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How to quantify household electricity end-use consumption

Abstract:
Information about total electricity consumption is available for most households. However, the electricity consumption related to different end uses, e.g. space heating, water heating, lighting and services from household appliances are usually not metered. Metering data are very costly to achieve, and in this paper we study two methods for end-use estimation, which can be applied on household data for appliance holdings, demographic and economic variables. The first method is the engineering model which has been used to calculate the so far only documented Norwegian end-use results applied on data from a Norwegian energy survey. The second method is an econometric conditional demand model applied on data from the same survey. We compare the numerical results from the two models and give some recommendations regarding choice of end-use approach and what questions to implement in household surveys designed to disaggregate electricity consumption.

Keywords: Electricity end-use consumption, econometric conditional demand model, engineering model.

JEL classification: C51, D12, Q40.

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1. Introduction

In combination with various types of appliances, electricity provides a number of different services to households, such as space and water heating, lighting and cooling. Thus, the households' stock of electricity-consuming appliances has a considerable influence on total electricity consumption and different electricity end uses. In the production of some end-use services, as for instance services from dishwashers, electricity is the only possible energy source, while in the production of other services, as for instance space heating, there are substitutes for electricity. Identifying the various components of electricity demand is important in forecasting energy consumption and doing policy analyses. The impact on electricity demand of an increase in e.g. the electricity tax will depend on the composition of electricity consumption for various end uses as the elasticity varies over end uses. Besides, the shares of households having various electric household appliances have increased over time.

The main aim of this paper is to find a method for estimating end-use consumption in a given year, which applied on data for more years will give consistently comparable results over time. The electric utilities measure total electricity consumption for each electricity meter. Thus total annual electricity consumption is known for most households. Even though metering data are available for some end uses in some countries, practically no country in the world have metering data giving sufficient information to decompose total electricity consumption on different end uses. As most countries have no metering data due to high costs of this measurement method, the question is how electricity for different end uses can be estimated in the best way without metering data.

The two main approaches for calculating electricity end-use consumption are engineering and econometric approaches. In this paper we consider a specific engineering model, ERÅD, as this model was used in the so far only documented Norwegian end-use results (Ljones et al., 1992). We also estimate an econometric model and assess the two approaches. The end-use results from ERÅD are estimated for 1990, and information from the 1990 Energy Survey is used in the estimations. The need for newer end-use results is the reason why we want to consider alternative end-use approaches to find the most appropriate approach for new end-use studies. The engineering method applied on the 1990-data is not necessarily the best method. As the data from the 1990 Energy Survey were available for us, we have used an econometric approach on these data to compare the results.

The engineering model ERÅD includes engineering knowledge regarding technical and constructional features of different houses enabling estimation of energy demand for space heating. Both survey information about the individual household and aggregated technical and behavioural information, e.g.

about average time use and power need of dishwashers and other household appliances, is used to estimate energy for water heating, lighting and appliances, as well as warmth from these end uses. Fung and Ugursal (1998) apply a similar approach when estimating residential lighting energy consumption in Canada. Estimated energy consumption for different end uses in ERÅD is summed up to total energy consumption. Total energy consumption reported in the survey as share of estimated total energy consumption in ERÅD is used to adjust electricity consumption for different end uses to match the survey information for each household.

The most common econometric approach for end-use estimation used in the literature is the conditional demand analysis (CDA), and the first in this tradition is Parti and Parti (1980). Other CDA studies are Aigner et al. (1984) focusing on electricity hourly loads for different appliances in Los Angeles and Lafrance and Perron (1994) focusing on the evolution of disaggregated electricity consumption in Quebec over time. 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 e.g. Bartels and Fiebig (1990), Aigner and Shönfeld (1990), Bauwens et al. (1994), Hsiao et al. (1995) and Bartels and Fiebig (2000). In this paper we use a traditional econometric CDA approach on data from the 1990 Energy Survey for end-use estimation, as metering data are not available. The CDA model includes dummy variables representing household appliance ownership. The main idea of the econometric model is that estimated coefficients of the dummy variables are interpreted as mean electricity consumption related to these appliances. Estimates of mean electricity consumption for each appliance are multiplied by the shares of households possessing the appliances, to give estimates of mean electricity consumption for different appliances for the average household. Electricity consumption for each end use divided by total electricity consumption gives end-use shares.

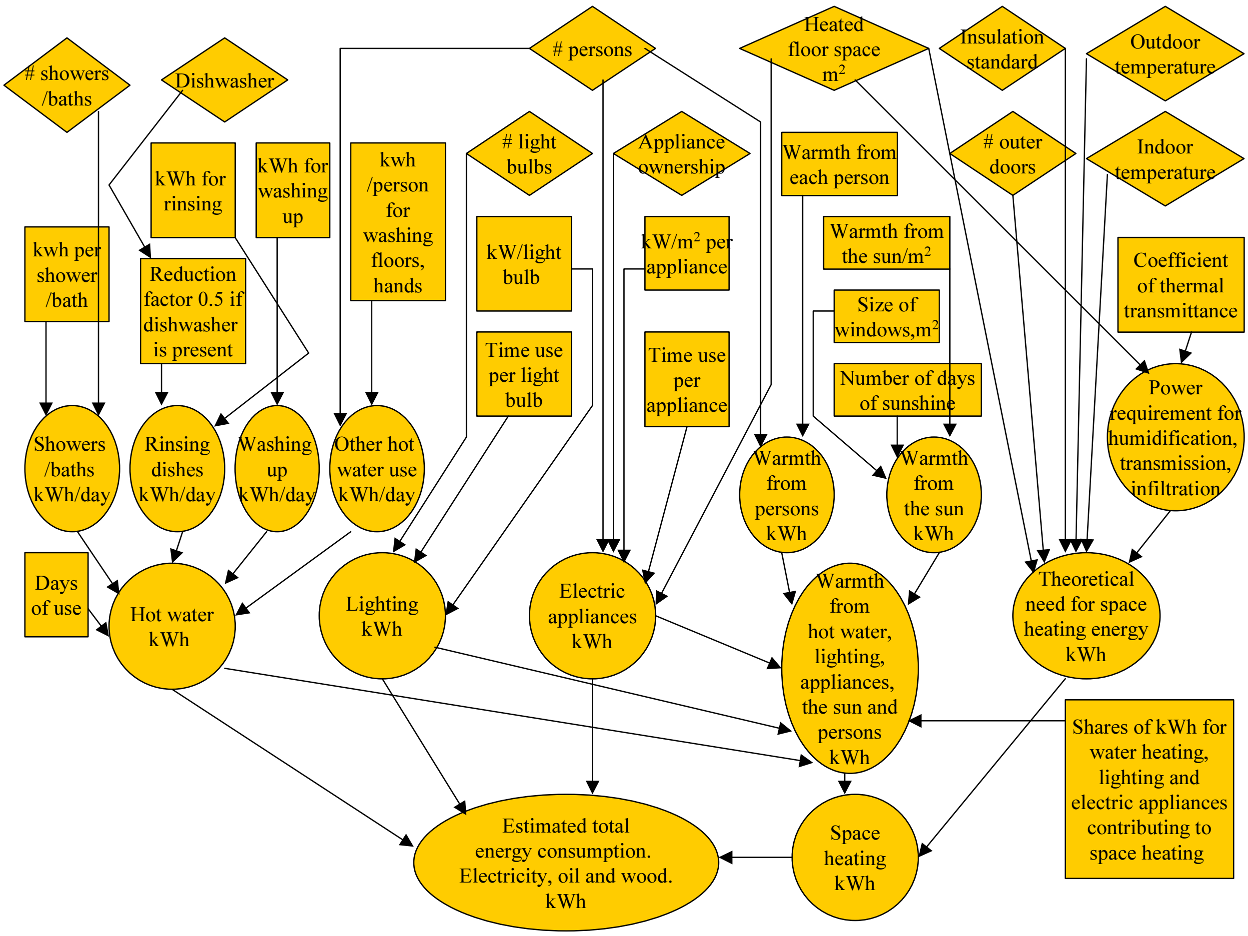
Our assessment of the two approaches applied on 1990-data and the literature on this topic give information which is relevant when considering different methods for new estimations of end-use consumption. Furthermore, the results give guidance regarding what kind of questions that should be included in future surveys intended for end-use studies.

