ELECTRICITY DEMAND FORECASTING 2030 BY DECOMPOSITION ANALYSIS OF OPEN DATA

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ABSTRACT

The demand of electrical energy in the household sector followed a nearly linear growth trend for a long time making demand forecasting relatively simple. However, in the last decade the growth has stalled due to energy efficiency policies, structural changes in the society and emergence of new technologies. In sparsely populated areas the population is continually declining which affects electrical energy consumption and increases average conductor length per customer. These changes in the operational environment pose challenges to demand forecasting. Historical data relating to the change factors could be used to improve demand forecasts. This study introduces a method that uses decomposition and time-series analysis of open data to forecast future electrical energy demand. The method is used to forecast the electrical energy consumption for the household sector in a group of Finnish municipalities which have a declining population.

INTRODUCTION

The development of energy demand is of great importance in long-term network planning. Long-term energy demand forecasts have to be drafted tens of years in advance because of the long lifetimes of network components. Electricity demand forecasts aid in distribution business planning and development of distribution tariffs. They also traditionally form the basis for load forecasts which in turn are of importance in distribution network planning such as dimensioning of cables and transformers. [1][2]

The population of rural areas in Finland has been continually decreasing in the last 30 years [3]. However, the consumption of electricity has been growing significantly in the period 1990–2007 after which the growth has stalled [4]. To be able to make accurate forecasts, it is important to evaluate factors in addition to population which can explain this development.

Traditionally distribution system operators (DSO) have made forecasts based on their own consumption data and a limited amount of outside data such as land use plans [2]. Forecasts based on only the historical demand of electricity may lead to highly inaccurate results if the development trends of underlying factors are not taken into account. Many demand forecasting methods have been proposed to improve on the traditional methods. The forecasting methods have their own advantages and disadvantages and specific use cases [1], [2]. This study aims to provide a method for demand forecasting in a municipality level that is easy to understand and implement while providing reasonable accuracy in the changing operational environment.

The electrical energy consumption method presented in this paper is based on decomposition of electrical energy consumption. Forecasts are made by using time-series analysis to forecast the individual components. The components' forecasts are then combined to form a consumption forecast. The databases used for the forecasts are presented and the methodology's forecasting performance is evaluated. The case area for this study is municipalities that have had a declining population during 1990–2017.

Structural changes

In the last decades large structural changes related to housing and population has occurred in Finland [3]. These changes are important because they have a direct impact to energy consumption. The population change in Finnish municipalities in 1990–2017 is shown in Figure 1.

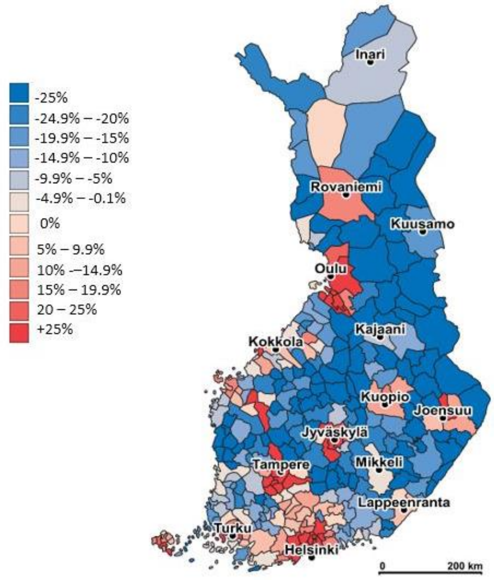

Figure 1. Population change in Finland in 1990–2017. [3]

In the majority of Finnish municipalities, the population has been significantly decreasing (215 municipalities out of 311), the decrease of population has been over 10% in the majority of these municipalities. This phenomenon is caused by increasing migration from rural areas to cities. The total population is nonetheless still growing since only

30% of the population live in these kinds of municipalities and the migration is largely internal. [3] Metrics related to changes in the household sector is shown in Figure 2.

