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Assessment of changes in households' electricity consumption

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Abstract. The purpose of this research is based on a literature review analysis mainly based on the evaluation of the effectiveness from the smart metering implementation as a behavioural feedback on the consumer daily lives and their motivations on reducing energy consumption. A feasibility analysis of the improved household monitoring system with integrated smart meters and assessment of changes in residential electricity consumption were performed. In this study, an initial assessment of the pilot project for smart meters installation were conducted; the preparation of the questionnaire survey for involvement of households in the pilot project were described; a literature review on the factors effecting users' behaviour were conducted; and based on this literature review an assessment of household electricity consumption and CO_2 emission savings were provided. This research serves as a basis for further research to explore factors influencing the user behaviour and to make analysis on electricity consumption reduction in households, as well as the further development of smart metering in Latvia.

Key words: electricity consumption, energy efficiency, assessment of electricity savings, smart metering.

INTRODUCTION

Latvia is on the path of green energy to reach the renewable energy target of 40% in 2020 (DIRECTIVE 2009/28/EC, (2009)). Different aspects affect the possibility of whether the target will be met or not. In line with the EU total energy consumption reduction targets, a growing emphasis is being placed on involving every consumer in the implementation of energy efficiency measures. Moreover, in recent years, final electricity consumption by households increases. Until now, energy efficiency measures at international and EU level have not provided the desired reduction of electricity consumption, and still there is a great potential to improve energy efficiency in the household sector. In order to promote energy efficiency in all end-use sectors, the European Parliament and the Council on 5 April 2006 adopted the Directive 2006/32/EC on energy end-use efficiency and energy services, determining national targets for final energy consumption based on international commitments to improve energy efficiency on the end-user side. For Latvia it is a 9% reduction in energy consumption during the period from 2009 to 2016 (DIRECTIVE, (2006)).

There are quite extensive end-user energy consumption reduction possibilities, however significant energy savings can be achieved only by changing the habits of electricity users. Several studies have concluded that monitoring of energy consumption is an effective control tool and information source for energy consumers, which creates a significant impact on consumer's behaviour and also contributes to the reduction of household electricity consumption (Almeida et al., 2006; Lomas et al., 2006; Firth et al., 2008; Vassileva et al., 2011; Vassileva et al., 2012). The authors of these studies have estimated that due to the introduction of energy consumption monitoring systems 10% of energy savings can be achieved.

In 2008 Latvia adopted its first National Energy Efficiency Action Plan (NEEAP) which set the total final energy saving target of 3,483 TWh in 2016 and lists key energy efficiency measures (Cabinet of Ministers Order No. 266, (2005)). Currently the only legal act that sets targets for promoting end-user energy efficiency and performing of energy efficiency monitoring as well as providing information to end-users (Energy End-use Efficiency Law, (2012)). The Second National Energy Efficiency Action Plan, adopted in 2011, determines the goal of 2,701 GWh energy savings in the household sector (i.e. 77.5% of the total final energy savings). One of the main priorities are building insulation measures for promoting energy end-use efficiency in households (Cabinet of Ministers Order No. 460, (2013)).

The final electricity consumption in households in Latvia accounts for a significant share of the total final electricity consumption, for example, in 2011 it was 1,772 GWh, or 28.6% of the total final electricity consumption (Central Statistical Bureau of Latvia, (2013)). Fig. 1 shows the total final electricity consumption and the share of the household electricity end-use consumption in Latvia from 2000 to 2011.

