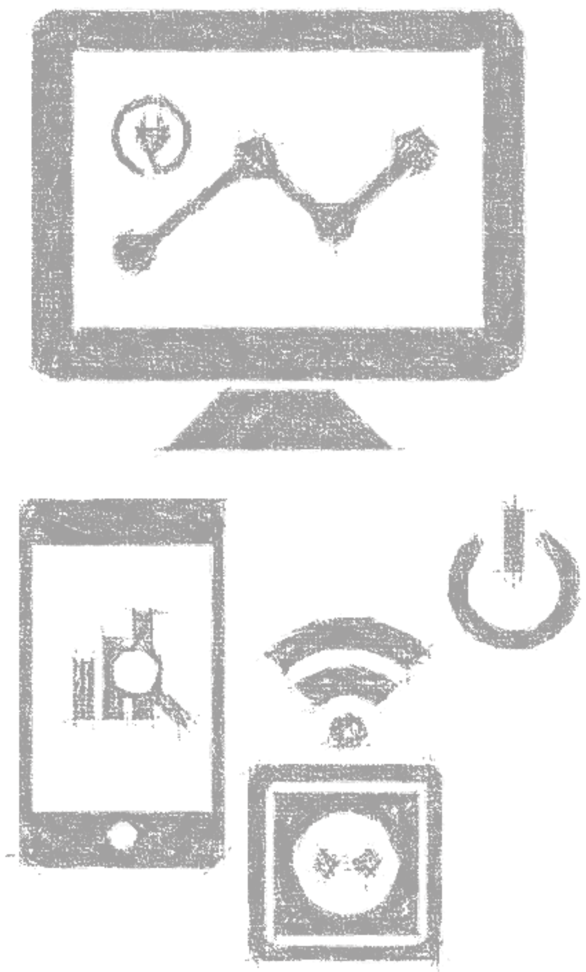
Electronic Devices & Networks Annex
EDNA



Own Energy Consumption of Smart Metering Infrastructure and Energy Monitoring Systems

Technical Report prepared for IEA 4E EDNA Task 1

April 2016

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List of Acronyms

AC – Alternating current

AIP – Average input power

DCO – Data concentrator

DSM – Distribution management system

DSO – Distribution system operator

EMS – Energy monitoring system

EKZ – Elektrizitätswerke des Kantons Zürich

GPRS – General packet radio service

HAN – Home area network

HiNA – High network availability

IMA-VO – Intelligente Messgeräte-Anforderungs-Verordnung

IP – Internet protocol

LAN – Local area network

MP – Metering point(s)

NIALM – Non intrusive appliance load monitoring

PLC – Power line communication

SM – Smart meter

SMc – SMART METERING consumption

SMI – Smart metering infrastructure

SP – Smart plug

TS1 – Technical solution 1

TS2 – Technical solution 2

WAN – Wide area network

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Executive Summary

SMI/EMS stands for smart metering infrastructure and energy monitoring systems. This is the title of the first Task of the Electronic Devices and Networks Annex (EDNA), which itself is anchored in the Energy Efficient End-use Equipment (4E) implementing agreement of the International Energy Agency (IEA). This task is supported by seven governments: Australia, Austria, Denmark, the Netherlands, Sweden, Switzerland and the United Kingdom. EDNA´s Task 1 covers two different types of systems:

- **SMI:** This topic covers smart meters and all other components of smart metering infrastructure. Smart metering can be understood as electricity metering enhanced by means of communication and various auxiliary functions.
  In this context, the smart metering infrastructure consists of the smart meter and everything needed for it to communicate with a distribution system operator. Large-scale smart meter roll-outs are under way in various countries.

- **EMS**: This topic covers standalone products as well as system installations for end consumers. These products can be in-home displays connected to smart meters, single-point measurement devices (smart plugs) connected to a server, or complex systems which are part of a complex home control system. The purpose of such systems is to visualize information on the electric energy consumption in the household. The EMS market is currently growing very quickly.