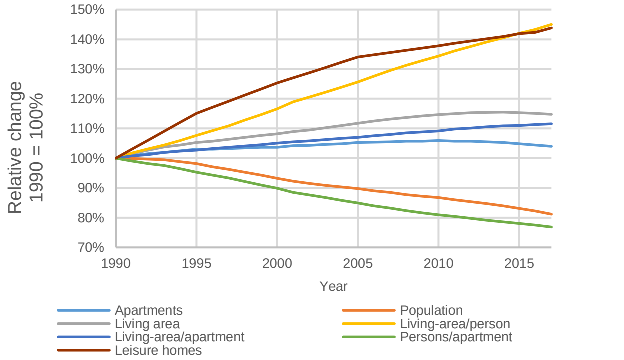

Figure 2 Key metrics in the household sector in municipalities with a declining population 1990–2017. [5]

From the figure it can be seen that in the case municipalities the population has been declining significantly. However, the number of apartments has seen steady growth despite the decline of population. This trend along with the increase of living area per apartment have resulted in the increase of total living area in the case municipality group. The combined effect of increasing living sparsity (living-area/person) and increasing apartment size can be seen in the very high growth (+41%) of living-area per person. The large increase in number of leisure homes (+40%) is another factor that can in part counteract the effect of the decreasing population in the energy consumption of the area.

Changes in heating and home devices

Electricity consumption in Finland can be divided to electricity used by heating and electrical devices. In 2017 heating consumed 64% of total electricity consumption of Finnish households while home devices consumed the remaining 34%. [6] Average heating demand and estimates for 2020 and 2050 are shown in Table 1.

Table 1 Heating demand of buildings in Finland in 2010 and estimated demand in 2020 and 2050 [2]

	Estimated heating demand in Finland compared with demand in 2010 (kWh/m^2,a)		
Building type	**2010**	**2020**	**2050**
Detached houses	148	134 (91%)	88-110 (59-74%)
Attached houses	145	136 (94%)	93-116(64-80%)
Apartment houses	151	142 (94%)	99-124(66-82%)

From table 1 it can be seen that in all building types the heating demand is estimated to decrease by a minimum of 26-28% by 2050. This is largely due to energy efficiency policies in Finland which demand that all new buildings have to be low energy or zero-energy buildings. [2]

The electrical energy consumption of household devices grew in 1993–2011 by 1.7 %/a [7] but in the last decade the consumption has started to decrease on average 1.1 %/a [6]. The decrease has been contributed mainly to the EU energy efficiency directive. Energy efficiency is expected to continue to improve in the future [2].

METHODOLOGY

In this study decomposition of open data has been used as a basis for the electricity demand forecast. The used methodology to forecast electrical energy consumption can be divided to three stages. In the first stage of the proposed methodology decomposition analysis was used to study the effects of selected impacting factors on electricity consumption. The second stage comprises of using ARIMA-models to forecast the trends of the components. Finally, the forecasts of the components are combined to form a forecast for electricity consumption. The proposed methodology is presented in Figure 3.