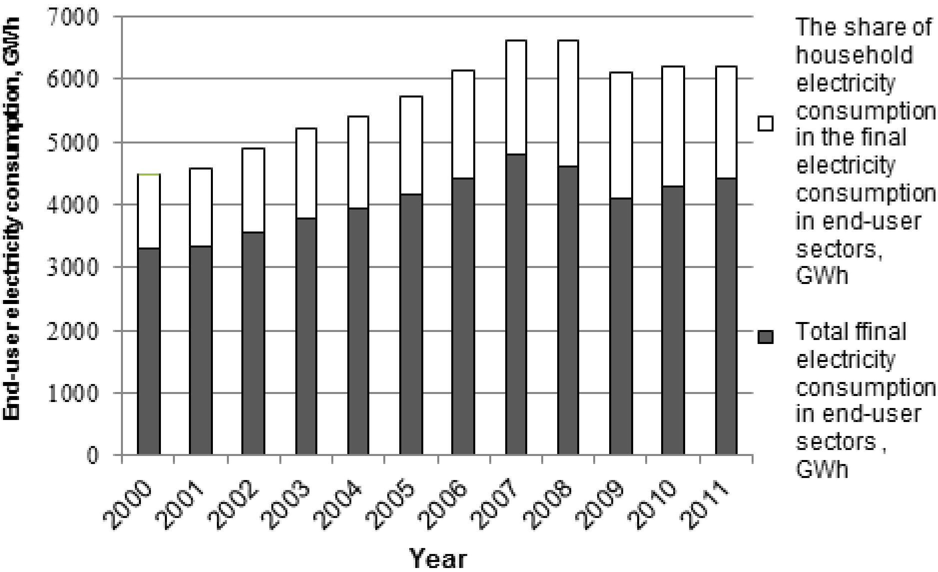

Figure 1. Total final electricity consumption in the end-user sectors and share of the household electricity consumption from 2000 till 2011.

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, purchase of new electrical equipment as well as real estate development and building construction.

At the beginning of 2013 the *Ministry of Economics* of the *Republic* of *Latvia conducted an* informative report on the risks of the increase of electricity prices and it's limiting and evaluated the related risks of the increase in electricity prices in the future (Cabinet of Ministers protocol No. 2, (2013)). This assessment includes the evaluation and modelling of the final energy intensity in the context of the development of Latvian energy scenarios till 2030 and is shown in Fig. 2.

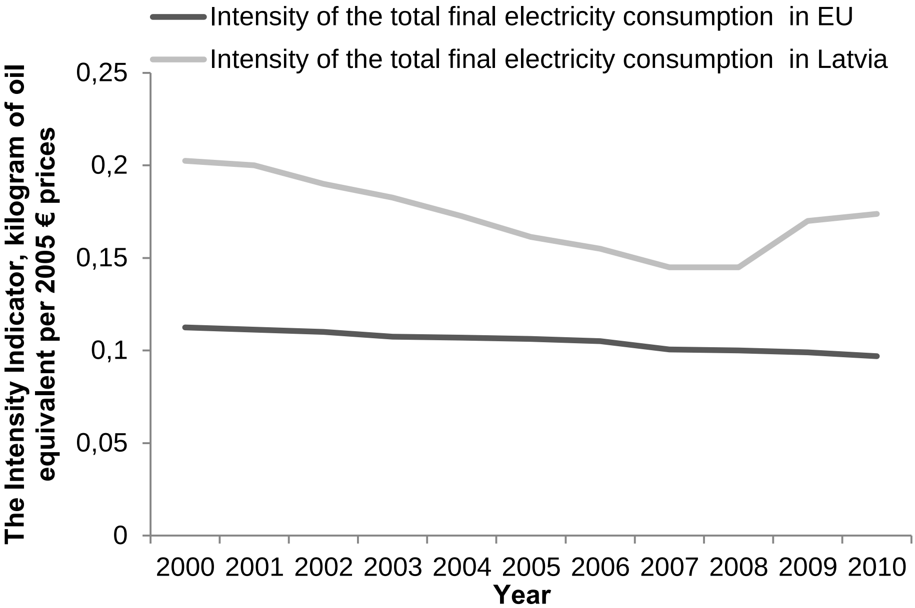

Figure 2. The comparison of the total final energy consumption in Latvia and the EU. Adapted from (Cabinet of Ministers protocol No. 2, (2013)).