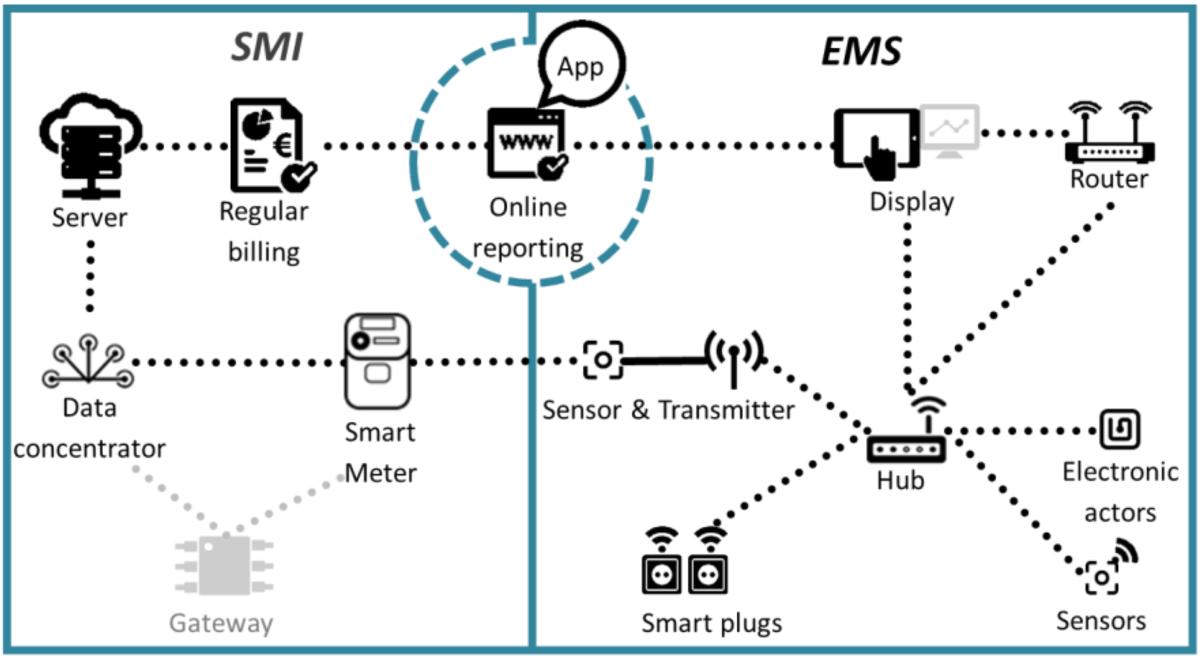


Figure 1: Simplified graphical depiction of the boundary between SMI and EMS

Policy makers expect that the provision of energy consumption data in households, as provided by these systems, will lead to increased energy efficiency and reductions in consumption. According to several studies, the average long-term consumption reductions typically lie in the range of a few per cent compared to households without feedback.

These systems however also consume electricity which may offset part of the positive effects and the widespread installation of these systems may have considerable impacts at a macro scale. The own power consumption of these systems is the main topic of this report which describes the objectives, methodology and achievements of Task 1 as of March 2016. To achieve a reasonable description and a realistic understanding of this issue, SMI and EMS have been analyzed and classified. Their own energy consumptions have been measured or determined through research, and modeled on the basis of appropriate reference units. In the case of SMI a metering point serves as a reference unit, while in the case of EMS the reference unit is one household. The small associated consumption of these reference units was then extrapolated to the number of entities in a whole region. The results allow policy-makers to make cross-comparisons with other product groups or energy demand figures.

For SMI, measured consumption data was not available in the EDNA member countries. Therefore, reference data originating from the project SMART METERING consumption - Own consumption of electricity meters (SMc), as shown in Figure 2 were used as the basis. SMART METERING consumption was a binational project undertaken on behalf of the Swiss Federal Office of Energy (SFOE) and the Austrian Federal Ministry for Transport, Innovation and Technology (BMVIT) from 2010 to 2012[1].