In section two and three we describe the engineering model and the econometric model. Section four gives an overview of the data. In section five we present the econometric results, and in section six we compare the results of the two approaches. Guidance regarding future end-use studies is given in section seven. Finally, some concluding remarks are made.

2. The engineering model ERÅD

In 1992, the Norwegian engineering bottom-up model ERÅD was used to decompose household electricity consumption into different end uses, see Ljones et al. (1992). The household specific input data were collected from the 1990 household energy survey described in section four. The ERÅD model includes engineering knowledge regarding technical and constructional features of different houses and the influence of these features on energy demand. The model consists of a large number of equations and parameters. The model user had to obtain the information needed for input values of these parameters from other sources than the survey. In the following we give an overview of the main structure of the ERÅD model. The end-use results from applying the ERÅD model are reported in section six, where we compare the results from ERÅD and the econometric model.

Figure 1. Flow chart illustrating the structure of the ERÅD model



2.1 The structure of the ERÅD model

The ERÅD model consists of a vast amount of equations, which makes it difficult to present the model in this paper. Thus, figure 1 serves as an illustration of the most important mechanisms and elements of the model. A thorough technical description of the ERÅD model is given in Energidata (1989).
In figure 1 the parallelograms indicate information given in the 1990 energy survey, the rectangles indicate parameters which have to be assessed by the model user (exogeneous variables) and the circles and ellipses indicate results following from running the model (endogeneous variables).

To give an impression of how this model is utilized to give end-use estimates, we list the main elements below.

1. Power requirement related to humidification, ventilation, transmission and infiltration are calculated as functions of e.g. heated floor space and coefficients of thermal transmittance, see the right part of figure 1.
2. Total theoretical need for energy for space heating is calculated as a function of insulation standard for windows, walls, roofs and floors, indoor and outdoor temperature (heating degree-days) and the power requirements in point 1.
3. Space heating from the sun and from persons is calculated. The heat from the sun depends on an estimate of warmth from the sun per square metre, the size of windows and the number of days of sunshine. Heat from persons depends on an estimate of warmth from each person and the number of persons in the household, which is reported in the survey.
4. Energy consumption for lighting, water heating and electric appliances is calculated. The calculations are among other factors based on assessments of average wattage and average time use for all households, or average energy consumption. These assessments are based on metering of electricity for all end uses in a few test-houses (other than the houses in the survey) and data collected from undocumented sources. Energy for lighting for each dwelling in the survey is calculated as average wattage for each light bulb multiplied by the number of bulbs reported in the survey and multiplied by an assessment of average time use of each bulb. Ownership of a lot of electric appliances, like for instance dishwasher, tumble dryer, freezer etc., is reported in the survey. Energy for each electric appliance possessed by the household is calculated as average wattage per square metre for the appliance multiplied by time used on the appliance (assessments, e.g. from metering) multiplied by the heated floor space reported in the survey. Information about the number of showers and baths, dwelling construction, heated floor space, washing and numerous kitchen activities is used to give assessments of energy for hot water. The assessments

of demand for energy for water heating per day are multiplied by assessments of time used on the water heating activities.

5. Energy consumption for space heating is calculated as theoretical demand for energy minus heat from persons and the sun and minus heat from electric appliances, lighting and water heating. A specific dwelling with certain characteristics as regards insulation standard etc. has to be provided by a certain amount of energy to achieve the wanted indoor temperature for given outdoor temperature. However this amount is reduced by the amount of warmth induced by use of appliances.
6. Total energy consumption is calculated for each household as the sum of energy for space heating, water heating, lighting and electric appliances for all energy sources.
7. The difference between this estimate of total energy consumption and total energy consumption reported in the survey is calculated for each household. This difference as share of total energy consumption from the survey is used to calibrate (adjust) end-use consumption if the share is below a certain limit of e.g. 5 percent. If the share is above the limit, the uncertain model parameters are adjusted until the share meets the requirement for calibration.
8. The share in point 7 adjusts all end uses in the household.

2.2 Evaluation of the ERÅD model

The fundamental weakness of the engineering approach is the need of a high number of numerical inputs. Except for space heating the input of the ERÅD model is energy consumption for different end uses, which is what should actually be the result of the end-use analysis. In this method all available information from the survey, from metering of some houses and from producers of appliances is combined, and the results are calibrated to get the same energy consumption as known from the survey. It is a weakness of the ERÅD model that all end uses are calibrated by the same factor without considering whether some end-use estimates are more uncertain than other end-use estimates.

A calibration is needed due to lack of information on several parameters and uncertainty of the applied numerical values. The ratio between actual energy consumption and calculated energy consumption prior to calibration gives an indication of the quality of the ERÅD model. The results reported from ERÅD show that 52 percent of the calculated energy consumption has to be calibrated more than 25 percent to fit actual consumption.

The survey does not give information about the age of different appliances. When using ERÅD, one has to choose between old technology and the present technology. The assessments of energy consumption and wattage of different appliances used in the end-use estimations were valid for new appliances, while the households in the survey actually had appliances varying in age.

It turned out to be very difficult to get information about assumptions and numerical input used to calculate end-use consumption, e.g. the assessments of energy consumption or time use. This makes it difficult to conduct periodic, comparable analyses by use of this model.