The indicator of the final energy consumption in Latvia is significantly lower than the average indicator of the final energy consumption in the EU. This means that at the current level of domestic electricity consumption in Latvia is approximately 2 times higher than at the same level of domestic household energy use in the EU: households in Latvia spend more on energy consumption from their budget in comparision with other EU countries.

There are various tools for analysing electricity consumption, but in order to achieve sustainable energy consumption, the most suitable tool is energy consumption monitoring. It is an effective electricity consumption control tool and information source for energy consumers contributing to the reduction of household electricity consumption. In recent years the development of legislation and regulation for smart metering in Europe has become highly dynamic. The EU has set an ambitious target for 2020: to equip 80% of households with smart meters (DIRECTIVE 2009/72/EC, (2009)). This goal can be achieved by providing consumers with quality information on smart systems and technologies. The development of smart technologies and services and the implementation of smart metering in Latvia is one of the slowest compared to other EU countries (Renner et al., 2011). Currently there is no national strategy, either for smart technology, nor legislation, nor any vision for the future.

Use of smart systems and technologies is an effective solution for consumer involvement in energy efficiency. The feasibility research on the factors that influence user behaviour and household electricity consumption, found that the information on smart systems and technologies significantly affect user's behaviour and increases awareness of environmental and energy issues. Therefore, it is essential and vital to provide users with quality information on electricity consumption and energy efficiency, using a variety of information resources that contribute to the motivation to reduce consumption (Laicāne et al., 2012).

MATERIALS AND METHODS

The purpose of this research is to make an assessment of changes in household electricity consumption based on an initial assessment of the pilot project for the installation of smart meters in households.

To be able to predict how the electricity consumption in households will develop in the future it should be based on the following factors: current trend of the household electricity consumption from 2001 till 2011 (Fig. 1), the assessment of electricity consumption forecasts for the future. Electricity consumption is affected by several factors: the increased level of social welfare and technological progress will contribute to the increase in electricity consumption. In turn, energy efficiency and a shrinking population will contribute to a decrease in electricity consumption. It can be assumed that in general the growth in electricity consumption in the future can be observed.

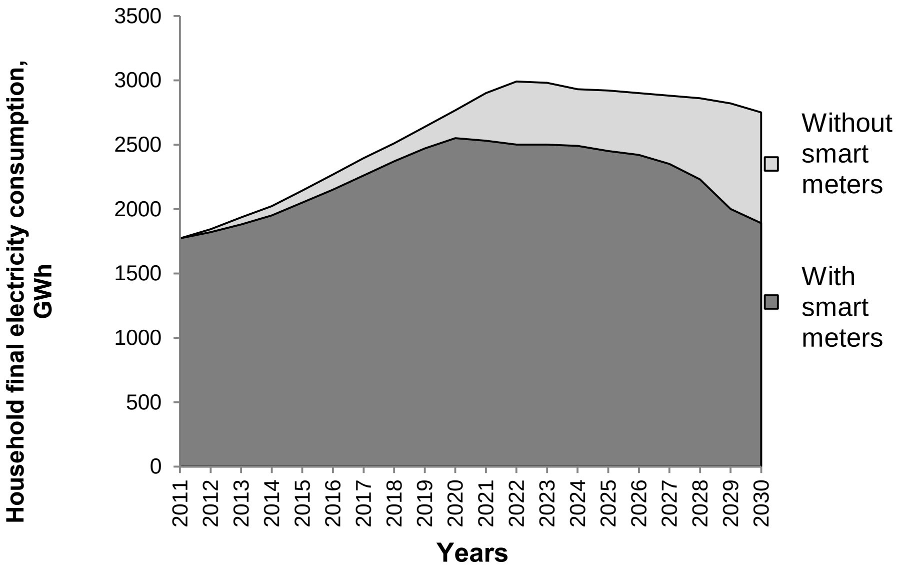

Figure 3. Household's final electricity consumption forecast for 2030 in cases with and without smart meters.