To derive country-specific case studies, this data was mapped according to key input parameters such as the number of 1 or 3 phase metering points, and the split into different communication technologies.
Overall, there is a factor four between the best and the worst performing technology, with regard to the own energy consumption. The communication technology plays a key role, greatly influencing this own energy consumption.

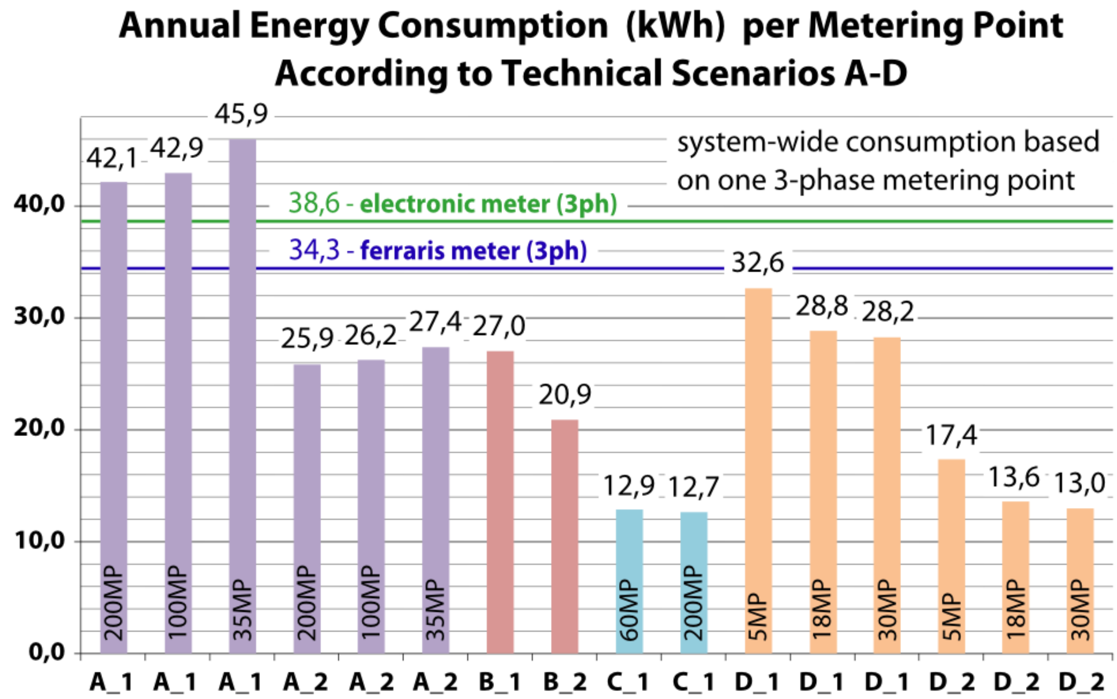


Figure 2: Comparison of energy consumption figures in kWh per metering point and over the time span of one year.[2] The colors of the bars indicate the used communication technology: A (violet) … PLC, B (red) … GPRS, C (blue) … radio transmission, D (orange) … wireless M-Bus with gateway.
For A, B and D, different manufacturers were analyzed and for A, C and D, different ratios of metering points per data concentrator were additionally assumed.

[1] Preisel, et al. 2012
[2] Preisel, et al. 2012

For EMS, testing measurements have been completed and additional consumption figures were derived from datasheets. Similarly to SMI, there is a considerable difference in the energy consumptions of systems which provide comparable functionality. The own energy consumptions can be substantial, especially for energy management systems with a large number of connected nodes (i.e., smart plugs), adding up to 101.5 kWh of electricity consumption per household and year, in one of the scenarios as shown in Table 1.

Table 1: Annual electricity consumption of different energy monitoring and energy management systems.