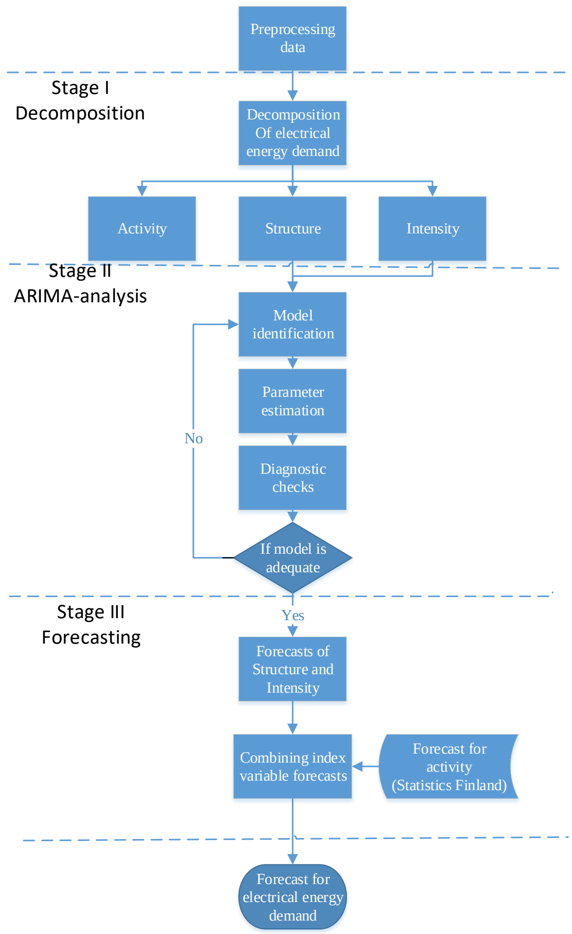

Figure 3. Proposed methodology for electrical energy consumption forecasting.

Open databases and data preprocessing

Statistics used in the forecasting methodology of this study was obtained from three different publishers. Data was obtained from municipalities that have a declining population. The used publishers and statistics are presented in Table 2. All of data used is publicly available.

Table 2. Statistics used to forecast electrical energy demand.

Publisher	Statistic	Time-period used
Finnish Meteorological Institute	Heating degree days[12]	1995–2017
	Temperatures [12]	1990–1994
Finnish Energy	Electrical energy consumption [4]	1990–2004 and 2006–2017
Statistics Finland	Population forecast [3]	2017–2030
	Household statistics [5]	1990–2017

The annual electrical energy consumption data for households and agriculture for the years 1990–2003 and 2006–17 was obtained from Finnish Energy. The consumption data also includes electrified leisure homes which can affect the results. The impact of energy consumption in agriculture is assumed to be low in the selected municipality group since the energy consumption has not changed much. The electrical energy consumption was assumed to have linear growth during the years 2004–05, when data was not available. Since heating degree days (HDD) were only available for the years 1995–2017 the remaining heating degree days for 1990–94 were calculated with the formula [12]

$$HDD = T_{ref} - T_{ave}, \quad (1)$$

where T_{ref} is the difference of the daily indoor and outside temperatures (indoor temperature is presumed to be +17°C) and T_{ave} is average daily outside temperature. If the daily average temperature exceeds 10°C the heating degree day is assumed to be 0. The electrical energy consumption can now be temperature corrected using heating degree days with the formula [8]

$$E_{corrected} = k_2 \frac{S_{N\,ref}}{S_{act\,ref}} \cdot E_{heating} + E_{other}\,, \quad (2)$$

where k_2 is the municipality dependent correction factor to the reference municipality, $S_{N\,ref}$ is the normal period (1981–2010) heating degree days, $S_{act\,ref}$ is the actual heating degree days, $E_{heating}$ is temperature dependent energy consumption and E_{other} is non temperature dependent energy consumption. Temperature dependent consumption was assumed to be 35% of the total consumption.

Stages of methodology

The first stage comprises of decomposition of electrical energy demand data. The decomposition was carried out using the Laspeyres method. Decomposition can be used to determine the effect of pre-defined factors in the change of electricity consumption [9],[11]. The electricity consumption within the household and agriculture sector of a designated area is separated into three components: the aggregate activity, sectoral structure and energy intensity. The selected indicator variables are based on suggestions by IEA for space heating in the household sector [13]. Indicators for space heating were selected because in Finland space heating is the largest source of electrical energy consumption of households [6]. The indicator variables and units are shown in Table 3.

Table 3. Decomposition indicator variables and their units.

	Indicator variable	Unit
Activity	Population	person
Structure	Living sparsity	m^2/person
Intensity	Energy intensity	kWh/m^2

Energy use of a sector can be represented by the product of the decomposition components

$$E_t = A_t \sum_j^n S_{jt}\, I_{jt}\,, \quad (3)$$

where *j* is the subsector, A_t is the aggregate activity at time *t*, S_{jt} is the sectoral structure and I_{jt} is the energy intensity. The effect of an individual component can be calculated by keeping the other two fixed at base year value while the studied component varies as a function of time. [9],[11]

In the second stage ARIMA-models are fitted in the time-series of structure and intensity. ARIMA-models can be used to forecast time-series that have a trend. The Box-Jenkins methodology [8] was used to estimate the necessary parameters for the ARIMA-model. The phases of the Box-Jenkins methodology are shown in Figure 3.

