2212	0.01
Various electrical equipment	3028	1601	0.06
R^2	0.53		

Several end uses are significantly estimated for all three years: electricity consumption for households with electric heaters, electric floor heating, individual central heaters based on electricity, electric water heaters, widespread lighting, washing machine, tumble dryer and refrigerator. Some potential appliance estimates are not significant for all three years. Dishwasher is not included in the 2006 estimation results due to poor significance. In 2001, both deep freezer and cabinet freezer are estimated as significant, while in 1990 no freezing equipment is estimated significantly. In 2006, this is a combined estimate. Refrigeration room and various electrical tools are estimated significantly in the 2001 estimation. In 2006, electricity consumption for swimming pools and various electrical tools are estimated as significant. In 1990, TV and VCR, sauna and outdoor electric ground heating are estimated as significant.

Heating is an important determinant of households' electricity consumption. In our estimations, electricity consumption for electric heaters, electric floor heating and individual central heating based on electricity is included.[4] All these parameters are estimated as highly significant and they are all reduced from 2001 to 2006 (see tables 2, 3 and 4).

[4] In 1990, electric heater and/or electric floor heating are estimated in common due to the phrasing in the questionnaires.

In order to significantly estimate electricity consumption for lighting, we have defined a dummy that is zero if the number of light spots is less than 10 in 1990 and 2001 and less than 20 in 2006, and one if higher than these values. This means that the estimates for lighting (2416 kWh in 1990, 2046 kWh in 2001 and 1289 kWh in 2006) are to be interpreted as the additional consumption associated with having more than 10 or 20 light spots.

To adjust the appliance estimates for household variation in economic, demographic and technical characteristics that are likely to influence electricity consumption, we have included interaction variables in the estimations (see the description of the model in section 2 and estimation results in Appendix A). The estimated electricity consumption for lighting, for example, is adjusted for dwelling size in both 2001 and 2006, and for detached houses with basement flats in 1990. These variables are estimated to be significantly positive, indicating that, on average, larger dwellings use more electricity for lighting than smaller dwellings (given that they both have more than 10 or 20 lighting spots). Interaction variables were tested if data was available and if they were seen as realistic. They were included in the models if significant at the 10 per cent level or better.

Miscellaneous electricity consumption, i.e. electricity consumption for appliances that are not explicitly included in the estimations, is captured by the intercepts. It was estimated to be 2998 kWh in 1990, 2812 kWh in 2001 and 3110 kWh in 2006.

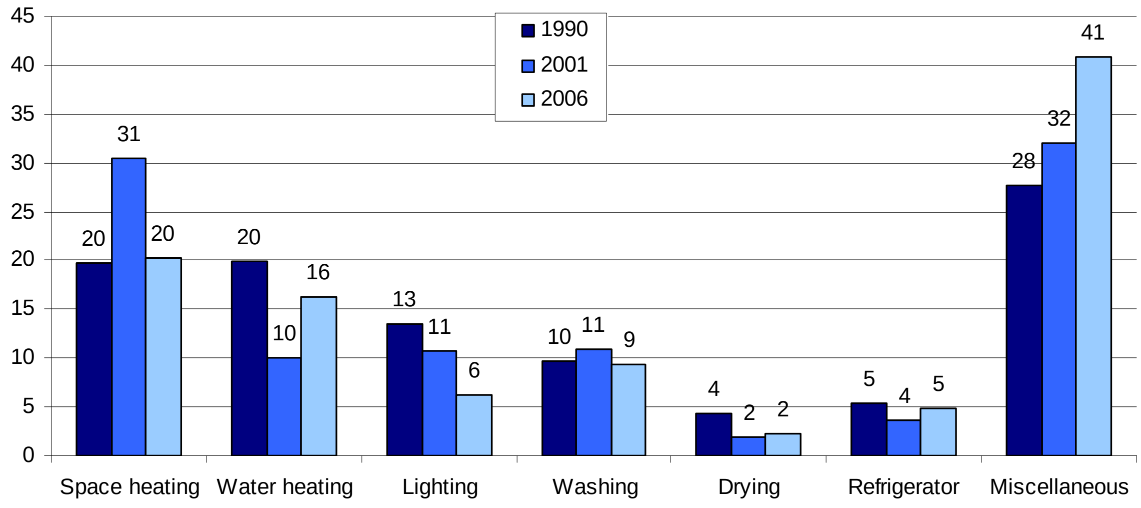
5. End-use electricity consumption over time

Since the proportion of households having the different appliances varies greatly between households (see Table 1), the above estimation results must be weighted by the share of households having the different appliances to say something about all households' electricity consumption. Furthermore, to calculate the average share of electricity consumption of different appliances relative to total household electricity consumption, we use the estimated consumption of different household appliances reported in section 4 and mean values for the frequency of different appliances in the estimation samples to calculate the average electricity consumption for end uses in 1990, 2001 and 2006 (as described in section 2.2).