		Basic	**Complex**	
Monitoring	*worst in class*	20.6	32.1	*kWh/y*
	best in class	8.9	0.1	*kWh/y*
Management	*worst in class*	48.3	101.5	*kWh/y*
	best in class	14.3	62.7	*kWh/y*

With respect to smart metering, the task findings indicate that the general awareness on the issue of own energy consumption of SMI is still low. There is limited information available in the EDNA member countries on the kinds of meters that will be installed or are currently being favored by the utilities. Relevant and valid data from the SMc project[3] shows that the meter itself contributes between 76% and 98% to the system-wide average input power per metering point. The meter properties and technical features, as well as the system conditions especially for communication of meter data are the main drivers influencing the overall own energy consumption of the SMI. In this sense, the communication technology takes up a key role and as such has been used as the main feature to distinguish between systems.

The assessment methodology developed in EDNA Task 1 applied to the conditions of specific countries, provided information on the possible energy impact from the own power consumption of the SMI rollouts which are likely to be deployed; or already deployed; in selected countries. Once a specific technology has been rolled out, the technology pathway for the next 20 to 30 years is set and may require large investments to be changed. This pathway will determine, not only the own consumption of the infrastructure for the years to come, but also the features, interoperability, and expansion options available to utilities and to end-consumers. A key finding from the Swiss case study, is that there are ways to account for the entire product life cycle of smart meters (considering their raw materials, manufacturing, distribution, installation and end their life). This case study shows that it is possible to integrate the meter exchange process in the regular re-calibration processes which the grid operators are carrying out for their park of installed meters. Currently the government policy approaches in most EDNA countries for SMI and EMS are decoupled, i.e., technical specifications are set for smart meters but not for EMS. In the United Kingdom though, the decision path is parallel for the SMI and EMS rollouts, namely, minimum technical specifications have been set for both type of systems.

Additional information, such as the strikingly low average input power (AIP) of the battery powered SM devices, and the substantial differences between the AIP of different communication technologies, suggest that there is potential for improvements, which policy makers could further evaluate for further SMI policy development.

The introduction of smart meters alone, without providing appropriate means of feedback to the end-users, will not result in a change of user behavior. A variety of research projects and field trials from around the world provide information on the successful implementation.

[3] Preisel, et al. 2012

The assessment methodology developed in EDNA Task 1 was also used to assess scenarios and the possible own energy consumption of EM systems available in the markets of EDNA member countries. Different approaches are incorporated into the EMS products offered in these markets, ranging from those using an interface with the electricity meter to transmit the overall consumption to a hub or directly to a display; to those using single node measurement points (smart plugs)to transmit the information to a hub. The investigation in Task 1 of EDNA clearly showed that, depending on the number and type of devices installed, the own energy consumption of EMS can be significant and could substantially offset the expected energy efficiency gains at the end user side. Users might not have appropriate information to make informed decisions on how many smart plugs and other devices are installed and how they will specifically need to be used to manage (and save) household energy. Large differences in consumption between different smart plugs were found, which suggests that efficient technologies are available.

In this sense, the EM systems have to be fit for purpose. Systems do not need to record everything but should provide the user with the necessary information to achieve reductions in consumption. EMS manufacturers would have to consider the data that really needs to be measured, logged and visualized to fulfill this energy saving function.

To visualize the consumption some of the investigated EM systems had dedicated displays. On first sight these do not seem necessary considering that the visualization function can be provided by other, existing devices. However, the energy efficient technologies available today, their low use times, and the benefit such devices may bring to specific user groups are worth considering versus their own energy consumption, especially if smart power management options are implemented. Most devices, be it smart plugs, hubs or displays, only require low network availability and the communication protocol should allow for a “wake from sleep” command. The EMS devices are generally programmed to a time profile once and can then run autonomously. The data only needs to be available on demand and the system can wake from sleep to transfer data or switch consumption as required. These capabilities would go hand in hand with smart power management features, which may also offer great saving potentials in this context.