Engineering models have been considered in the literature, e.g. in Parti and Parti (1980): "The primary disadvantage of the engineering estimates is that they are based upon theoretical considerations, rather than observed consumer behavior, and cannot be adjusted in any systematic way for regional differences or changes in price, income, or household size as can the current econometric estimates. The primary disadvantage of the use of direct appliance metering is its great cost." (end-of-quote). Bartels and Fiebig (1990) state, (quote): "Engineering models are only appropriate, however, in situations where individual behaviour plays a minor rule, for example, heating and cooling in extreme climates. Most appliance use depends on the life style; in temperate climates, even heating and cooling appliances are, in many households, only used when the occupants are at home."(end-of-quote). Sanchez et al. (1998) state in their paper (quote): "Data on miscellaneous electric uses is sparse, and in some cases simply non-existent. Developing a detailed bottom-up estimate entailed assembling appliance stock data from disparate and sometimes obscure sources, conducting a metering campaign to derive estimates of average product power, and making engineering estimates of consumption when alternative methods were unavailable. The approach used in this study is best classified as 'back-of-the-envelope'." (end-of-quote). Fung and Ugursal (1998) also point out a weakness of the bottom-up approach. They estimate residential lighting energy consumption in Canada, using an engineering bottom-up approach and survey data for the number of bulbs for each of three lighting categories. Additional input data needed are average wattage of each type of lighting and average number of hours of usage for each type of lighting. They discuss the difficulty of finding reliable data for these parameters.

3. The econometric model

The 1990 Energy Survey provides data for total electricity consumption, appliance holdings, household characteristics and economic variables. Our aim was to formulate an econometric model, which is suitable for utilizing these data to estimate electricity for different end uses. We formulate a model for total electricity consumption where different appliances are included as variables. Then the coefficients of the appliance variables indicate the importance of these variables for total electricity consumption and are the basis of the end-use estimates.

3.1 The conditional demand model (CDA model)

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

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

where the variables C_{im} (m=1, 2,..., M) represent 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 for end use *j* are equal for all households. However, e.g. dwelling size varies across households, and electricity for electric heaters is assumed to increase by dwelling size. Thus, the second term of equation (1) represents adjustment of end-use consumption due to impact of economic and demographic variables. The economic and demographic variables are defined in terms of deviation from the mean value for those households possessing the appliance in question, as we only want to adjust end-use consumption of households with values of economic and demographic variables differing from the "typical" households with end-use consumption γ_j .

As we do not have data for electricity consumption for different end uses, equation (1) cannot be estimated. However, total electricity consumption of each household is observed. Thus we use equation (1) and the equations $x_i \equiv \sum_{j=1}^{J} x_{ij} D_{ij}$ and $\sum_{j=1}^{J} \varepsilon_{ij} D_{ij} \equiv \beta + \mu_i$ to derive annual electricity consumption of household *i* as a function of (i.e. conditional on) appliance holdings and economic and demographic variables. Our econometric conditional demand specification of household electricity consumption is given by

$$x_i = \sum_{j=1}^{J} \gamma_j D_{ij} + \sum_{j=1}^{J} \sum_{m=1}^{M} \rho_{jm} (C_{im} - \overline{C}_{jm}) D_{ij} + \beta + \mu_i \quad . \tag{2}$$

D_{ij} is a dummy variable with value zero or one indicating whether household *i* possessed or executed activity *j* (*j*=1, 2,..., *J*). The demand equation (2) is estimated by Ordinary Least Squares. β , γ_j and ρ_{jm} are parameters to be estimated, and μ_i is a stochastic error term.

The error term in equation (2) consists of two components; β which is constant across households and μ_i which varies across households. The parameter β is estimated as an intercept, and the interpretation of β is electricity consumption associated with appliances that are not included in the model. Heteroskedasticity problems may follow from the specification of the CDA model, and in section 5.1 results regarding significance of the variables are reported both for the ordinary OLS-estimation and for estimation when the covariance matrix is corrected for heteroskedasticity.

All explanatory variables in the demand function (2) are assumed to be exogenous to the household. Over time the households may change their stock of energy-using equipment. However, we focus on the short run effects and assume that there is no change in the stock of electricity-using equipment.

3.2 Model for end-use decomposition

The CDA method exploits the variation in appliance ownership or usage across a sample of households. We calculate expected electricity consumption related to end-use *k* in household *i* by

$$E(x_{ik}) = \gamma_k + \sum_{m=1}^{M} \rho_{km} (C_{im} - \overline{C}_{km}) \quad , \tag{3}$$

where *E* is the expectation operator. The mean electricity consumption of the appliance *k* equals 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 having the appliance ($D_{ik} = 1$). The coefficient γ_k is interpreted as the difference in electricity consumption (measured in kWh per year) between households that have appliance *k* and those that do not. $\sum_{m=1}^{M} \rho_{km} (C_{im} - \overline{C}_{km})$ is interpreted as an adjustment of end-use electricity consumption due to a deviation from the mean value of e.g. a demographic variable among those possessing appliance *k*. Thus, $\gamma_k + \sum_{m=1}^{M} \rho_{km}(C_{im} - \overline{C}_{km})$ can be interpreted as electricity consumption of the average household possessing appliance *k*.

D_{ik} represents the stock of household appliance *k* and has a value of zero or one. Average electricity consumption for end use *k* in the household sector is estimated by

$$\hat{x}_k = \hat{\gamma}_k \overline{D}_k + \sum_{m=1}^{M} \hat{\rho}_k \overline{(C_{im} - \overline{C}_{km})D_k} \quad , \tag{4}$$

where parameters with the symbol ˆ indicate the estimated parameter. $\overline{D}_k = \frac{1}{N}\sum_{i=1}^{N} D_{ik}$ is the average value of dummy variable D_{ik} for the survey households and, similarly, $\overline{(C_{im} - \overline{C}_{km})}$ is the average value of $C_{im} - \overline{C}_{km}$. Thus, average electricity consumption related to appliance *k* is calculated as average electricity consumption for households having appliance *k* multiplied by the share of households having the appliance and corrected for interaction variables.

Average total household electricity consumption is decomposed into its constituent end-use components by dividing the estimate of average electricity consumption for end-use *k* by the estimate of the average total electricity consumption. The share of electricity consumption for end-use *k* is then

$$s_k = \frac{\hat{x}_k}{\overline{x}} \quad . \tag{5}$$

As an estimate for $\overline{x}$ we use mean electricity consumption of the survey households, i.e. $\overline{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$.

Miscellaneous electricity consumption is included in the intercept. The share for miscellaneous electricity consumption is calculated as the residual end use when end uses represented by the dummy variables are accounted for,

$$s_{misc} = 1 - \sum_{j=1}^{J} s_j = \frac{\beta}{\overline{x}} \quad . \tag{6}$$

3.3 Evaluation of the CDA model

An advantage of the econometric CDA model, is that end-use parameters are estimated directly, without having to make assumptions regarding behaviour and technicalities. The estimated coefficient of an appliance is interpreted as end-use consumption (measured in kWh) and thus gives summarized information on the average technical condition of the appliance stock (kW) and the behavioural part of electricity demand (hours of utilization, i.e. how often and how long) on average in households. This information is estimated in one or two parameters for each appliance, see γ_j and ρ_j in equation (2). This approach is a diametrical opposite to the ERÅD-model in that the data requirements are modest. Basically, in addition to electricity consumption, only two types of input are needed, that is information about whether the household possesses the particular appliances, or the number of appliances, and socio-economic characteristics. Such data are relatively easy to obtain by asking the households, and the input of the econometric model in this analysis is solely observed micro data from the survey. The data are as such controllable.