Figure 1 shows the estimated average shares of electricity consumption for different end uses in 1990, 2001 and 2006. The figure shows that electricity for heating purposes accounts for a large share of total electricity consumption. The share of electricity used for heating purposes varies from year to year due to, for example, the composition of heating equipment, relative and absolute prices of different energy goods and outdoor temperature. The share of electricity used for heating purposes in 2001 is 55 per cent higher than in 1990 and 2006.

The miscellaneous share in Figure 1 includes all end uses that are not explicitly specified in the estimations. For best comparison over time, we have defined electricity consumption for end uses that are not specifically estimated for all years as miscellaneous (e.g. dishwasher and PC). We see a sharp increase in this share, from 28 per cent in 1990 to 32 per cent in 2001 and 41 per cent in 2006. This share includes several small and large electric appliances that we are not able to significantly estimate separately for each year, although, collectively, they represent a large and increasing proportion of the total electricity consumption. For these miscellaneous end uses, both the consumption patterns and distribution of appliances among households are likely to have drastically changed during the period. Also in the international context, Norwegians are quick to buy and make use of new electronic equipment. Growth in real household income was 12 per cent from 2001 to 2001, while the growth in miscellaneous electricity consumption was 16 per cent. This growth is both due to an increase in the share of households having existing appliances (e.g. share of households having dishwasher was 61 per cent in 2001 and 73 per cent in 2006) and new appliances. The miscellaneous end use is mainly a luxury good category, and as income increases, such end uses increase the most. This is confirmed by our results.

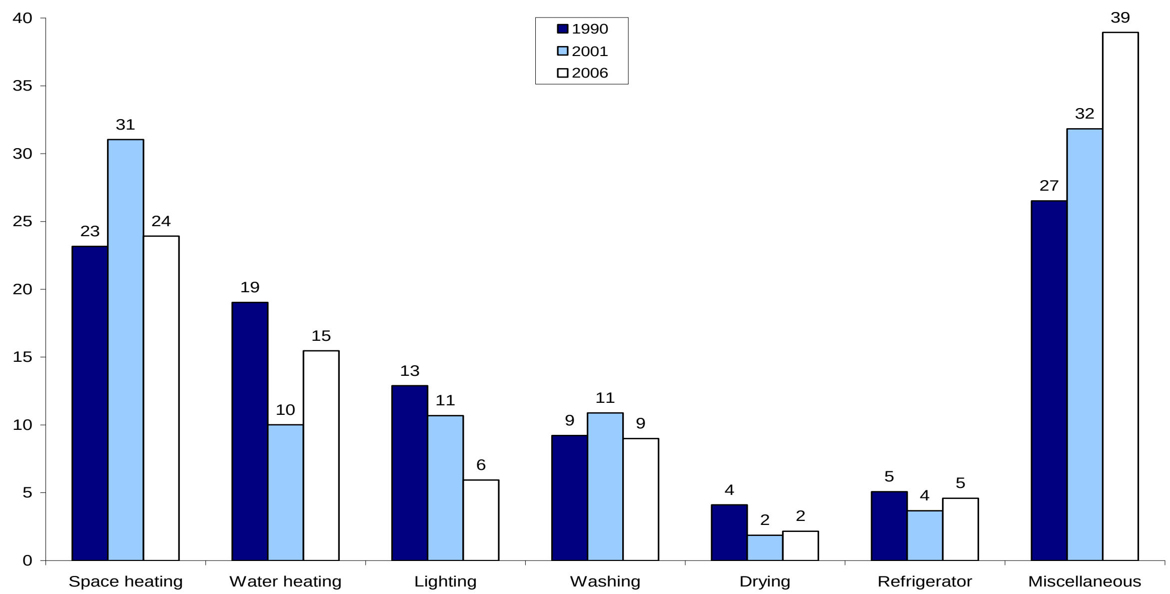
Figure 1. Electricity consumption for different end uses in 1990, 2001 and 2006. Average for Norwegian households. Per cent



Total electricity consumption per household was relatively stable between 1990 and 2006. The average number of kWh used per household in the weighted sample in these analyses was 16 923, 17 382 and 15 852 in 1990, 2001 and 2006, respectively.[5] This means that the changes in average kWh per end use are quite similar to the changes in shares shown in Figure 1.