There is a great difference in the own energy consumption between battery and mains powered EM devices, though it is not fully clear if these devices all provide the same functionality. Though battery powered devices often operate very efficiently by using efficient components and smart energy management settings, a widespread penetration of these devices in the market could lead to considerable increases in battery waste.

To ensure that users can take full advantage of the products, devices should be shipped with energy efficiency settings enabled by default. Manufacturers would not only need to integrate these settings in the devices, but actually ensure that their intended benefits are available to the consumers right from the start.

It is important that EMS devices, and especially complex systems for the home, are installed correctly. Training and courses may be required to bring electricians up to speed on these installations, their maintenance and optimization, so that these systems deliver the maximum savings potential. As the frequency of interaction with the EM systems decreases over time, periodic maintenance, reminders and interactions with the user may be required to achieve the “expected” energy savings, and to avoid that the EMS becomes another parasitic energy load, no longer delivering the function and benefits they were designed for.

The investigations presented in this report suggest further work would be needed in the fields of communication technologies and their interoperability, energy harvesting technologies, and transferring technologies employed in battery powered devices.

1 EDNA context

1.1 Purpose and motivation for EDNA in IEA-4E

After 5 years of successful activities, the IEA - 4E Standby Power Annex formally concluded in May 2014 with the creation of the Annex on Electronic Devices and Networks "EDNA"[4]. This newest initiative of the International Energy Agency's Implementing Agreement on Energy Efficient End-Use Equipment (IEA - 4E) focuses on network connected devices.

Network connected devices can be controlled, and this offers enormous opportunities for energy management. At the same time, there is a responsibility to ensure that these devices use a minimal amount of energy to stay connected. The scope of the Annex is broad, including most types of electronic equipment and associated networks serving the information technology and related communications needs of consumers, businesses, institutions, and utilities.

The policy discussion and activity to date has been focused on limiting the network related power consumption within a product, primarily in low power modes as well as increasing the time spent in low power modes. However, the concern should be on more than just power use in low power modes. Network connectivity can induce considerable extra energy consumption by keeping products in higher power modes when they would otherwise be able to enter low power modes (both the product itself and other products on the network). These are all part of the "energy cost" of having network connectivity. To ensure that we help to shape the efficient low energy networks of the future, it is important that we move beyond the issue of "network standby" and look at the overall energy impact of networks.[5]

In this sense, EDNA seeks to assist policy makers in the development, implementation, and measurement of policy action of connected devices. The EDNA goals are:

> *To monitor, measure, report and compare the extent of, and changes in, energy consumed by electronic devices and associated networks within Annex participant countries and other selected locations; and*
>
> *To support the alignment of government policies (including voluntary or mandatory approaches) which permit participating Annex members to minimize excessive energy consumption by electronic devices and associated networks.*

EDNA currently engages the following member countries: Australia, Austria, Canada, Denmark, France, Japan, Republic of Korea, the Netherlands, Sweden, Switzerland, United Kingdom, and the United States of America. These countries agree to support selected tasks and projects of common interest.

There are currently two active tasks within ENDA: Task 1 on "Smart Metering Infrastructure and Energy Monitoring Systems" (SMI/EMS) and Task 2 on "Energy Efficient Internet of Things" (EEIoT). In addition EDNA is taking an active role in the G20 Networked Devices Task Group under the G20 Energy Efficiency Action Plan, launched after the G20 Summit in November 2014.

4 http://edna.iea-4e.org

5 Harrington et Nordman, 2014

1.2 Overview on EDNA members and tasks

This report is presented by the ECODESIGN company GmbH on behalf of the Austrian Federal Ministry of Transport, Innovation and Technology (BMVIT), as member and lead of EDNA Task 1 “Smart Metering Infrastructure and Energy Monitoring Systems” (SMI/EMS).

SMI/EMS is the first Task of EDNA, launched in November of 2014 with the support of 7 governments: Australia, Austria, Denmark, The Netherlands, Sweden, Switzerland and the United Kingdom (see Figure 3).

