Forecasting electricity consumption based on smart metering case study in Latvia

ILZE LAICANE[1], ANDRA BLUMBERGA[2], MARIKA ROSA[3], DAGNIJA BLUMBERGA[4], ULDIS BARISS[5]
[1,2,3,4] Institute of Energy Systems and Environment, Faculty of Power and Electrical Engineering
Riga Technical University
Kronvalda boulevard 1, Riga, LV-1010
LATVIA
ilze.laicane@rtu.lv; andra.blumberga@rtu.lv; marika.rosa@rtu.lv; dagnija.blumberga@rtu.lv
http://www.videszinatne.lv

[5] The public limited company Latvenergo AS
Pulkveza Brieza iela 12, Riga, LV-1230
LATVIA
uldis.bariss@latvenergo.lv
http://www.latvenergo.lv

Abstract: - Purpose and rationale for this study is based case study research within the first smart metering pilot project in Latvia „Promotion of energy efficiency in households, using smart technologies". This pilot brings new opportunities for exploiting smart metering efficiency and reliability for boosting energy energy efficiency measures and demand response programs in household sector.

The overall question raised within this study is how electricity consumption in households will change in the future. Trying to answer this question the aim of the study has accordingly been to forecast electricity consumption in 500 „target group" households involved in this pilot.

By combining evaluation of baseline situation, the planned results from the pilot project and demand response predictions, 3 scenarios for forecasting has been presented. Based on various assumptions described in this study, the overall forecasting result shows that users' behaviour and demand response has a significant impact on future electricity consumption.

Finally, the paper provides further research directions for smart systems use in perspective to achieve energy efficiency goals in the future.

Key-Words: - Smart metering, electricity consumption, electricity forecasting, energy efficiency, household, historical data analysis, demand response

1 Introduction

In line with the EU total energy consumption reduction targets, still there is a growing need for improved means of evaluating policy instruments determining the purpose of promoting energy efficiency in the residential sector. Until now, energy efficiency measures at international and EU level have not provided the desired results and still there is a great potential to improve energy efficiency in household sector. The key factors determining energy efficiency requirements has been set by the European Parliament and Council Directive (2006/32/EC) of 5 April 2006 on energy end-use efficiency and energy services [1]. For Latvia it is a 9% reduction in energy consumption during the period from 2009 to 2016 [1]. Successfully reach this goal, increasing emphasis is being placed on involving every consumer in implementing energy efficiency measures. Action is needed instantly, especially now, because in recent years the final electricity consumption in the EU and Latvia by households increases.

Electricity consumption in the residential sector represents an important part of the total electricity demand. Moreover, in recent years, final electricity consumption by households increases. Energy Efficiency Status Report 2012 shows that between 2009 and 2010 residential energy consumption in the EU Member States increased by 3,6%. Household consumption accounted for 26.7% of total final energy usage in 2010 in the EU [2]. For

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Latvia, electricity consumption in residential sector amounted to 1,772 TWh in 2011, which represents 29% of total electricity end-use in Latvia [3]. Fig. 1 shows the total final electricity consumption and the share of the household electricity end-use consumption in Latvia from 2000 to 2011 [3].

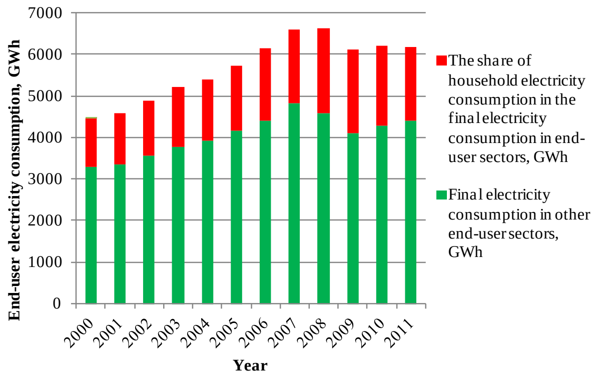

Fig.1. Total final electricity consumption in the end-user sectors and share of the household electricity consumption from 2000 till 2011.

As it can be seen in Fig. 1, in recent years the final electricity consumption in households increases. This is mainly due to economic growth, the increased level of social welfare, purchase of new electrical equipment, technological progress as well as real estate development and building construction.

Implementation of improved monitoring systems in households plays an important part in promoting energy efficiency in Latvia and other EU countries. Use of smart metering system in households has been identified as a promising pathway for achieving significant electricity consumption reduction. Smart metering system in households provides more detailed data collection and consumer segmentation resulting in more accurate forecast of electricity consumption in households. In this context, the European Union has set an ambitious target for 2020: to equip 80% of households with smart meters (DIRECTIVE 2009/72/EC, (2009)) [4]. However, it is clear that without additional feedback/information tools and metering services there is no benefit for the end-users.