To correct for differences in outdoor winter temperature between years when calculating end-use shares over time we use a temperature correcting factor. This factor is based on the relationship between temperature-corrected and non-corrected electricity consumption as reported by Statistics Norway. Figure 2 shows end-use electricity consumption corrected for outdoor winter temperatures. Both 1990 and 2006 were very warm years, while 2001 was an approximately normal year. By comparing Figures 1 and 2, we see that, when electricity consumption is corrected for winter temperatures, the variation in the proportion of electricity used for heating is reduced.

Figure 2. Temperature-corrected electricity consumption for different end uses in 1990, 2001 and 2006. Average for Norwegian households. Per cent



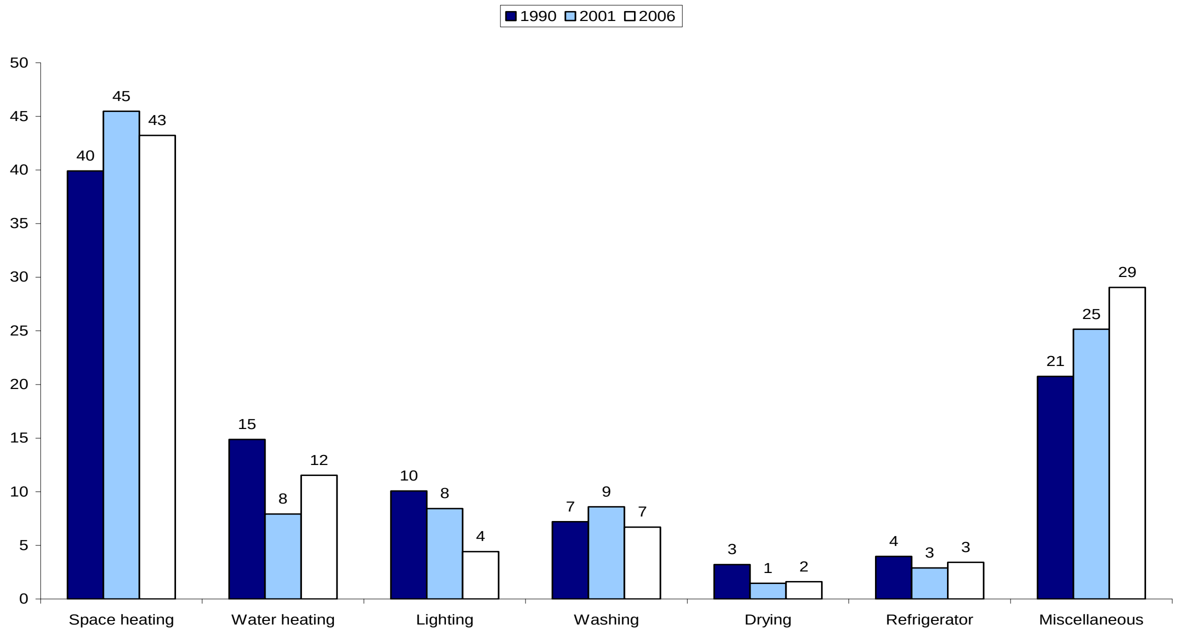
Like outdoor winter temperatures, absolute and relative energy prices are important to the year-to-year composition of the consumption of different energy goods. Most Norwegian households have the possibility of using different energy sources for heating, and they change their energy consumption mix from year to year depending on, for example, energy prices. Figure 3 shows the development in Norwegian households' stationary *energy* consumption, that is the sum of wood, oil and electricity

[5] This corresponds well with official statistics for total average household electricity consumption in Norway.

consumption. As in Figure 2, the consumption in Figure 3 is corrected for outdoor temperatures. All energy used for stationary purposes beside electricity is used for heating purposes.