A weakness of the econometric CDA model is that we are not able to estimate significantly electricity for appliances that almost every household owns. One possible method for improving the imprecise estimates from CDA involves the incorporation of data obtained by directly metering specific appliances, and use of a random coefficient approach. This method is thoroughly discussed in e.g. Bartels and Fiebig (1990) and Fiebig et al. (1991), where they develop extensions to the CDA that allow for improvements in the end-use estimations. Another method for improving the estimates involves incorporation of metering data and use of a Bayesian approach, see e.g. Bauwens et al. (1994) and Hsiao et al. (1995).

Obviously, the usual standard methodological problems of econometric approaches regarding model specification and imposed assumptions regarding the error term also prevail for the CDA model. However, these assumptions may be tested.

4. The data

Data from Statistics Norway's 1990 Energy Survey have been used in order to elicit the composition of residential electricity demand on different end uses. A questionnaire was sent to 4004 households and about 53 percent answered. Out of the net sample of 2107 households, 654 households are excluded from the econometric analysis due to missing values for important variables. Thus, our econometric study is based on micro data for 1453 households. The engineering bottom-up model ERÅD is applied on data for 2013 households, as missing values are replaced by mean values. For example, 11 percent of the households have not reported values for the number of light bulbs. These missing values are replaced by mean values for survey households with the same house type and dwelling size.

The survey gives information about each household's energy consumption, type of heating equipment and electric appliances as well as income and household and dwelling characteristics.[1] The electric utility of each household is known, as are electricity tariffs for each of about 250 electric utilities in Norway. Thus, we have electricity prices for each household. Household electricity consumption is either obtained from the electric utilities or from the survey. Several questions in the 1990 Energy Survey were designed for the specific purpose of being used in ERÅD. As a result, the survey contains a number of questions regarding physical characteristics of the dwelling, for example several questions regarding insulation, construction materials and house shape. A more detailed documentation of the data is given in Ljones et al. (1992). Summary statistics for variables included in the econometric model are given in appendix A.

The data used as input in the engineering model and in our econometric model differ in two respects. Firstly, the number of observations differs due to different policy with respect to whether missing data should be replaced by estimated values. Secondly, while only data for each household from the energy survey are used in the econometric model, additional information regarding e.g. behaviour (use of time, kWh) and technical information (power) for different appliances is used in the engineering model. Comparing methods is satisfactory despite these data differences, as the data handling in the engineering model is part of the method, which involves extended use of assessments and guesstimates of behavioural and technical parameters.

As the econometric model is based on a sample of 1453 households, while the original questionnaire was sent to 4004 households, we may face problems regarding biases of our results. To investigate this potential problem the distributions of some variables of our sample are compared to distributions of these variables for all households (the population). We found that the share of 14 percent for single person households in our sample is less than half the share in the population (36 percent). The shares of households living in the largest city (Oslo) were 12 percent in the sample and 14 percent in the population, i.e. the shares differed not to the same extent. The mean value of electricity consumption

[1] Appliances included are microwave oven, refrigerator, freezer, combined refrigerator and freezer, kitchen stove, mixmaster, kitchen ventilator, dishwasher, vacuum cleaner, washing machine, tumble dryer, drying wardrobe, sauna, solarium, swimming pool, cold-storage chamber, car engine heater, outdoor electric ground heating, waterbed, whirlpool baths, TV, VCR, radio and cassette player.

of the sample is 18955 kWh, which is about 15 percent higher than reported from the household energy survey in 1990 (Ljones et al., 1992). The question is whether the end-use shares for single person households in small dwellings differ from end-use shares of other households. These households probably use less electricity (in kWh) both for space heating, water heating, lighting and household appliances, like for instance dishwasher and washing machine. Thus, the end-use shares for these households are not necessarily different from other households; i.e. the bias problem due to non-response and missing data need not be large.

5. Results from the econometric model

We carried out econometric analyses based on the data and model described in section 3 and 4. In the following we first present our econometric results and then our end-use results.

5.1 Econometric results

Our econometric results from estimating the CDA model by the Ordinary Least Squares method are presented in table 1. Variables determining electricity consumption are shown in the first column, estimated effect on electricity consumption of different variables in the second (β , γ_j and ρ_{jm} in equation 2) and t-values in the third column of table 1. P-values from OLS estimation are shown in the fourth column, while p-values following from correcting the OLS Covariance Matrix for heteroskedasticity are reported in the fifth column (see Greene, 1995). The first part of table 1 shows the appliance variables, and the second part of table 1 shows the interaction variables, i.e. variables represented by $(C_{im} - \overline{C}_{jm})D_{ij}$ in equation (2). The estimated coefficients (γ_j) are interpreted as electricity consumption related to the appliances (measured in kWh) for a household with average demographic characteristics. The end-use results are reported in section 5.2.

Electricity consumption is estimated to be significantly higher for households having electric heaters, individual central electric heating, tumble dryer, washing machine, dishwashing machine, refrigerator, outdoor electric ground heating, TV&VCR and sauna than for households not having these appliances. We have defined the variables for showers and baths as interactions with the dummy variable electric water heater. This is because we want to sort out households that get heated water by use of other energy types than electricity. Electricity consumption is 2684 kWh higher for the 80 percent of households taking showers and having an electric water heater than for other households. The electricity consumption for the 44 percent of households both taking baths and having an electric water heater is 1014 kWh higher than for other households. Because all households have light bulbs, we have defined the dummy variable for lighting as 0 for those having 12 light bulbs or less (5 percent of the households) and 1 for those having more than 12 light bulbs. This means that our estimate of electricity for lighting of 3034 kWh represents the additional lighting consumption associated with having more than 12 bulbs. The significance of the result for lighting is high despite that the households are grouped into two groups only, as electricity consumption for the mean households with a few light bulbs will be clearly lower than for the mean household in the household group having about 30 light bulbs in average.

The dummy variables representing electricity consumption for showers, light bulbs and dishwashers etc. may be seen as instruments for the services from different types of equipment and appliances. For instance the service from showers is the number of showers and the time used on this activity. However, we are interested in the electricity consumption (kwh) for different end uses, and as pointed out in section 3.3 our CDA approach gives estimates of electricity consumption directly.

The heating system is important for the composition of energy consumption. Many Norwegian households have heating systems based on electricity in combination with fuel oil or wood. Our analysis provides estimates of the difference in electricity consumption for households having electric heaters, electric floor heating or individual central heating based on electricity compared to other households. Households having electric heaters and/or electric floor heating use 3700 kWh more than households not having such equipment. Correspondingly, electricity consumption for households with individual central heating based on electricity is estimated to be 5052 kWh.