Based on this prediction, the hypothesis was raised that in the case of the installation of smart meters into households, the rate of electricity consumption growth will be lower than in the case without smart meters. Our hypothesis of the final electricity consumption in household sector by 2030 is shown in Fig. 3. It has been foreseen that without the installation of smart meters in households, this growth rate will be quite high, i.e. increase by 6% every year (Fig. 3). In the case of smart meters, at the begining there will be a trend of electricity consumption growth (approximately 3% every year), but starting from 2020 electricity consumption will decrease. In 2030 the level of electricity consumption in households will be at the current electricity consumption level (i.e. 2012).

With the study included in this research, the aim is to achieve the following tasks:

1. to conduct an initial assessment of the questionnaire survey aimed at households involvement in the pilot project for smart meters installation in 500 Latvian households, which provides the basic baseline data for the evaluation of electricity consumption and CO_2 emission reduction;

2. to make the assessment and analysis on the factors influencing user behaviour that contributes to electricity consumption reduction based on the literature review (in case of available various information tools, smart meter displays, web sites, informative billing and other factors).

The survey questionnaire design and formulation of questions

Currently, JSC 'Latvenergo' is implementing the pilot project of installation of smart meters in households: it is the first project in Latvia which engages the involvement of households in the promotion of electricity efficiency through the installation of smart meters. The project will involve 1,000 households: 500 households (the 'target group' of the pilot project) where existing analog meters will be replaced with smart electricity meters. Along with the target group there will also be a 'control group' of 500 households which will not receive smart electricity meters. This group will serve as a 'reference' group for the comparison of data before and after the project. The goal is to achieve CO_2 emission reductions of 10% or 267,975 kg CO_2 year^{-1}.

The research idea underpinning the project is that RTU IESE researchers will conduct research and analysis on the impact of information on the behaviour of electricity customers and on the reduction of electricity consumption (project duration from 2013 to 2018) and the major research objectives and methodology of the study reflected in the previous study (Laicāne et al., 2012).

The survey questionnaire is formed from the combination of qualitative (i.e. questions related to attitude and awareness) and quantitative approach (questions related to socio–economic issues) including the questions about household characteristics, number and type of electrical appliance and usage *habits,* level of knowledge, behaviour, etc. (Brandon & Lewis, 1999; Genjo et al., 2005; Ek & Söderholm, 2008; Ouyang & Hokao, 2009; Ek & Söderholm, 2010; Vassileva et al., 2012; Vassileva et al., 2012).

The survey's questions are classified in four main categories and subquestions in order to obtain more detailed information (Table 1). The survey questionnaire includes a list of the main types of electrical appliances used in households, in total 65 electrical appliances. The survey questions were divided into different parts, similar to those that have already been used in previous similar studies. Currently, there are no available questionnaire responses. In this research the aim is to conduct a preliminary assessment of the survey questionnaire that will be essentially important and useful for further studies and in–depth analysis of electricity consumption and CO_2 emissions savings due to smart metering.

Table 1. The survey questionnaire classification: four main categories of the questions and description of the questions