Comparing the proportions used for heating in Figure 3 with those in Figure 1, we see that the variation from year to year is much smaller when correcting for outdoor temperature and the composition of energy consumption. The proportion of energy used for heating purposes is relatively stable over time, and the evening out of the energy share compared to the electricity share shows that much of the variation in electricity used for heating purposes in Figure 2 is due to changes in the composition of total energy use from different energy sources as a result of changes in relative energy prices.

Figure 3. Temperature-corrected energy consumption for different end uses in 1990, 2001 and 2006. Average for Norwegian households. Per cent



6. Conclusion and further work

In this paper, we have studied end-use energy consumption in Norway over a period of 16 years. Our results show that electricity consumption for many of the estimated end uses varies somewhat from year to year. While the temperature-corrected share of *electricity* consumption for heating varies between years, we find that the temperature-corrected share of *energy* consumption used for heating Norwegian residences is quite stable for the years 1990, 2001 and 2006. This reflects the good substitution possibilities between energy types for heating Norwegian homes. Other end uses, such as washing, drying and refrigeration, are also relatively stable. While end use for necessities like heating and washing is quite stable, we find that the end use including new electronic equipment increases substantially over time. Examples are smart phones, smart TVs, laptops, tablets and kitchen equipment. Many of these appliances are luxury goods, and, as household income increases, such end uses increase more than necessity goods. This is confirmed by our results as the end use containing luxury goods increase more than household income.

Our results show no clear trend as regards the consumption of electricity and other types of energy for heating. Since 1990, ovens using oil/paraffin are reduced, but the substitution possibilities in residential energy consumption still seem to be high (the use of wood is very common). The next few years will see a further phasing out of the use of oil in Norwegian homes (regulated by the government). Furthermore, since 2006 there has also been a huge increase in the use of air-to-air heat pumps, and they are now very common. Electrical heat pumps affect energy consumption in many ways, and the effect on end-use consumption of this huge change in the stock of heating equipment over quite few years is an interesting topic for future research. All these aspects of the development of end-use consumption are important information when considering policy measures.

All grid companies in Norway are required to install advanced metering technology for all customers by the end of 2018. This smart metering will enable the automatic registration of electricity consumption, both on an hourly and yearly basis. This will make it possible to estimate household electricity consumption using high quality data. End-use consumption can then be estimated more precisely and there will be a higher degree of freedom also as regards estimating explanatory variables (interactions). For example, it would be interesting to know more about price and income effects for different end uses. At present, hourly data can only be stored by the grid companies for maximum 15 months, and monthly and yearly data for three years. To be able to make use of the smart metering technology to analyse and optimise the grid and ensure efficient household energy use and support, the grid and power sector want to establish a central data hub for storing hourly data for up to three years and for monthly and yearly data for 10 years. This is the subject of an ongoing debate in Norway.

References

Aigner, D.J., C. Sorooshian and P. Kerwin (1984): Conditional Demand Analysis for Estimating Residential End-Use Load Profiles, *Energy Journal* 5, 81-97.

Aigner, D.J. and P. Schönfeld (1990): “Experimental Design for Direct Metering of Residential Electricity End-uses”, in Gabszewitcz, J.J., J.-F. Richard and L.A. Wolsey (eds.): *Economic Decision-Making: Games, Econometrics and Optimisation*, Elsevier Science Publishers B. V.

Bartels, R. and D.G. Fiebig (1990): Integrating Direct Metering and Conditional Demand Analysis for Estimating End-Use Loads, *Energy Journal* 11, 79-97.

Bartels, R. and D.G. Fiebig (2000): Residential End-Use Electricity Demand: Results from a Designed Experiment, *Energy Journal* 21, 51-81.

Bauwens, L., D.G. Fiebig and M.F.J. Steel (1994): Estimating End-Use Demand: A Bayesian Approach, *Journal of Business and Economic Statistics* 12, 221-231.

Hsiao, C., D.C. Mountain and K.H. Illman (1995): A Bayesian integration of end-use metering and conditional-demand analysis, *Journal of Business and Economic Statistics* 13, 315-326.

Lafrance, G. and D. Perron (1994): Evolution of Residential Electricity Demand by End-Use in Quebec 1979-1989: A Conditional Demand Analysis, *Energy Studies Review* 6, 164-173.