Economic, demographic and technical variables were tested as interactions with the appliance dummies (deviation from their mean values), as suggested in e.g. Aigner et al. (1984). Bartels and Fiebig (2000) also include interaction variables in their CDA model. Only interaction variables which seem realistic and are significant at 10 percent level are included in the model. For example, dwelling size is an important explanatory variable for electricity consumption, and the higher the dwelling size the more electric heaters are needed. This effect is captured by the interaction variable for dwelling size and electric heaters.

The intercept represents electricity consumption for end uses which are not captured by the significantly estimated appliance dummies, i.e. miscellaneous electricity consumption is estimated to 3526 kWh.

Table 1. Estimated household electricity consumption, kWh per year (1990)

Variables	*Coefficient*	*t-value*	*p-value (OLS)*	*Corrected p-value*[a]
Intercept	3526	2.95	0.00	0.00
Appliance variables:				
Electric heaters and/or floor heating (0 or 1)	3700	4.80	0.00	0.00
Individual central electric heating (0 or 1)	5052	3.64	0.00	0.00
Showers * electric water heater (0 or 1 * 0 or 1)	2684	5.28	0.00	0.00
Baths * electric water heater (0 or 1 * 0 or 1)	1014	2.60	0.01	0.01
Lighting (0 or 1)	3034	3.79	0.00	0.00
Tumble dryer (0 or 1)	2338	5.58	0.00	0.00
Washing machine (0 or 1)	2099	2.38	0.02	0.00
Dishwashing machine (0 or 1)	2015	4.65	0.00	0.00
Refrigerator (0 or 1)	1957	3.02	0.00	0.00
Outdoor electric ground heating (0 or 1)	3552	2.91	0.00	0.00
TV&VCR (0 or 1)	1301	3.27	0.00	0.00
Sauna (0 or 1)	2265	2.70	0.01	0.02
Interaction variables: [b]				
Dwelling size * electric heaters and/or floor heating	42	9.30	0.00	0.00
High-income household * electric heaters and/or floor heating	1330	2.23	0.03	0.03
Age over 60 * individual central electric heating	8068	2.77	0.01	0.06
Energy saving activity * individual central electric heating	-7340	-2.78	0.01	0.03
Heating degree days (HDD) * individual central electric heating	-14	-4.36	0.00	0.00
Single person household * showers * electric water heater	-1765	-2.46	0.01	0.00
Age over 60 * baths * electric water heater	-3188	-3.08	0.00	0.00
Age of the interviewed person * baths * electric water heater	147	4.95	0.00	0.00
Number of household members * lighting	1428	7.53	0.00	0.00
Farmhouse * lighting	1901	2.06	0.04	0.03
Detached house with basement flat * lighting	1926	2.36	0.02	0.01
Farmhouse * tumble dryer	8175	5.69	0.00	0.01
Age over 60 * dishwashing machine	-1797	-2.33	0.02	0.02
Electricity price * refrigerator	-174	-3.54	0.00	0.00
Detached house with basement flat * outdoor electric ground heating	25772	3.48	0.00	0.00
HDD * outdoor electric ground heating	-3	-1.86	0.06	0.00
HDD * TV&VCR	2	3.89	0.00	0.00
R^2	0.48			

[a] Corrected for heteroskedasticity.

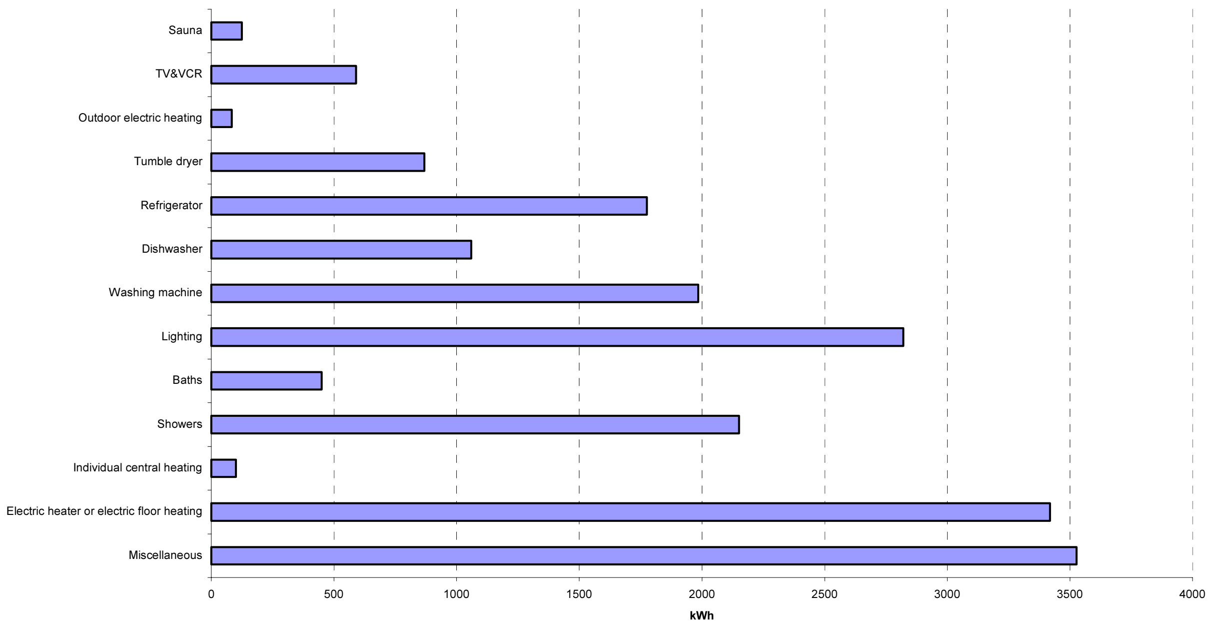
[b] Deviations from mean values for those having the particular end use multiplied by end-use dummies.

Empirical evidence from earlier CDA studies has indicated the presence of heteroskedasticity. Thus the OLS Covariance Matrix was corrected for heteroskedasticity, and corrected p-values are reported in the right column of table 1. The differences in p-values are small, and all variables are still significant at ten percent level or lower.

5.2 End-use results from the econometric model

Estimated coefficients of appliance variables and interaction variables from the econometric model and sample means of these variables are used to calculate average electricity consumption for different appliances, as shown in equation (4). Estimates of the end-use coefficients ($\hat{\beta}$, $\hat{\gamma}_j$ and $\hat{\rho}_j$) are presented in table 1, while mean values of the corresponding variables ($\overline{D}_j$ and $\overline{(C_{im} - \overline{C}_{jm})\overline{D}_{ij}}$) are reported in appendix A. Figure 2 shows the estimates of average electricity consumption for end uses that we are able to estimate significantly at 10 percent level, measured in kWh per year. Insignificant econometric results for freezer, combined fridge and freezer, cold-storage chamber, kitchen stove and microwave oven imply that electricity consumption for these appliances is calculated as a residual (represented by β), together with other miscellaneous electricity consumption.