The categories of the questions	Description of the subquestions
Questions on Household's personal characteristics	Questions on respondent's language (Latvian/Russian), gender (female /male), age, number of people living in household (adults, young children, pensioners, grandparents, other relatives, babysitter, etc.), education, the household's monthly income.
Questions on use of electrical appliances and electricity consumption	Questions on average electricity consumption per month, types and number of electrical appliances, usage *habits,* how often each member of the household use the electrical appliances (how often on weekdays and on weekends), how many of them are older than one year, how the respondents will describe and evaluate the necessity of their electrical appliances (certainly indispensable and can not do without it, could be used less frequently, can be avoided).
Questions on the level of awareness/behaviour/attitude on electricity consumption and energy efficiency	Questions on *maintained temperature* in the building, what electricity efficiency measures are implemented in the household (for example, whether are used double or triple glazed windows, exterior walls or roof insulation, are being used energy saving light bulbs), are installed/used *any energy extraction equipment* from alternative energy sources (wind generators, solar collectors), questions about the behaviour and *habits* when using electrical appliances (are listed some of the modes/habits for electrical appliances, allowing to assess how the respondent uses any specific electrical appliance), the level of knowledge/awareness/attitudes towards electricity consumption, are residents interested in electricity consumption and energy efficiency, are residents interested in receiving information on the comparison of typical (average) electricity consumption of similar households, how they would like to get such information in future (in their bills, as text message to their mobile phone, in the Internet or other types of information sources).
Questions on household's structural characteristics	Questions on type of building (detached, row house, apartment) building area (m^2), year of construction, type of building, type of heating (central heating, boiler, electric heating or other type), type of ventilation (natural ventilation, fans, air heaters or blowers, air extractor, heat recovery ventilation system or other types), the building materials used in construction.

The assessment and analysis of factors influencing user behaviour

Although smart systems and smart technologies are relatively common, little research has been done in respect to consumer experience with smart meters and systems.

Darby (2006) analysed user's behaviour and the effect of feedback on household electricity consumption after the implementation of smart meters. Darby (2006) provided the following classification of feedback:

- direct feedback (immediate, from the meter or display monitor, for example, electricity consumption data);
- indirect feedback (feedback that has been processed in some way before reaching the electricity user, for example, billing).

Based on the cross-country analysis of existing practice Darby (2006) found that the average energy consumption reductions due to direct and indirect feedback that can be achieved are, respectively, 5–15% and 0–10%. The greatest energy savings due to indirect feedback in the range of 0–12% can be achieved through informative electricity bills. Darby (2006) also points out that the most effective solution is to combine direct and indirect feedback: direct displays in combination with improved billing which is the basis for future electricity consumption decreases (up to 20%) and CO_2 emissions savings. In addition Jensen (2003) found that by improving bills with 'environmental information' (for example, providing information on the impact of energy consumption on climate change, on CO_2 emissions, etc.) can be achieved 20% energy savings.

Later Fischer (2008) conducted a review to find out which feedback is the most effective with regards to energy consumption reduction. Fischer (2008) highlighted some criteria for the evaluation of successful feedback:

- the information provided is based on actual consumption;
- is given frequently (ideally, daily or more);
- involves interaction and choice for households;
- involves appliance–specific breakdown;
- is given over a longer period;
- may involve historical or normative comparisons;
- is presented in an understandable and appealing way.

Later, Darby (2010) continued with his literature review and found that increasing the frequency of feedback (for example, if users are often sent bills) consumers are more motivated to reduce energy consumption. Darby (2010) pointed to the efficiency of online feedback (Internet): it is relatively inexpensive, can be updated rapidly, and can ensure access to all the detailed information on daily/monthly consumption and there can be reflected the demand curve for the nation or region indicating CO_2 emissions and electricity consumption constraints (limitations).

Stromback et al. (2011) conducted a study based on data collection of about 100 smart metering pilot projects and found that the project results were dependent on a number of variables. Stromback et al. (2011) classified these variables into the following categories:

1) particularly important (region of pilot, participant segmentation, participant education, automation, combining dynamic pricing and feedback);

2) varied impact across pilot type but the results were nonetheless robust in one of the pilot types (length of pilot duration, number of participants, interaction with participants);

3) provided interesting results but the findings were not robust enough to be judged definitive and deserve further research (feedback content).

RESULTS AND DISCUSSION

Based on the conclusions and findings from the several studies described above, the user's behaviour has a significant impact on household electricity consumption. According to the literature review done, it is important to evaluate the individual character traits and habits of each user. Therefore, the use of the continuous monitoring of electricity consumption plays an important role in order to analyse changes of electricity consumption.

