Energy Efficiency of Residential Energy Monitoring Systems.

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ABSTRACT:

Smart meter roll-outs are under way in various world regions and end users are increasingly installing energy monitoring systems (EMS) to better understand and manage their residential energy consumption. Policy makers expect that the installation of such systems will lead to energy savings, as the user gets access to information to make informed decisions. The hypothesis that improved feedback will have both immediate and longer-term effects on energy use is supported by a number of studies. On average, the effect on energy savings is in the order of a few percent. This paper presents the results of investigating the own energy consumption of residential energy monitoring systems. It describes a variety of installations and their associated own energy demand. The results are presented in the context of scenarios of adoption of EMS in Austria. Relevant findings are discussed in relation to the expected engagement of consumers and the associated energy saving benefits, with recommendations for EMS improvement areas and future work.

1. INTRODUCTION

Energy generation and use globally account for a large proportion of greenhouse gas emissions (GHG), therefore, transforming the energy sector and reducing consumption are essential for addressing the climate challenge. In the preparation process to COP21, energy ministers recommended key steps to reduce greenhouse gas emissions from the energy sector, while maintaining the economic and sustainable development prospects of all regions. In the European Union and other world regions countries intend to deploy smart grids on a regional scale. In general the aim is a functional extension for the current energy supply system, hosting more renewable energy, and better controlling consumption and supply relevant data.

The rollout of smart grids reaches all levels of the energy supply down to the final customer and therefore the individual households need to be equipped with the corresponding hardware to connect to this infrastructure. As a consequence, the conventional metering systems will be converted to smart metering systems and governments are already increasingly involved in ambitious rollout programs aimed at a nationwide installation of smart meters in households. In the UK alone it is planned to exchange 47 million conventional meters to smart meters by 2020 (DECC, 2009).

The involvement of final customers and their change in behavior are important to achieve energy efficiency targets, as well as smart grid benefits such as the reduction of future capacity and energy needs. Energy monitoring systems have the potential to enable residential energy savings in the order of few percent (DECC, 2015). The provision of feedback and information on energy consumption at the end use side, and securing demand as much as possible with renewable energy, is a challenge that requires careful, appropriate, and coordinated deployment of technologies and accompanying measures and incentives.

2. ASSESSMENT OF THE ENERGY CONSUMPTION OF EMS

This paper describes representative energy monitoring systems available and likely to be installed in selected countries, e.g. in Austria. These EMS were investigated in the framework of the Electronic Devices and Networks Annex (EDNA) of the International Energy Agency[1]. The results of this work are publicly available (Krautzer et al., 2016).

Many technologies and configurations, stand-alone as well as complex installations for end consumers, are already available in the market all across the world. In Germany alone, over 180 companies were involved in the EMS market in 2014 (Kotschi, 2014). It was possible to distinguish different types of systems available through the features and functions they offered, as to classify them into three types of systems, respectively labeled as Monitoring, Management and Automation.

Monitoring systems merely provide energy monitoring (usually on an overall household level through an interface with the (smart) electricity meter and can be composed of devices such as a sensor, transmitter, hub and a display. Monitoring systems only provide information on the electricity consumption to the user. They are mainly intended to support energy savings through behavior changes. Management systems, usually consists of devices such as a hub, smart plugs and a display, allowing the user to monitor the energy consumption of individual devices in the home and switching these devices On and Off, either in real time or by setting time profiles.

Automation systems are in general more complex, offering a multitude of additional features beyond energy monitoring and management such as security, lifestyle and comfort features. In an automation system the actuators react autonomously to inputs from sensors within the system. These systems are often composed of a large number of different devices, resulting in diverse installations and uses. These systems need to be professionally installed, individually programmed and continuously maintained. This paper concentrates on results for Monitoring and Management systems (Automation systems were excluded from the investigation). The Monitoring and Management systems were grouped as:

- Monitoring system without display - composed of a transmitter and a hub only. These systems can be accessed through a smartphone or PC.
- Monitoring system with display - typically composed of a transmitter, a hub and a dedicated display. No further external devices (smartphone or PC) are needed to access the system, though some systems offer this feature as well.