Figure 2. Electricity consumption for different appliances and activities from the econometric model in 1990, average kWh for all households



The estimate of annual electricity consumption for individual central heating based on electricity is 5052 kWh. However, as only 2 percent of the households have this type of central heating, this implies an estimate of only 101 kWh for this heating equipment for an average household. Nearly all households (92 percent) have electric heaters or electric floor heating, and the estimate of electricity consumption for households having such heating equipment is 3700 kWh. Thus, the average household use 3418 kWh for electricity for electric heaters and/or electric floor heating. The total estimate for space heating seems low. However in the period 1960-90, 1990 was the year with highest winter temperature (15 percent higher than the average).

The estimate of electricity for showers (2152 kWh) is clearly higher than for baths (451 kWh) for the average household, partly because it is more common to take showers than baths. The estimated coefficients show the kWh for showers and baths for the 89 percent of the households that get heated water from an electric heater.

Electricity for lighting depends on the number and use of light bulbs. Our estimate of average electricity consumption for lighting is 2821 kWh in average per year. The households have 31 bulbs on average. If we assume that each bulb uses 50 W in average, our results indicate that each bulb is used about 1820 hours a year, i.e. approximately 5 hours a day.

The estimated impact on electricity consumption of washing machine and refrigerator, which are among the most common appliances of Norwegian households, is 1985 kWh and 1776 kWh for an average household. Assuming the power consumption of washing machine and refrigerator being 2000 W and 160 W, estimated time use of the appliances is approximately 2.6 hours and 34.5 hours, respectively, for those possessing these appliances. Households possessing more than one refrigerator may partly explain the high estimate of time use for refrigerators.

Electricity consumption for a dishwashing machine in an average household is estimated to 1060 kWh per year, as 53 percent of the households possess a dishwashing machine. If the power consumption of the appliance is assumed to be 2000 W, the average household uses the dishwashing machine about 1.5 hours a day, or 2.8 hours for those having a dishwashing machine.

Electricity use for tumble dryers is estimated to 869 kWh, due to 2338 kWh in average per tumble dryer and a share of 37 percent having this drying equipment. This indicates a use of approximately 0.8 hours per day (if the load is 3000 W) or 2.1 hours for those having a tumble dryer.

The estimated electricity consumption for TV&VCR is 590 kWh for an average household and approximately 1300 kWh per year for those possessing TV&VCR. This implies that the TV or video is switched on for 24 hours each day in a video-owning average household (if the load is 150 W). This is high compared to a result from the time budget survey for 1990, which shows TV-watching for approximately 1.5 hours per person (Statistics Norway, 1992). However, our estimate pertains to an average household with 3 persons, which means that the TV is on both during children and adult programs and that two or more TVs may be on simultaneously. In addition, those who own a video probably have more than average interest for watching TV. Our estimate may also include an indirect effect of need of higher indoor temperature when watching TV or video than when the household is more physically active. In addition, standby electricity consumption related to TV's may be high. IEA (2001) find that standby power consumption is about 10 percent of OECD residential energy use.

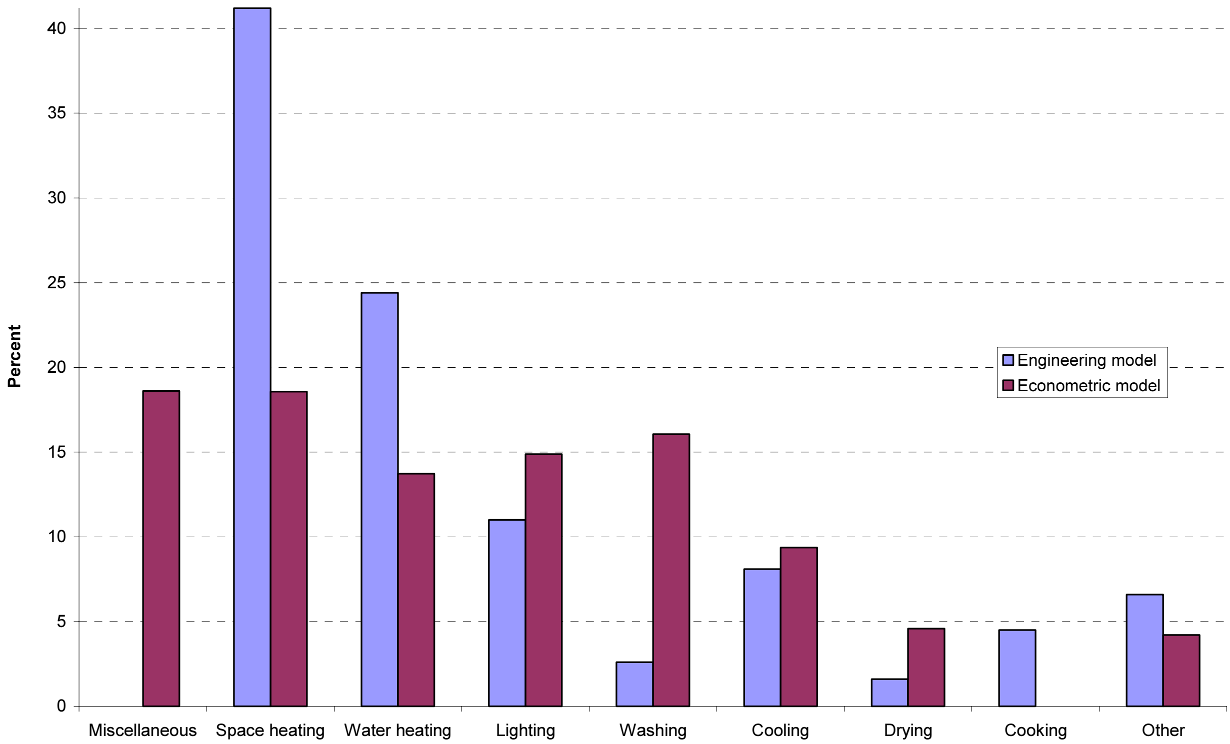
Only 2 percent of the households in our sample have outdoor electric ground heating. Electricity consumption for those having this equipment is 3552 kWh and the average electricity consumption for outdoor electric ground heating is 83 kWh. For sauna, the average electricity consumption is estimated to 125 kWh, as only 6 percent of the households have a sauna.

6. Comparison of end-use results

We have grouped the-end use results presented in figure 2 to provide estimates for *Space heating, Water heating*, *Lighting*, *Washing*, *Cooling*, *Drying, Other* and *Miscellaneous*. This grouping of end uses allows us to compare the results with those obtained from the engineering model ERÅD. We have tried to group the results from the econometric model and the engineering model in a consistent way. However, in some instances we have not been able to include exactly the same end uses in each category. This is due to some insignificant results from the econometric analysis, but also poor documentation of the grouping of results from ERÅD.