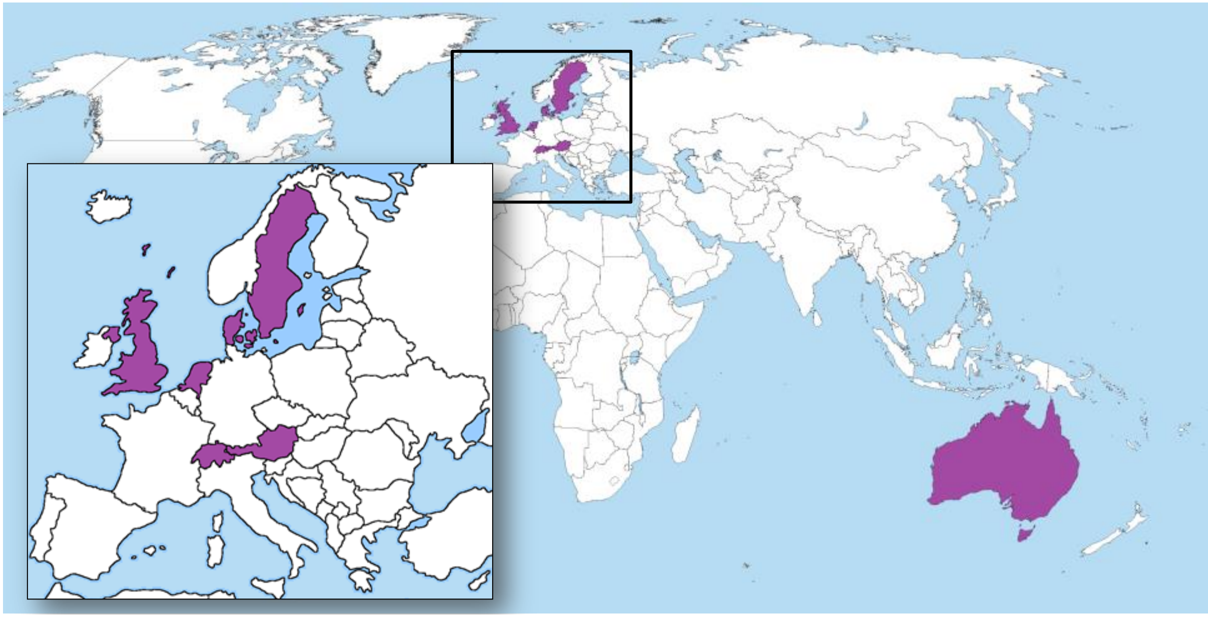


Figure 3: Member countries to the IEA – 4E EDNA task “Smart metering and Energy monitoring systems” (SMI/EMS). [Source: ECO - EDNA meeting May 2015].

This technical report describes the objectives, methodology and achievements of Task 1 as of March 2016, and provides an outlook of the coming work under this task.

2 SMI/EMS: Background of Task 1

EDNA Task 1 covers two different sorts of products or systems, respectively:

- **SMI** stands for smart metering infrastructure. This area is focusing on smart meters and all other components which are somehow involved in the smart metering infrastructure. Smart metering can be understood as electricity metering enhanced by means of communication and various auxiliary functions.
- **EMS** stands for energy monitoring systems. This area covers standalone products or system installations for end consumers. These products can be in-home displays to be connected to smart meters, single-point measurement devices (smart plugs) to be connected to a server, or complex systems which are just part of a high-level home control system. The purpose is, in any case, to visualize information about electric energy consumption in the household.

Figure 4 shows a schematic arrangement of devices for SMI and EMS, the boundary in between and the overlapping area where the internet provides online reporting.