[1] http://edna.iea-4e.org/tasks/task1

- Management system with smart plugs - composed of a hub with smart plugs, without dedicated displays.

Different devices are used to build the technical installation scenarios in each category. The own energy consumption of these individual components was measured or gathered from selected data sources. The measurements followed, wherever possible, the approach outlined in the standard EN 50564:2012 (ÖNORM, 2012). The input power of individual devices is shown in Figure 1. The hub shows the highest values, and the displays and the smart plugs follow in terms of own power requirements. The transmitter (battery powered) shows the lowest value of own energy consumption.

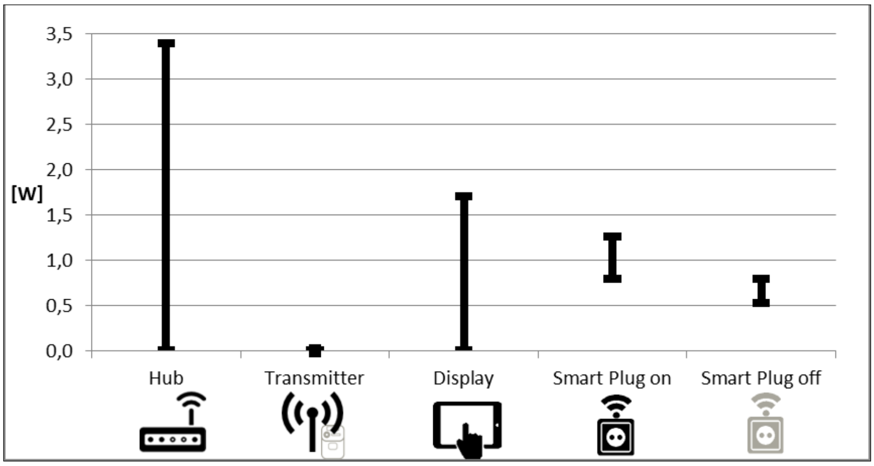

Figure 1: Input power of selected EMS devices (Krautzer et al., 2016).

Table 1 shows the best and worst in class with respect to the average input power (AIP) for each system (Components listed in parenthesis are not included in the corresponding systems).

Table 1: Average input power of EM systems (Krautzer et al., 2016).

System Type	Monitoring Basic			Monitoring Complex			Management Single Node Management			
Devices	Transmitter Hub (Display) (Smart plugs)			Transmitter Hub Display (Smart plugs)			(Transmitter) Hub (Display) Smart plugs: 1 On and 1 Off			
Name	a	b	c	d	e	f	g	h	i	j
Average Input Power [W]	1.02	2.02	2.35	0.01	1.33	3.66	1.61	1.69	4.41	5.32
	Best ->worst in class			Best ->worst in class			Best -> worst in class			

Each device has its own specific use scenario, defined as a combination of "On" and "Off" modes. It is considered that the transmitter, the hub and the central smart plug (SP) are always in On mode. The dedicated display is assumed to be On and active 24h per day. The switching smart plugs are On for 8 hours per day, and Off for the remaining 16h. The technical scenarios for the Monitoring systems include those with and without dedicated displays, as shown in Figure 2. The scenarios for Management systems with a hub and smart plugs differ only in the number of such smart plugs installed. A "Basic" Management installation would be composed of two smart plugs, one a central smart plug and one a switching smart plug. "Complex" Management installation can include up to nine smart plugs - one central smart plug and eight switching smart plugs such as in ready-made starter packages[2]. The central smart plug is used to monitor the energy consumption of certain devices, such as a fridge, while the switching smart plugs are used to switch loads that can be managed according to a time schedule. These two types of smart plugs have slightly different own energy consumptions. These technical scenarios were named "Basic" and "Complex", referring only to the extent of devices in the installation. The grey personal computer symbol indicates the possibility to access the system using a PC screen via web portal, or a handheld device, especially for the systems with no own (dedicated) display[3].