JSC „Latvenergo", which is the largest electricity producer, trader and supplier in Latvia, has undertaken a major challenge and is currently implementing the pilot project „Promotion of energy efficiency in households, using smart technologies" – the first attempt to promote broader household involvement in energy efficiency measures using smart technologies in Latvia. Since smart meter implementation in Latvia is still in the initial stage and there is still no legal framework for smart metering development, in the context of this pilot project interaction between electricity companies, households, researchers and other stakeholders aiming for electricity savings will be provided.

2 Modeling approaches

2.1 Case study research

Purpose and rationale of this study is to forecast electricity consumption in households based on research on smart metering pilot case study. Within the pilot project 500 households have been installed smart meters replacing existing analog meters. „Target group" households will be dividend up into several groups according to their electricity consumption per month: for example, 0 – 200 kWh, 201-400kWh, 401-1000 kWh, 1001-2000kWh, 2000-4000 kWh, 4001 kWh - and above. In total, the pilot will involve 1000 households: 500 households („target group") with smart electricity meters and 500 households („control group") which will not receive smart electricity meters but this group will serve as a „reference" group for the comparison of data before and after the project. The pilot duration is from 2013 to 2018.

The goal is to achieve CO_2 emission reductions of 10% per year from „target group" households. Other important objectives of the pilot are: 1) to provide the households included in the project with information on actual electricity consumption and carbon dioxide emissions; 2) to promote the active participation of households in energy efficiency and conservation measures; 3) to explore possibilities for promoting energy efficiency in households using smart technology opportunities. To successfully reach these goals pilot also involves the researchers of Institute of Energy Systems and Environment of Riga Technical University (RTU IESE researchers) who will contribute to the preparation and presentation of information for „target group" and „control group" households with or without the collaboration of JSC „Latvenergo".

The research idea within the pilot is that RTU IESE researchers will conduct research and analysis on the impact of information on end-user behaviour and reduction of electricity consumption. The aim is to understand main differences and key factors influencing end-user bahavior and motivation to reduce electricity consumption, depending on the volume and frequency of the information provided. 4 research groups are set up in the course of further study:

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1) „Target group +": 250 households have been provided with the usual information package from JSC „Latvenergo" and additional information from RTU IESE researchers;
2) „Target group –": the other 250 households have been provided with the usual information package from JSC „Latvenergo" , but without additional information from RTU IESE researchers;
3) „Control group +": 250 households without any information have been provided from JSC „Latvenergo, but with additional information from RTU IESE researchers;
4) „Control group -": the other 250 households without any information have been provided from JSC „Latvenergo" or RTU IESE researchers.

In general, the information activities provided by IESE researchers will include direct meetings, seminars, various thematic events, regular consultations, evaluation and analysis of results.

The implementation of pilot has started at the beginning of 2013 with households survey questionnaire. Smart metering data reading from target group" households has started from April 1, 2013. Currently, the compiled information on questionnaire responses from 1000 households are not available jet. However, historical data on „target group" electricity usage ar availabe.

The overall objective of the study is to forecast electricity consumption in „target group" based on evaluation of baseline situation, the planned results from the pilot project and demand response predictions within the case study research.

2.2 Baseline situation analysis

Evaluation of baseline situation is based on „target group" historical electricity consumption data collection and analysis. 60 months of historical electricity consumption data form „target group" is collected from the electricity suplier JSC „Latvenergo" customer service and billing system (data collection period is from 2008 until 2012). Due to some technical reasons, all historical data of 500 households were not available for the full analysis. Table 1 summarizes „target group" households' electricity consumption data for the period from 2008 until 2012 as well as shown the number of households have been provided historical data for each particular year. This entries in the Table 1 consists of total electricity consumed annually in „target group" households expressed in megawatt-hours (network losses is not included).

Households' consumers in Latvia may use three payment methods for the consumed electricity: self declaration method (monthly self-reading and payment), according to adjusted payment plan (payment of equal monthly consumption rate through the year) or according to electricity supplier bills (monthly bills on actual electricity use). From the obtained data it can be concluded that the majority of these households made payments using self declaration method. Most of them have made the payments for almost the same amount of electricity consumption for several months both in winter and in summer.

Table 1.

„Target group" households' electricity consumption data for the period from 2008 until 2012.