Electricity for S*pace heating* is calculated as the sum of electricity for individual central heating and electricity for electric heaters and/or electric floor heating. Electricity for *Water heating* is calculated by summing the estimates of electricity for showers and baths. In Norway, the majority of households use cold water in their washing machines and dishwashing machines (the water is heated within the machine), and as the service is not hot water but clean dishes and clothes, we do not include these in the end-use category *Water heating*. Our estimate of *Water heating* is too low, because domestic hot water for purposes other than showers and baths is not included. The end-use category *Washing* includes electricity for dishwashing machine and washing machine. The end-use category *Cooling* includes electricity for refrigerator. Combined refrigerator&freezer, separate freezer and cold-storage chamber are not included in the end-use estimates because of insignificant results. The end-use category *Drying* includes electricity for tumble dryers. Electricity consumption for TV&VCR, outdoor electric ground heating and sauna are grouped as the category *Other*. The end use category *Miscellaneous* includes end uses, which are not included in any of the categories specified above, as for instance cooking. The electricity consumption for different end uses is divided by total average electricity consumption to get the share of electricity consumption related to different end uses, see equations (5) and (6). In figure 3 the results from the econometric and the engineering models are compared.

Figure 3. Electricity consumption for different end uses from the econometric and the engineering models in 1990



The results show that the engineering model estimates are higher with respect to *Space heating*, *Water heating*, *Cooking* and *Other* than the results from the econometric model. In the econometric model, the category *Other* includes outdoor electric ground heating, sauna and TV&VCR. It is not clear which end uses that are included in the *Other* category of the engineering model, although, in theory it should include all miscellaneous electricity consumption. However, it is not reasonable to believe that the engineering model is capable of specifying all miscellaneous consumption. Therefore, some miscellaneous consumption will, in the calibration of the model, be distributed into the end-use categories which are explicitly taken into account, rather than calculating miscellaneous electricity consumption as a residual. This pulls in the direction of an overestimation of all specified end-use consumption in the engineering model. The econometric model gives high estimates for *Lighting*, *Washing*, *Drying* and *Miscellaneous* compared to the engineering model. However, estimated time use related to lighting, dishwashers, washing machines and tumble dryers for households possessing these appliances of 5, 2.8, 2.6 and 2.1 hours per day, respectively, seems plausible (see discussion in section 5.2).

Figure 3 shows that the results for end-use electricity consumption from the econometric and engineering models differ for all end uses. Ideally we want to know whether the results differ significantly. For the econometric model we have calculated 95 percent confidence intervals (estimate +/- 1.96 * standard deviation) for the estimated parameters. We have then calculated intervals where the lower value is the lower value of the confidence interval of the parameter estimate for an appliance (or interaction variable) multiplied by the mean value of the appliance dummy (or interaction variable), and the upper value of the interval is calculated as the upper value of the confidence interval multiplied by the mean value. We have summarised the lower values and summarised the upper values of the intervals of the appliance variables and interaction variables related to the same end-use category. The intervals of different end uses are shown in the figure of appendix B. The estimates from the engineering model are included in the figure. However, no information of uncertainty of each estimate is reported for the engineering model, and it is not possible to calculate confidence intervals of the end-use estimates. We find that the engineering model estimates of lighting and cooling are inside the interval of the econometric model, while the other estimates of the engineering model are outside the intervals of the econometric model. These results do not allow us to draw conclusions regarding significance of the differences between the results of the two models, but they indicate that the results are considerably different.

7. Guidance for future studies

Knowledge from our analysis and the literature provide guidance for future estimation of electricity end-use consumption. Based on the assessments of the engineering and econometric approaches in section 2 and 3 and the results from the two approaches presented in section 6, we find drawbacks of both approaches. The most important drawback of the engineering approach is the high need of detailed information about household behaviour and technical features of appliances at average household level. The most important drawback of the econometric approach is insignificant results for appliances which are common in most households, giving a high estimate of the end-use share for the category *Miscellaneous*. We believe that an econometric approach is preferable in future studies of end-use consumption, as the potential for improvement of the econometric end-use results by use of better data seems promising. Direct metering or other engineering techniques and equipment may, however, be useful if combined with econometric methods. Our data are not optimal because the survey was not designed specifically for studying end-use consumption econometrically. Despite this, our model explains nearly 50 percent of the variation in electricity consumption. Econometric methods are unlikely to explain 'all' variation in electricity consumption. Data can always be improved, and there may be a problem regarding model specification, although testable. These problems are probably less when the results are used for detecting trends in end-use consumption. The implicit assumption is then that the degree of under- or overestimation is constant over time.

Standard CDA is not able to estimate significantly electricity consumption for appliances possessed by nearly all households. Thus, 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 e.g. Bartels and Fiebig (1990). However, there may be problems with poolability of the two sources of data (CDA and direct metering), see Bartels and Fiebig (2000). Aigner and Shönfeld (1990) and Bartels and Fiebig (1990, 1996, 2000) focus on how to determine which end uses to meter in the households. Bartels and Fiebig (1990) conclude that when considering which appliances to be metered it seems preferable to meter appliances for which the variation in use is small, and that it is advisable to spread the meters over different types of appliances. Based on this, our results indicate that it would be preferable to meter electricity use related to cooking and cooling to get more precise estimates of electricity consumption for these end uses.

Installing technology for direct metering of appliances in Norwegian households is a high-cost alternative. There is also a question of to what extent direct metering is needed. An alternative to direct metering is trying to include questions in the survey, enabling us to estimate end-use consumption which has been difficult to identify so far. A challenge lies in designing the questionnaire in an optimal way. Our analysis shows insignificant results for some appliances with a high penetration rate, such as kitchen stove and freezer. Thus, more detailed information about these appliances is required. Questions regarding use of kitchen stove as well as number and size of freezer may give useful information. Besides, questions regarding number of electric heaters and number of rooms with electric floor heating may improve the space heating results. Our hypothesis is that such questions will enable us to give better end-use estimates of electricity consumption. Data from a new survey including the suggested questions will be available in 2003. We look forward to testing our hypotheses regarding improvements of the estimates of end-use consumption by use of these data.

8. Concluding remarks

In this paper we find drawbacks of both the approach of the Norwegian engineering model ERÅD and our econometric model. The drawbacks of the ERÅD model seem to be hard to eliminate. However, our econometric analysis indicates that there is potential for improvements of end-use results by conducting surveys designed for analysing end-use consumption econometrically. Therefore, our proposal is to make further surveys and econometric studies to get better estimates of electricity end-use consumption in Norway.

The stock of heating equipment and appliances is assumed to be constant in our analysis. This assumption is not very problematic as we focus on end use in a specific period. However, if our results were to be used in simulations to forecast electricity consumption for different end uses, it would be unrealistic to assume no changes in the stock. If an assumption of unchanged mean energy consumption related to different heating equipment and appliances is realistic, electricity for different end uses may be estimated from estimated mean values of electricity consumption for different appliances combined with estimates of future stock of heating equipment and appliances. The model should be estimated over a period of time to find out whether mean electricity consumption related to different appliances changes significantly over time (see also Halvorsen and Larsen, 2001 for a study of electricity consumption for some appliances over a longer period). In this study we are not able to trace any trends over time, as we have data for one year only. By conducting periodic surveys, either for panels of households or independent cross-sections, we may be able to compare end-use results in different years and trace any changes or trends in the decomposition of electricity consumption over time.