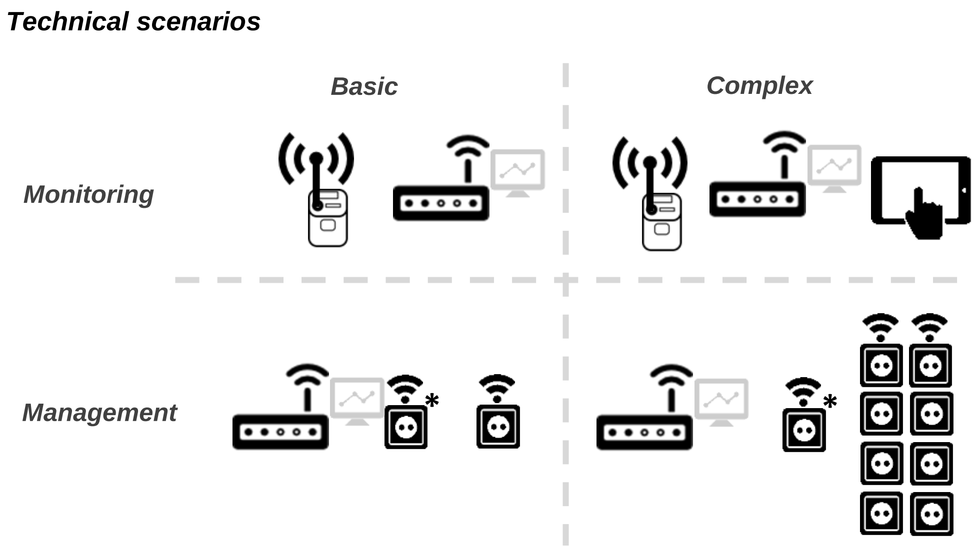

Figure 2: Depiction of the technical scenarios for EMS (Krautzer et al., 2016).

The energy consumption of the devices according to their use scenarios, and the combination of devices in the technical scenarios were used to obtain possible ranges of overall an-

[2] For example see https://www.plugwise.com/products/appliances-and-lighting/starter-packages.

[3] Although mobile phones and PCs might be necessary peripheral devices in some of the scenarios considered, they are not included in the assessment of the technical installation scenarios. Their own energy consumption is considered negligible, due to their low power consumption and the rather low use time. It is assumed that when there are dedicated displays, these are always on, e.g. the dedicated displays on smart meters are continuously displaying the energy figures and other wall mounted displays (e.g., security displays) are also always on.

nual energy consumption of EM systems when installed in a household, as presented in Table 2.

There is a large difference between energy consumption of EM systems providing comparable functionality. The own energy consumptions can be substantial, especially for Management systems with a large number of connected nodes (smart plugs), adding up to 101,5 kWh of electricity consumption per household per year.

Table 2: Annual electricity consumption of different energy monitoring and management systems (Krautzer et al., 2016).

System type		Basic [kWh/y]	Complex [kWh/y]
Monitoring	worst in class	20.6	32.1
	best in class	8.9	0.1
Management	worst in class	48.3	101.5
	best in class	14.3	62.7

2.1 AUSTRIAN CASE STUDY OF EMS

The data at the household level were used to estimate ranges of energy consumption at the level of the country, considering demographic information and specific market data of EMS systems. In Austria an average household consumes 4.753 kWh of electricity per year, and there are 3,72 million households. The implications of an installation of EMS on the household's energy consumption are presented in percentage figures, indicating the amount of electricity consumed by the EMS as a share of the household's total annual electricity consumption.

To provide monitoring of the entire household electricity consumption, different systems require between 0.001% and 0.36% of the household's consumption. Basic Management systems require between 0.30 % and 1.02% while Complex Management systems require between 1.32 % and 2.14 %. To identify the country wide implications of the market penetration of these systems, Figures 3 and 4 show the range of the overall electricity consumption of different systems, as a function of their market penetration. For a 50% penetration scenario, the energy consumption could increase by up to 189 GWh/year.

This additional energy consumption could demand a significant share of the installed power capacity in the country, e.g., in the case of Austria up to 18% of the yearly production of the Danube Hydropower plant Freudenau would be needed to power EMS systems at a 50% penetration scenario.