Larsen, B.M. and R. Nesbakken (2004): Household Electricity End-Use Consumption: Results from Econometric and Engineering Models, *Energy Economics* 26, 179-200.

Parti, M. and C. Parti (1980): The Total and Appliance-specific Conditional Demand for Electricity in the Household Sector, *The Bell Journal of Economics* 11, 309-321.

Appendix A. Estimation results for interaction variables

Table A1. Estimated interaction variables, 1990. Weighted sample

Interaction variables (ρ_{jm})	Coefficient	p-value
Living floor space * electric heaters and/or floor heating	42	0.00
High-income household * electric heaters and/or floor heating	1621	0.01
Age of a person is over 60 years * individual central electric heater	7983	0.00
Energy saving activity * individual central electric heater	-7642	0.00
Heating degree days * individual central electric heater	-12	0.00
Age of a person is over 60 years * electric water heater	-2002	0.01
Age of interviewed person * electric water heater	111	0.00
Number of household members * lighting	1485	0.00
Detached house with basement flat * lighting	2265	0.00
Farmhouse * tumble dryer	11169	0.00
Age of a person is over 60 years * dishwasher	-1606	0.05
One person household * refrigerator	-1629	0.00
Electricity prices * refrigerator	-183	0.00
Detached house with basement flat * outdoor electric ground heating	21309	0.01
Heating degree days * outdoor electric ground heating	-2	0.20
Heating degree days * TV and VCR	1	0.00

Table A2. Estimated interaction variables, 2001. Weighted sample

Interaction variables (ρ_{jm})	Coefficient	p-value
Number of electric heaters * electric heater	349	0.00
Wood-burning stove * electric heater	885	0.08
Central heater with oil, wood and possibly electricity * electric heater	-7104	0.00
Paying rent * electric heater	-1718	0.00
House unoccupied >15 days during winter * electric heater	-4010	0.01
Electricity price * electric heater	-295	0.00
Area with floor heating * electric floor heating	23	0.00
Living floor space * central heater with electricity (possibly oil, wood)	75	0.01
One person household * electric water heater	-1105	0.10
Detached house * electric water heater	1283	0.04
Living floor space * lighting	15	0.00
Block of flats * lighting	-2117	0.00
Number of tumble dryers * tumble dryer	5	0.03
Detached house * tumble dryer	1227	0.12
Income * dishwasher	+0	0.07
Number of manual dish washings * dishwasher	-13	0.23
Number of washings with dishwasher * dishwasher	3	0.28
Number of household members * dishwasher	609	0.02
Age main income contributor * dishwasher	26	0.23
One person household * refrigerator	-2070	0.01

Table A3. Estimated interaction variables, 2006. Weighted sample

Interaction variables (ρ_{jm})	Coefficient	p-value
Household income * intercept	+0	0.01
Number of electric heaters * electric heater	191	0.01
Pellet stove * electric heater	7184	0.06
Electricity price * electric heater	-175	0.00
House unoccupied >15 days during winter * electric heater	-1934	0.00
Consumption estimated using expenses/electricity price * electric heater	-1722	0.00
Household income * electric heater	-0	0.02
House with more than two rooms * electric heater	2498	0.00
Area with floor heating * floor heating	17	0.04
One person household * electric water heater	-2117	0.00
City > 100 000 inhabitants * electric water heater	1158	0.04
Living floor space * lighting	37	0.00
Number of household members * lighting	491	0.04
Studio apartment in the house * refrigerator	4740	0.00
Paid rent * refrigerator	-1758	0.01
Block of flats * deep freezer	-1764	0.04
Use tumble dryer > 4 times a week * tumble dryer	1520	0.06
Use washing machine > 4 times a weak * washing machine	854	0.12
Not a household-specific electric meter * washing machine	9788	0.00
Detached house * washing machine	1189	0.02

B

Return to:
Statistisk sentralbyrå
NO-2225 Kongsvinger

From:
Statistics Norway

Postal address:
PO Box 8131 Dept
NO-0033 Oslo

Office address:
Kongens gate 6, Oslo
Oterveien 23, Kongsvinger

E-mail: ssb@ssb.no
Internet: www.ssb.no
Telephone: + 47 62 88 50 00

ISSN 0809-733X

Statistisk sentralbyrå
Statistics Norway

Design: Siri Boquist