References

Aigner, D.J., C. Sorooshian and P. Kerwin (1984): Conditional Demand Analysis for Estimating Residential End-Use Load Profiles, *Energy Journal* 5(3), 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(4), 79-97.

Bartels, R. and D.G. Fiebig (1996): Metering and Modelling Residential End-use Electricity Load Curves, *Journal of Forecasting* 15, 415-426.

Bartels, R. and D.G. Fiebig (2000): Residential End-Use Electricity Demand: Results from a Designed Experiment, *Energy Journal* 21(2), 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(2), 221-31.

Energidata (1989): The Model ERÅD – A Documentation, Energidata 13.02.1989. (In Norwegian)

Fiebig, D.G., R. Bartels and D.J. Aigner (1991): A Random Coefficient Approach to the Estimation of Residential End-Use Load Profiles, *Journal of Econometrics* 50(3), 297-327.

Fung, A.S. and V.I. Ugursal (1998): Residential Lighting Energy Use in Canada, *Energy Studies Review* 8(3), 264-68.

Greene, W.H. (1995): Limdep Version 7.0. User's Manual, Econometric Software, Australia.

Halvorsen, B. and B.M. Larsen (2001): "Norwegian residential electricity demand - A microeconomic assessment of the growth from 1976 to 1993", *Energy Policy* 29(3), 227-236.

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(3), 315-26.

IEA (2001): *Things That Go Blip in the Night. Standby Power and How to limit it*, International Energy Agency.

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(2), 164-73.

Ljones, A., R. Nesbakken, S. Sandbakken, A. Aaheim (1992): *Household Energy Consumption. The Energy Survey 1990*, Reports 92/2, Statistics Norway. (In Norwegian)

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(1), 309-21.

Sanchez, M.C., J.G. Koomey, M.M. Moezzi, A. Meier and W. Huber (1998): Miscellaneous Electricity in US Homes: Historical Decomposition and Future Trends, *Energy Policy* 26(8), 585-93.

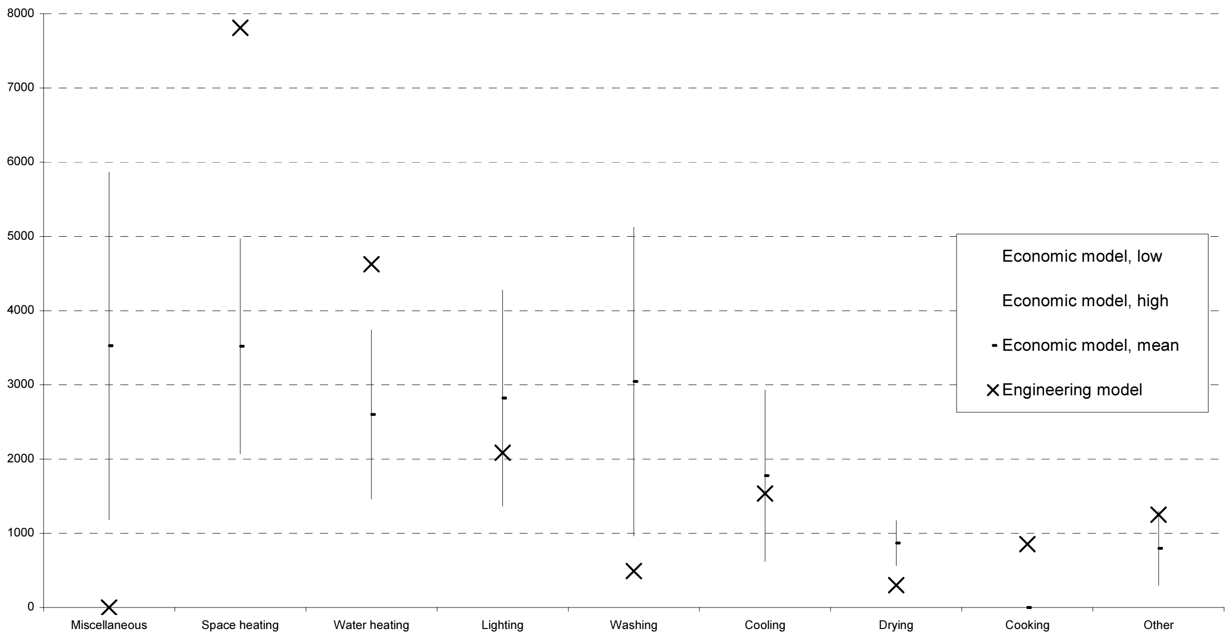
Statistics Norway (1992): The Time Budget Surveys 1970-90, Official Statistics of Norway C 10.

Summary statistics, the 1990 Energy Survey (1453 households)

Variable	*Mean*	*St. dev.*	*Min*	*Max*
Electricity consumption (kWh per year)	18955	9575	735	98046
Appliance variables:				
Electric heaters and/or floor heating (0 or 1)	0.92	0.27	0	1
Individual central electric heating (0 or 1)	0.02	0.14	0	1
Showers * electric water heater (0 or 1 * 0 or 1)	0.80	0.40	0	1
Baths * electric water heater (0 or 1 * 0 or 1)	0.44	0.50	0	1
Lighting (0 or 1)	0.93	0.26	0	1
Tumble dryer (0 or 1)	0.37	0.48	0	1
Washing machine (0 or 1)	0.95	0.23	0	1
Dishwashing machine (0 or 1)	0.53	0.50	0	1
Refrigerator (0 or 1)	0.91	0.29	0	1
Outdoor electric ground heating (0 or 1)	0.02	0.15	0	1
TV&VCR (0 or 1)	0.45	0.50	0	1
Sauna (0 or 1)	0.06	0.23	0	1
Interaction variables: [a]				
Dwelling size * electric heaters and/or floor heating	0.03	47.12	-90	330
High-income household * electric heaters and/or floor heating	0.00	0.33	0	1
Age over 60 * individual central electric heating	0.00	0.07	0	1
Energy saving activity * individual central electric heating	0.00	0.07	-1	0
Heating degree days (HDD) * individual central electric heating	-0.01	59.37	-840	807
Single person household * showers * electric water heater	0.00	0.30	0	1
Age over 60 * baths * electric water heater	0.00	0.28	0	1
Age of the interviewed person * baths * electric water heater	0.00	9.24	-42	28
Number of household members * lighting	0.00	1.26	-2	8
Farmhouse * lighting	0.00	0.26	0	1
Detached house with basement flat * lighting	0.00	0.23	0	1
Farmhouse * tumble dryer	0.00	0.16	0	1
Age over 60 * dishwashing machine	0.00	0.27	0	1
Electricity price * refrigerator	0.00	3.81	-21	14
Detached house with basement flat * outdoor electric ground heating	0.00	0.03	0	1
HDD * outdoor electric ground heating	0.00	113.90	-879	2385
HDD * TV&VCR	0.17	427.21	-729	2535

[a] Deviations from average values for those having the particular end use multiplied by end-use dummies.

Engineering estimates and uncertainty intervals for the econometric model, kWh



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