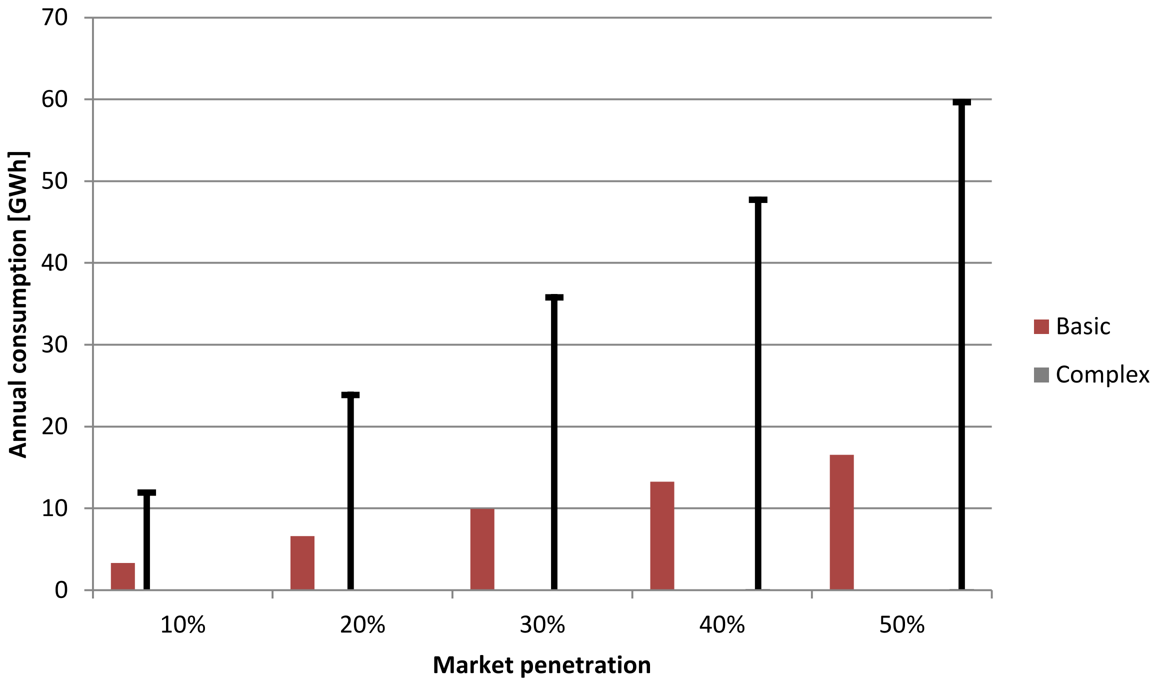

Figure 3: Lower and upper bound of the total electricity consumption of different energy Monitoring systems in Austria, according to their market penetration (Krautzer et al., 2016).