Year	2008	2009	2010	2011	2012
Electricity consumption per year, MWh	5351,6	5418,2	6598,4	5927,3	6057,3
Number of huoseholds	413	423	430	430	434

In this study historical data analyses is performed using computer program Microsoft Excel and computer program software Stat Graph. Analyzing electricity consumption data for „target group" households, it can be seen that starting from 2008 the total electricity consumption in households has increased. Electricity consumption in 2009 compared to 2008, has increased by 1%. In turn, the electricity consumption in 2010 compared to 2009, has increased by 22%. However, in 2011 electricity consumption decreased by 10% compared with 2010. But in 2012 can be observed electricity consumption growth by 2% compared with 2011. Total household electricity consumption data for the period from 2008 until 2012 is 29352,75 MWh.

The essence of the results has been presented in-depth analyses of the historical data.To assess whether households electricity consumption has been changed considerably from year 2008 until 2012, mathematical and statistical data analysis were performed. Data processing was performed using the computer program software „Stat Graph" which is one of the most commonly used statistical method of analytical data analysis.

In order to evaluate and compare changes in „target group" households' electricity consumption for a given period, it has been performed analysis of cluster based historical electricity consumption breakdown data aggregation. Analysis is based on 500 households classification by electricity consumption rate per month (in total 21 clusters). Data sorting is based on clustering households electricity consumption into intervals of 200kWh/per month (for example, for the 1.cluster the lower limit is 0 kWh/ per month and the upper limit is 200 kWh/per month, for the 2.cluster the lower limit is 201 kWh/ per month and the upper limit is 400 kWh/per month, and so on). Each cluster contains of households with similar energy consumption characteristics.

The histogram method was used for a representation of households distribution into clusters depending on each household electricity consumption level for each year (see Fig. 2). For this purpose was used the mathematical function „Frequency Histogram" reflecting number of household clusters and their frequency. Households' clusters (or electricity consumption groups) are plotted on the x axis and their frequencies on the y axis.

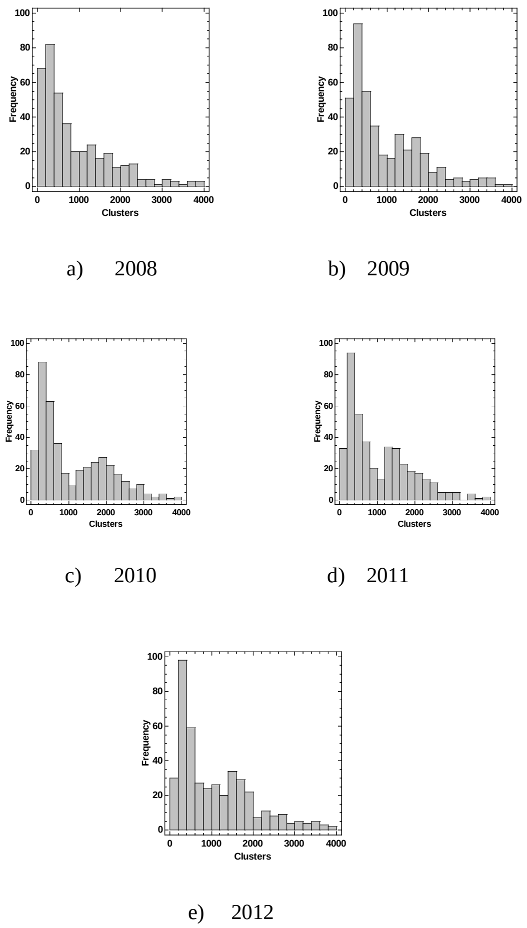

Fig.2. Households' cluster histograms during the period from 2008 until 2012.

Histogram illustrates the breakdown of households electricity consumption and calculates the sum of values (absolute frequency) of how many households are included in each identified cluster (see Fig.2). As can be seen from Fig.2 the highest share of households for all years are in the 2nd cluster (where electricity consumption rate is from 201 to 400 kWh/month): on average 21.6% of total households. Quite similar share of households for all years are in the 1st cluster (that consume the least amount of electricity consumption, i.e. 0-200 kWh/month) and 3rd cluster (401-600 kWh / month): on average, 10% and 13.6%, respectively. In addition, significant frequency changes were occured in 1st cluster: starting from 2008 the number of households in 1st cluster decreased from 16% to 7% in 2012. Total number of households represented in the first three clusters are on average 45% share of all households.