In the final stage the forecasts for structure and intensity are made by making use of the previously fitted ARIMA-models. The forecast for activity (population) is obtained from Statistics Finland. The forecast for electrical energy demand is finally obtained as the product of the forecasts of the decomposition components.

RESULTS AND DISCUSSION

Decomposition

Decomposition was used to separate the effects of structural, intensity and activity changes that affect electricity consumption in households. The decomposition results of the case area are shown in Figure 4.

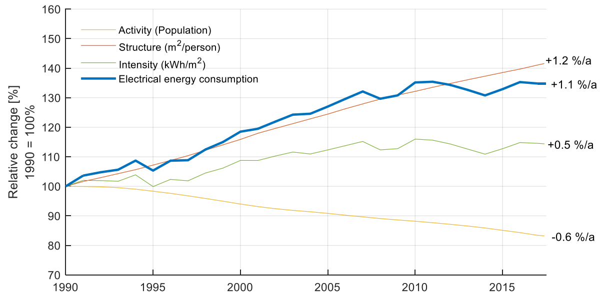

Figure 4. Decomposition of electricity consumption of households and agriculture in the case area.

From Figure 4 it can be seen that despite a large decrease in population the electrical energy demand has grown significantly. Structure has been the largest factor relating to the growth from the three components. Intensity has also grown significantly (0.5%/a) however the growth has stalled after the year 2007. The growth of intensity can be explained in large part by the increase of electrical devices and substantial increase of new electrified leisure homes and the electrification of existing leisure homes. The stalling of the growth could be attributed to increasing energy efficiency of home devices and decreasing heating demand [2]. From these results it can be seen that population alone is not enough to forecast future electrical energy consumption accurately.

Forecasts

The case area forecasts were made for the period of 2018–2030 using ARIMA-models. The forecasts for the decomposition components and electrical energy consumption and it's 90% confidence intervals are shown in Figure 5. Confidence intervals were calculated as a product of confidence intervals of activity and structure.

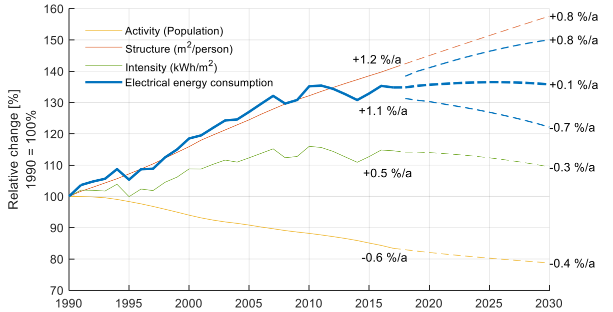

Figure 5. Historical data from 1990–2017 and forecasts of decomposition components and electrical energy consumption 2018–2030.

As seen from Figure 5 the population continues to decline albeit somewhat more slowly compared to the historical trend. The migration from sparsely populated areas is expected to continue however the population decrease forecasted by Statistics Finland in 2015 has been more positive than the actual trend in years 2015–2017. Therefore, the actual trend could continue to decline more than forecasted also in the years 2017–2030.

The forecasted trend of structure shows continued growth, however the forecasted growth is slower compared to the average historical growth. Based on only historical data the continued increase of living sparsity seems probable because of the clear historical trend. However most of this increase is due to the number of single person households increasing and since this development cannot continue indefinitely, the growth is likely to stall at some point in the future.

The trend of intensity is negative in the forecast after the growth of historical trend stalling in 2010. The decrease of energy intensity seems likely due to continually increasing energy efficiency and the decreasing number of new leisure homes. In the future the intensity trend could be altered by new factors that are not yet seen in the historical data such as electrical vehicles (EV's) or policy changes.