To assess the changes of CO_2 emissions it is important to choose independent variables as well as assess the relevance of each variable in CO_2 emissions reduction. Based on the literature review, the evaluation of changes of CO_2 emissions are dependent on several key factors: electricity consumption, user behaviour, information and feedback, technology development.

Estimated changes of CO_2 emissions from households can be described by the following formula:

$$\Delta CO_2 = f\{E, Ub, In, Td\}, \tag{1}$$

where ΔCO_2 – changes of CO_2 emissions from households, t; $f\{E, Ub, In, Td\}$ – the function of the variables, where E, Ub, In, Td are electricity consumption, user behaviour, information and feedback and technology development, respectively.

Changes in CO_2 emissions depend both on the specific variables and conditions affecting them. Electricity consumption depends on the types and numbers of electrical appliances, habits of use, electricity consumption, level of knowledge and attitudes towards electricity consumption, awareness of environmental and energy efficiency issues in the household and household structural characteristics (type of building, building area, construction year, type of heating, building location area and other information). User's behaviour is influenced by several factors: users' personal and socio-economic data (age, gender, native language, education, number of persons in household (children/adults), time spending in household, household income and other factors). The impact of feedback on user's behaviour is characterised by many factors that determine the relevance and importance of the feedback: frequency of feedback, duration, content, distribution, performance of presentation, comparisons, additional information. Technological development is affected both by the general technology development factors and standards, as well as a variety of political and regulatory decisions on sustainable energy consumption and promotion of energy efficiency.

An assessment of the potential CO_2 emission reduction in the case of implementation of smart metering based on the factors highlighted in the literature review is performed. In accordance with the pilot project the determined electricity performance is to achieve greenhouse gas (CO_2) emission reduction of 10% per year i.e., 267.975 t CO_2/ per year. Consequently, the initial estimation of CO_2 emissions in baseline or reference situation is 2,679.75 t CO_2 year^{-1}. The evaluation period was adopted from 2012 (a reference year) till 2020.

System of equations for the planned and the theoretically estimated CO_2 emission reduction, respectively, can be described by the following equations (2) and (3):

$$CO_{2planned}=\sum f(i,j) = \sum CO_{2i}-(CO_{2i}\times\Delta CO_2) - \ldots - CO_{2i+8}-(CO_{2i+8}\times\Delta CO_2), \qquad (2)$$

$$CO_{2estimated}=\sum f(i,j) =CO_{2i}-(CO_{2i} \times\Delta\, CO_{2i}\, f\{E, Ub, In, Td\}) - \ldots$$
$$\ldots - CO_{2i+9} - (CO_{2i+8} \times\Delta CO_{2i+8}\, f\{E, Ub, In, Td\}), \qquad (3)$$

where $CO_{2planned}$ – achieved CO_2 emissions for the pilot project at the end of the modelling period, t; i – describes the year of the simulation period, i.e. from 2012 till 2020; ΔCO_2 – the indicator of the pilot project energy efficiency performance 267,975 t CO_2 year^{-1}, i.e., 10% reduction; CO_{2i+8} and CO_{2i+8} – CO_2 emissions for each modelling year, i.e. from 2012 till 2020; $CO_{2estimated}$ – the estimated CO_2 emissions at the end of the modelling period; $\Delta\, CO_{2i}$ f{ E, Ub, In, Td} and $\Delta\, CO_{2i+9}$ f{F E, Ub, In, Td} – are the independent variable functions of CO_2 emission reduction in the case of the estimated results, different for specific simulation year in according to equation (1).

The comparison of the planned and the theoretically estimated results of CO_2 emissions reduction till 2020 are shown in Fig. 4. For a reference year (2012) the planned and estimated CO_2 emission reduction results were equal: 2679,75 t of CO_2.