The other relatively large households' cluster group consists of households with electricity consumption rate from 601 – 2000 kWh/month. The average share of households in these clusters are: in 4th cluster – 8%; in 10th and 5th cluster – 5%; 6th cluster – 4%; 7th, 8th, 9th cluster – 6%. Total number of households represented in the clusters 4th – 10th are on average 39% share of all households. Analysis of changes in number of household and frequency in these cluster shows no significant changes during the period from 2008 until. Some groups showed a slight increase, others – a slight decrease, but changes do not exceed the 2-3% per year.

Households' clusters with consumption rate from 2001 - 4000 kWh/month (i.e. 11th – 20th cluster) represents on average 14% share of all households. The latest 21st cluster (with the highest level of electricity consumption i.e. more than 4001 kWh/month) represents on average 2.5% share of all households. In addition, during the period from 2008 to 2012 the number of households in 21st cluster decreased: 15 households in 2008 (4% share of total households) and 7 households in 2012 (2% share of total households).

In addition, it should be noted that the obtained data does not offer the required detailed information on households specific features (for example, number of family members, user's personal characteristics, socio-economic conditions, time spent at home during weekdays, number of electrical appliances, mean indoor temperature in wintertime, building properties, heating system, energy-saving installations etc.). Therefore, in the context of lack of essential detailed data on households, it can not be performed analysis of independent variables impact assessment, load curve variations among similar households, as well as seasonality effect evaluation.

2.4 Demand response

Notwithstanding the benefits of increased demand response activities in the past years, residential electricity consumption is still rising. Although many appliances are becoming more efficient, the number of appliances is rising, appliances are used more often and for longer periods of time, and many appliances have more functions or special features that require more electrical energy. The Baseline scenario of European Energy and Transport 2030 report shows a progressive slowdown in the expansion of electricity consumption. However, during period up to 2020 for residential sector electricity demand is expected to increase 1.5% annually than reducing to 0.7% annual increase [5]. The trend considers that the proliferation of new electricity usage continues as in the recent past. However, for the longer term the scenario takes into account energy efficiency improvements in appliance design and other energy efficiency measures. Also US Energy Information Administration has forecast that electricity demand in US grows by 0.7% per year through 2035 in the residential sector [6].

There are a number of main drivers for electricity consumption in residential customers. On the one hand it is actual households' appliances, country specific consumption habits, price of electricity and economic situation in the country. Also a policy measures to improve energy efficiency are important factors. For example, EU decision to stop production of incandescent bulbs or information activities, like labelling energy efficient equipment (Energy Star). On other hand, residential customers should have information about their actual electricity consumption to increase motivation and to understand what happening in their houses. It has been shown in number of smart metering pilots that feedback programs, such as detailed invoice, access to Web sites with information about their electricity consumption etc., can provide energy savings up to 5-9% [7]. Residential consumer could get different types of feedback about their electricity consumption:

1. direct feedback (consumer learning by looking): self-meter readings, in-house energomonitors, interactive feedback via utility or service provider web page, „Ambient" devices, simple energy measuring devices;
2. indirect feedback (data processing by utility company): detailed bills based on detailed data readings, historical and comparative information, annual or quarterly energy reports.

For households, there is a great potential for encouraging the adoption of demand response programs. Several authors have analysed the impact of implementing different pricing mechanisms, such as time of use billing, demand based pricing, etc. [8-10]. Another aspect of demand response programs is various pricing schemes that are designed to encourage customers shift consumption away from peak consumption periods to lower consumption periods so lowering distribution and supply costs. However, these scheme tend to bring lower payments for consumers and reducing peak loads for supply side supporting about the same average electricity consumption level [11].

Demand response activities can contribute to reduction of electricity prices, reducing and shifting demand during peak hours so reducing the higher marginal cost generation and decrease grid reinforcement costs. However, there are a few but common factors that currently undermine effective demand response activities in Europe[12]:

1) the lack of real time price information reaching consumers;
2) regulated retail prices in some countries;
3) out-dated metering technologies;
4) system operators mainly focused on supply side resources.

Exactly out-dated metering technologies could be identified also as a main factor hindering demand response programs in Latvia. Another aspect that have to be taken into account is an average household's electricity consumption in Latvia that is relatively low (approximately 140 kWh/per month) in comparison with other EU countries. At the same time as already mentioned electricity consumption of residential sector is 26,7% from total consumption in the EU (data for year 2010) and that is widely expected to grow thus underlining its importance for energy efficiency measures.

Countless studies related to comparison of household electricity consumption with end-users' behavioural characteristics have been reflected recently [13-28]. The main conclusions from these studies highlighted that provision of information to end-users of their energy consumption has contributed to energy consumption savings. Some of these estimations shows that 10% of energy savings can be achieved due to changing end-users habits and daily routines. Based on these estimations, it can bee forseen that aim of the pilot – 10% reduction of electricity consumption due to provision of information to end-users – can be achieved.