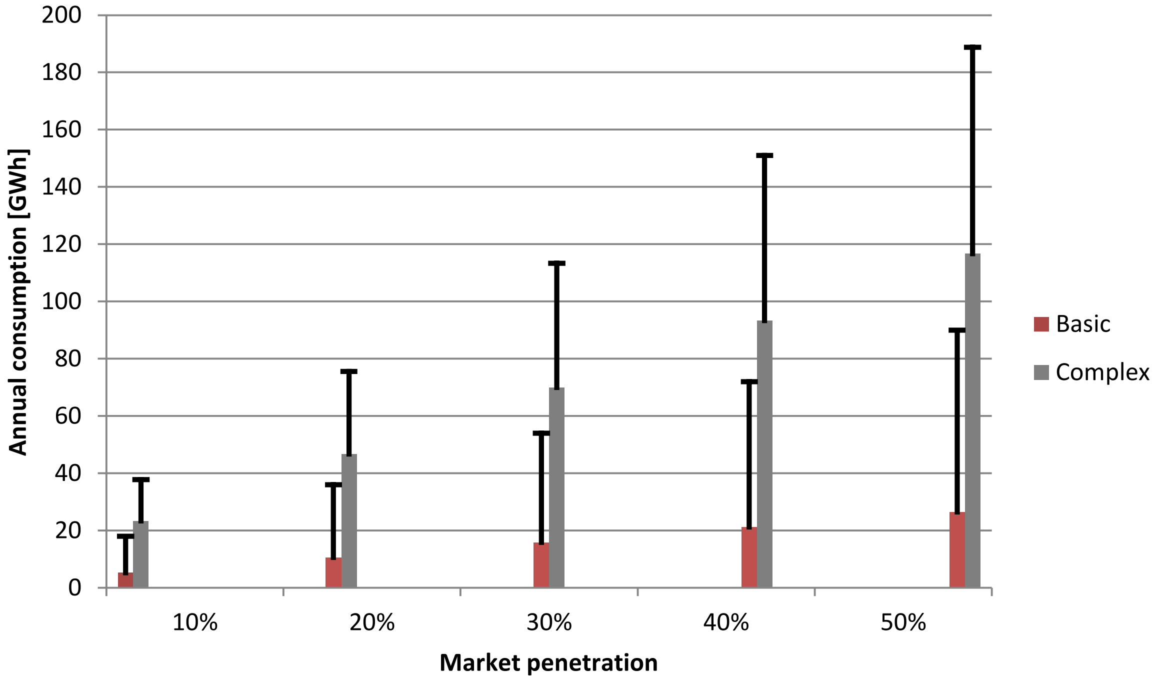

Figure 4: Lower and upper bound of the total electricity consumption of different energy Management systems in Austria, according to their market penetration (Krautzer et al., 2016).

3. RECOMMEDATIONS

The results presented above indicate that it is necessary to understand the EM system as a whole and at an early stage, to decide on the specific features which are necessary, and to identify the devices or components which carry the greatest efficiency improvement potential. EMS manufacturers should carefully consider which data has to be measured, logged and visualized to fulfill the core function, which is to help the users reduce their consumption. This would also require that EMS manufacturers interact and understand the requirements from other stakeholders in the energy sector now and in the future. Direct rebound effects need to be considered as they may offset the potential of energy savings. As an example, a new TV set sold in the EU has a standby input power of less than 0,5 W. The measured smart plugs have an equivalent or greater own input power in the Off mode. Installing this smart plug to eliminate the standby consumption from that TV would indeed add to the parasitic energy consumption instead of reducing it.

A differentiation between long term analysis and real-time information must also be made as well as a clear differentiation between devices providing energy reduction relevant features and auxiliary features offering comfort, security and lifestyle features. These could possibly offset some of the energy savings achieved. Users might even not have appropriate information to make informed decisions on how many devices might need to be installed and how they would specifically need to be used to manage (and save) household energy. It should also be considered that the large amount of data generated in these EM systems has to be stored, protected and analyzed. This creates considerable additional energy consumption in server farms and other infrastructure. This should be taken into account when considering the projected growth of this sector.

Large differences in consumption were found between different devices, suggesting that technologies do exist, which would greatly reduce the power consumption of these devices, especially for smart plugs and hubs. Smart power management features, such as a deep sleep mode and especially an auto power Off mode with a physical on switch can greatly reduce the overall use time of these devices before stringent energy consumption thresholds for these operating states are defined. Further work could also focus on energy harvesting technologies, and transferring low power technologies (e.g. used in battery powered devices) to mains-powered EMS.

To ensure that users can take full advantage of the EMS installations, the energy efficient settings should be enabled by default, so that devices are shipped with energy efficiency settings enabled. Once the products have been shipped, it is important that they are correctly installed. Periodic maintenance, reminders and interactions with the user may be required to achieve the expected maximum benefits and ensure that these systems do not simply become additional energy consumers, no longer delivering the function and benefits they were designed for.

4. CONCLUSIONS

This paper explored the magnitude of the impact of installing energy monitoring systems (E, by identifying the functionality of the different systems and their energy consumption ranges; both at the device level and for systems as a whole. The results were extrapolated and presented for an Austrian case study. The scope of potential improvements and recommendations to encourage efficient technologies and solutions were discussed.

AKNWOLEDGEMENT

This research has been supported by the Austrian Federal Ministry of Transport, Innovation and Technology, under the International Energy Agency (IEA) Research Cooperation Grant: FFG 848115; and by the IEA under the Technology Cooperation Program on Energy Efficient End-Use Equipment (4E) – Electronic Devices and Networks Annex (EDNA).

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