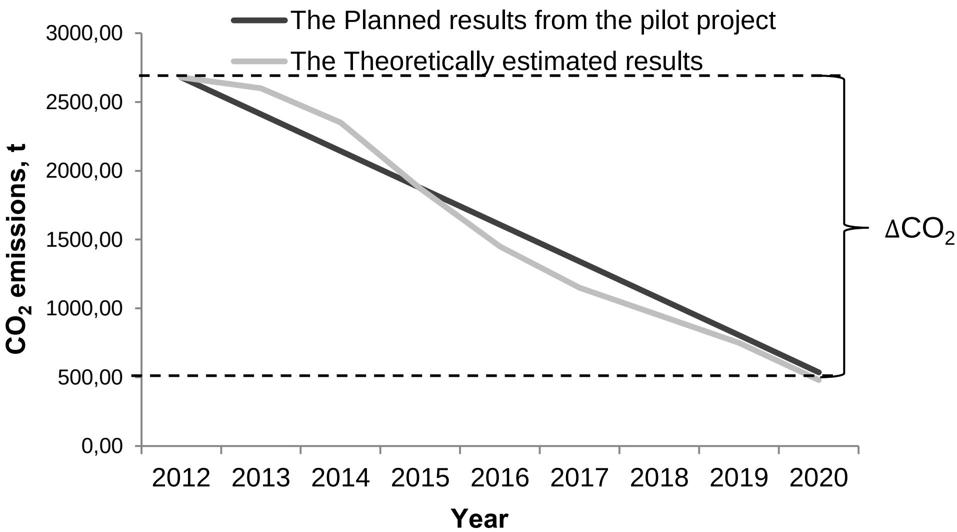

Figure 4. The graphical comparison of the planned and the theoretically estimated CO_2 emissions reduction rates due to smart meters installation by 2020.

The trend of CO_2 emission reduction for the pilot project over the years is shown as the constant changes (dark gray curve in Fig. 4). Evaluation of the potential CO_2 emission reduction are based on the several studies estimations on electricity consumption savings from smart meters ranged about 5–15%. As household electricity consumption is affected by various factors over time described above (see formula (1)), it was assumed that CO_2 emission reduction will not change in the same range every year, but will change dynamically (see Fig. 4 light gray curve).

The light gray curve in Fig. 4 shows the trend of estimated CO_2 emission reduction over the years. It was assumed that at the beginning CO_2 emissions reduction, in 2013 and 2014, probably will not reach the goal of 10% CO_2 emissions reduction compared with the baseline situation, and CO_2 emissions reduction will be, respectively, 8.6% and 9 %. However, over time the level of awareness and knowledge of the users will increase due to a variety of information resources, as well as direct communication tools (stakeholder meetings, seminars, organised activities, discussions, etc.) and indirect communication tools (informative billing, web based information and other forms of communication). It will contribute to user's behaviour change, thus the reduction rates of CO_2 emissions will grow: in 2015 reduction of 10.1%, in 2016 and 2017 CO_2, respectively, 12.7% and 12.3%, but from 2018 till 2020 there will be a steady reduction, around 10%.

CONCLUSIONS

This paper presents the initial investigation of the advanced household monitoring system with smart electricity meters and it's feasibility for Latvia's situation. The description of the survey questionnaire for the pilot project, literature analysis on the factors affecting user's behaviour and assessment of the potential CO_2 emission reduction in the case of implementation of smart meters being performed.

Based on the estimations on electricity consumption savings, considerable reduction of CO_2 emissions can be achieved due to smart technologies: 5–15% due to direct feedback from smart meters and 20% due to indirect feedback for improved bills. The assessment of the planned and the theoretical results of CO_2 emission reduction found that the goal of the pilot project –10% reduction of CO_2 emissions each year – can be reached.

Since smart meter implementation in Latvia is still in the initial stage and there is still no legal framework for smart meter implementation, in the context of this pilot project it will provide the interaction between electricity companies, households, researchers and other stakeholders aiming for electricity savings. This work serves as a basis for further research on investigation of the factors influencing the user behaviour and analysis on electricity consumption reduction in households, as well as the further development of smart metering in Latvia.

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