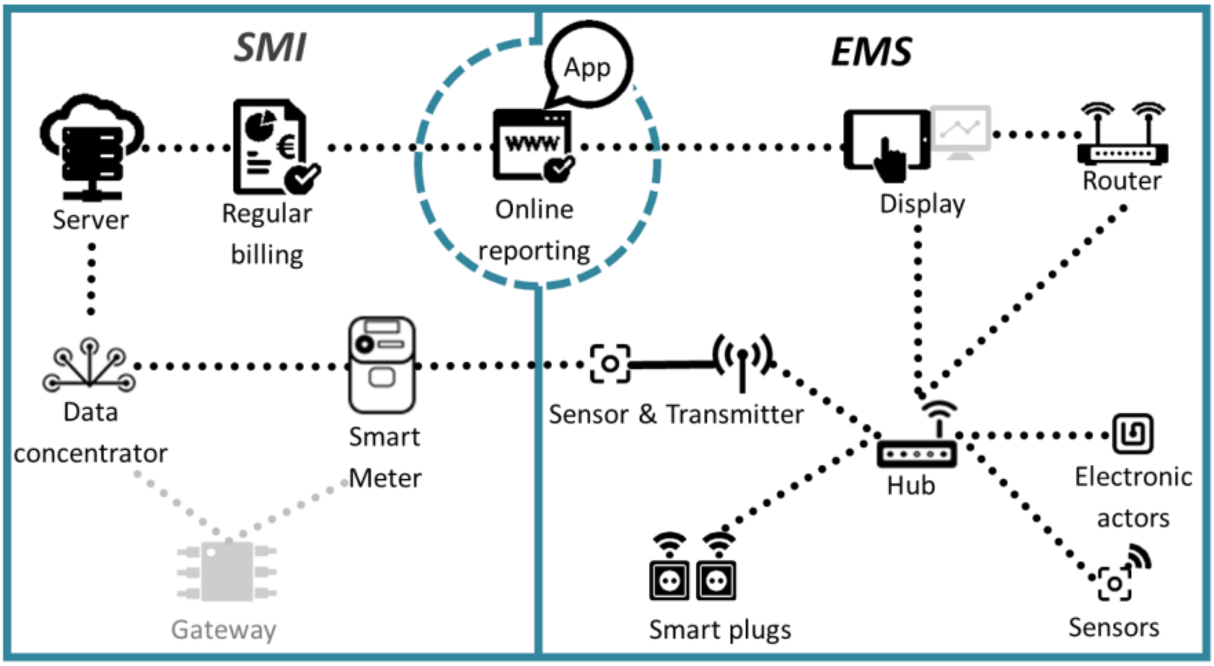


Figure 4: Simplified graphical depiction of the boundary between SMI and EMS

Smart meter roll-outs are under way in various world regions and end users are increasingly installing energy monitoring systems to better understand and manage the energy consumption of appliances in their homes. In this context, the smart metering infrastructure consists of the smart meter (SM) and everything needed for the SM to communicate with a distribution system operator (DSO).
The EMS on the other hand is a system used to visualize the energy consumption[6] in a household to the consumer. This information has to be accessible to the user in almost real-time and/or on-demand, and should include the current consumption as well as logged data.

Policy makers expect that, in the short term, these measures will increase the energy efficiency of households, by providing the user with relevant information to make more informed decisions. The hypothesis that improved feedback will have both immediate (motivational) and longer-term

6 Energy consumption in a household might cover heat, gas, and electricity flows. Task 1 focuses on electrical energy and the corresponding monitoring systems in the residential sector.

(learning) effects on energy use is supported by a large number of studies. On average, the effect is typically of the order of a few per cent compared with households without the feedback.[7]

Policy development carried out so far has been mainly focused on the critical role the new generation meters play in the operation of national electricity markets and on competitiveness, as well as on access and management of consumer information. The potential impact of the own energy use of SMI/EMS technologies themselves has not been thoroughly investigated. These energy impacts need to be considered against the potential benefits of the deployments, programs, and behavior changes that will improve energy efficiency over the long term. EDNA's Task 1 "Smart metering infrastructure and energy monitoring systems" is addressing these energy impacts of the SMI/EMS infrastructure, focusing its research on the following issues:

- The energy consumption ranges of the different smart metering and energy monitoring systems, as well as its influencing parameters; both at the components level, and systems as a whole.
- The type of functionality of the SMI/EMS as basis for possible comparisons.
- The impact on the overall energy consumption of the systems by means of extrapolating measured data into "roll-out scenarios" for different countries, to identify the scope of potential improvements.
- The potential for policy interventions by governments within the SMI/EMS market, to encourage the adoption of efficient technologies and solutions.