3 Results

One of the main tasks adressed in this study is to develop electricity consumption forecasting (hypothesis) for „target group" households via smart metering pilot project.

To be able to predict how the electricity consumption in households will develop in the future, we relay on the following factors:

1) current trends of household electricity consumption changes (see Fig.1);

2) demand response expierence in Europe;

3) historical electricity usage data analysis and baseline situation evaluation for the case study (smart metering pilot);

4) forecasts for electricity consumption increase by 1.5% per year compared to base consumption in 2012 – that is 6057,29 MWh in total of 434 „target group" households. This assumption is applied to all scenarios.

On the basis of the overall trend, which shows that household electricity consumption will increase in future, it has been foreseen electricity consumption growth in „target group" households as well. Households electricity consumption forecasting from 2012 to 2020 were performed based on three developed scenarios:

1) baseline situation forecasting scenario;

2) planned results of the pilot forecasting scenario;

3) demand response forecasting scenario.

Our hypothesis of electricity consumption forecast in households by 2020 is represented in Figure 3. Year 2012 was adopted as a reference year regarding the comparison of the scenarios.

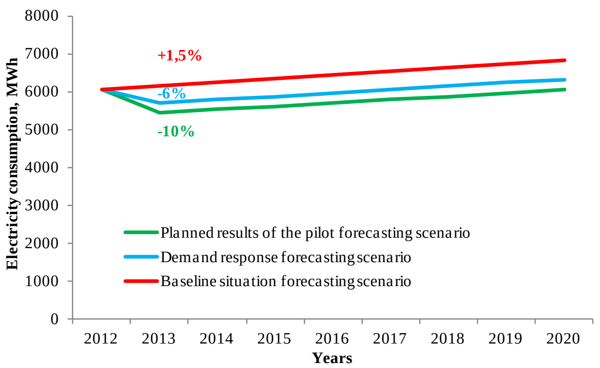

Fig. 3. Households electricity consumption forecasting from 2012 to 2020 in case of three scenarios (planned results of the pilot, baseline situation and demand response scenarios).

In the baseline scenario it has been foreseen the increase in electricity consumption by 1.5% per year compared to base consumption (see red curve in Fig.3). The planned results of the pilot scenario states the electricity consumption reduction of 10% compared with the historical consumption in the baseline situation i.e. year 2012 (see green curve in Fig.3). This reduction can be achieved through a variety of information resources provided to end-users. In the context of this pilot 10% reduction are expected to be achieved with the additional efforts and active dissemination of information to end-users (for example, stakeholder meetings, organised seminars, discussions, etc. activities contributed to user's behaviour change). And finally, in demand response scenario it has been foreseen the decrease of 6% compared with the baseline situation (see blue curve in Fig.3). Electricity consumption reduction of 6% can be achieved as a „simple user reaction" on the detailed billing and the Internet.

4 Conclusion and discussion

By combining several methodological approaches for forecasting with historical electricity usage data, 3 scenarios for forecasting within the case study of smart metering pilot in Latvia has been presented.

Comparing with the historical consumption the baseline scenario estimated increase in electricity consumption by 1.5% per year, however, in turn, the planned results of the pilot and demand response scenarios is expected electricity consumption reduction of 10% and 6%, respectively. In fact, not an easy task to compare results, because of electricity consumption is affected by various independent factors, including factors resulting in electricity consumption growth (for example, increase in number of household members).

Forecasting results are suitable not just for prediction of electricity demand for households involved in the pilot, but also for testing different policies and flexible demand strategies. This strategy testing process will be required in order to explore further solutions in smart metering development in Latvia for long term perspective.

This pilot outlines new directions for further research in perspective:

1) in future developments, forecasting should adjust real time information on feedback and end-users behavioural change in order to increase forecasting prediction accuracy;

2) further research on investigation of factors influencing end- user behavior, in–depth analysis of electricity consumption and CO_2 emissions savings due to smart metering. This research will involve both developed and verificated methodology for evaluation of electricity consumption changes form households based on multi criteria analyses and investigation of various aspects – resident's personal, soci-economic characteristics, households

structural characteristics, electricity consumption, energy related behavior/attitude/awareness, information/feedback impact assessment etc.);

3) in the context of policy-making and long-term energy efficiency goals further assessment of smart metering development in Latvia is required.

This will be discussed in future research papers.

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