The forecasted electrical energy consumption increases slightly until 2025 when the trend starts to decline. The changing trend is caused by the declining intensity. The confidence intervals are fairly wide, in large part due to uncertainty in the trend of intensity.

Model evaluation

In order to evaluate the models predicting capability back testing was used. The forecasts were made using different amounts of data while the rest of the data was withheld for validation. Forecasts were only made for structure and intensity. The forecast for activity is based on the population forecast produced by Statistics Finland. For this reason, activity cannot be assessed by back testing. Figure 6 shows the results of the forecasts and the actual historical trend of intensity.

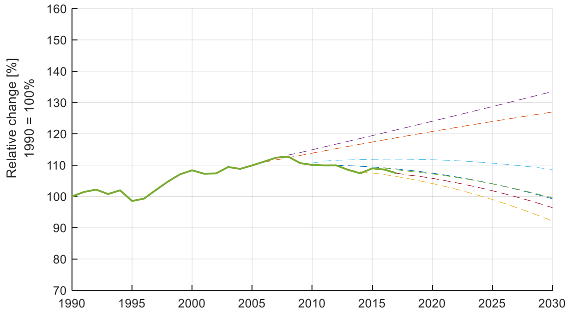

Figure 6. Forecasts of intensity (dashed lines) compared to actual trend (solid line) when estimates are done based on differing amounts of data.

From Figure 6 it can be seen that the two earliest forecasts deviate from the historical data significantly. This is mainly because the change in trend has not happened yet. After this the forecasts adapt to the change leading to smaller errors. A large source of error in the forecasts is the irregular trend. For structure the forecats follow the atual development very closely due to the almost linear trend.

The main sources of uncertainty in the forecast can be divided into three categories:

1. Errors and incompleteness of data used
2. Errors in decomposition
3. Errors in the ARIMA-model

The assumption of 35% temperature dependent load does not likely apply to all municipalities due to differences in heating methods and other variables leading to some error in the temperature correction.

The Laspayres decomposition method includes an error term, therefore the model is not considered complete. [9]

However, in this study the error term is not significant. The electrical energy consumption is assumed to be explained completely by living sparsity, population and electrical energy consumption per living-area which leads to some error. Furthermore, since the consumption data includes agriculture and electrified leisure homes whose consumption has low correlation with the selected indicator variables the error is further increased. The amount of leisure homes has grown significantly in the area so the impact to the total electrical energy consumption of the household and agriculture sector could be notable. The electrical energy consumption of agriculture in the case area is unknown but nationwide it has been relatively stable during the years 1990–2017 [6]. A better result could be obtained by further disaggregating the electrical energy consumption to different sub-sectors such as space heating, water heating and lighting and by separating the electrical energy consumption of agriculture and leisure homes from the data.

The uncertainty of the ARIMA-models used in this study is increased due to small amount of data points available and the partly irregular the trend of the intensity. The ARIMA-models also cannot take into account future changes that are not seen in the historical data. One likely change in the near future could be the increase of popularity of EV's.

These inaccuracies could be minimized in the future by using more accurate statistics and by removing the energy use of agriculture and leisure homes form the consumption data. More accurate forecasts for the individual components could be made by using additional data related to them. Furthermore, a more accurate decomposition method could be used. Further research is needed to assess the accuracy of the forecasts produced by the methodology in smaller regions such as for municipalities or DSO's distribution network areas.

CONCLUSION

Multiple factors affect the electrical energy demand of municipalities. These factors should be taken into account when forecasting future electrical energy demand. This study provides a methodology where the effects of a number of these factors have been studied by decomposition analysis and the electrical energy demand forecasts are formed from the individual components' forecasts.

The electrical energy demand forecasts are made for municipalities that have a declining population. The forecasts show that the declining population and energy intensity cause the electrical energy consumption to also decline when approaching the year 2030 despite the continued growing trend of living sparsity.

It is shown by back testing that when a sufficient amount of historical data is available the forecasts follow the actual historical trend for the case area. However, in the methodology there are multiple sources of uncertainty which should be taken into account when analyzing the results.

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