The European Commission expects consumers to benefit from smart meters through the following possible ways [EC 2014 b.]

Energy savings:
smart meters demonstrably help consumers reduce their consumption and save energy. Smart meters help consumers master their consumption and therefore increase their energy efficiency.

Innovative services for consumers:
smart meters open the door to smart home solutions and innovative home automation services.

Consumers' empowerment:
smart meters will improve competition in retail markets.

Environment protection:
less energy consumption and higher energy efficiency help protecting the environment.

Distribution system efficiency:
management of distribution systems becomes cheaper and more effective, leading to lower distribution costs.

2.1 Goal, scope, and objectives

The key actions in Task 1 SMI/EMS are:[8]

- Researching SMI/EMS technologies and systems present in the market: to classify the systems and their functionality (such as provision of two-way communications, control, and the end user functionality for home monitoring devices such as handhelds, in-home display, or web portals) to enable the comparisons of their power use.
- Measuring and reporting the energy use of different SMI/EMS technologies, so that comparisons can be made of the different implementations of these systems.

7 Harrington et Nordman, 2014

8 Preisel et al., 2015

- Developing a flexible and broadly applicable assessment methodology, combining the research results with the measurement data, to extrapolate plausible scenarios and their energy consumption implications.
- Engaging with stakeholders, including manufacturers, standardization organizations, energy agencies, energy utilities, and other groups dealing with smart metering and energy monitoring systems.
- Identifying market trends on future energy monitoring technologies and their functionalities at an early stage so as to enhance global collaboration at the scientific and policy level.
- Identifying focus areas and scope for policy development (e.g., energy consumption relevant features and functions).

In chapter 2 of this report the status of SMI/EMS is presented according to the information available from EDNA member countries. Chapter 3 gives an overview of the approach followed in this task, particularly concerning the methodology, data sources and measurements completed in the course of this Task. In chapter 4 the results from chapter 3 are assembled in case studies with scenarios for SMI/EMS in the EDNA member countries. These case studies show the possible ranges of energy consumption associated with the SMI/EMS systems and their probable implementation. Chapter 5 includes a discussion of the key factors that influence the results, summarizes key lessons learned in this task, and in relation to possible future work.

2.2 Introduction to SMI/EMS and status in EDNA countries

Smart metering is rapidly gaining momentum across the world. In all EDNA Task 1 member countries there are plans for roll-outs, as shown in Figure 5.

Austria and Switzerland have completed small scale pilot roll-outs. Austria has a target of 80% roll-out until 2020, and Switzerland plans an 80% roll-out by 2025.

Denmark has rolled out around 50% of all smart meters (1.63 million smart meters), and the remaining 50% is mandated by law by 2020. The Netherlands has also completed a partial roll-out replacing 7% of metering points, and the plan foresees 100% coverage (7.6 million smart meters) by 2020. Sweden has completed a full roll-out with 5.2 million smart meters installed.

The current roll-out status in the United kingdom is 1 million smart meters, with plans for 97% coverage by the end of 2020 (32.94 million smart meters) with the remaining 3% until 2030.

In Victoria (Australia) a full roll-out of 2.8 million smart meters is complete. This covers 24% of the Australian population. Other regions are launching smart meter roll-outs, such as New South Wales, Queensland, Western Australia, and South Australia. Australia is preparing legislation to facilitate the further national roll-out based on customer choice of smart meters.

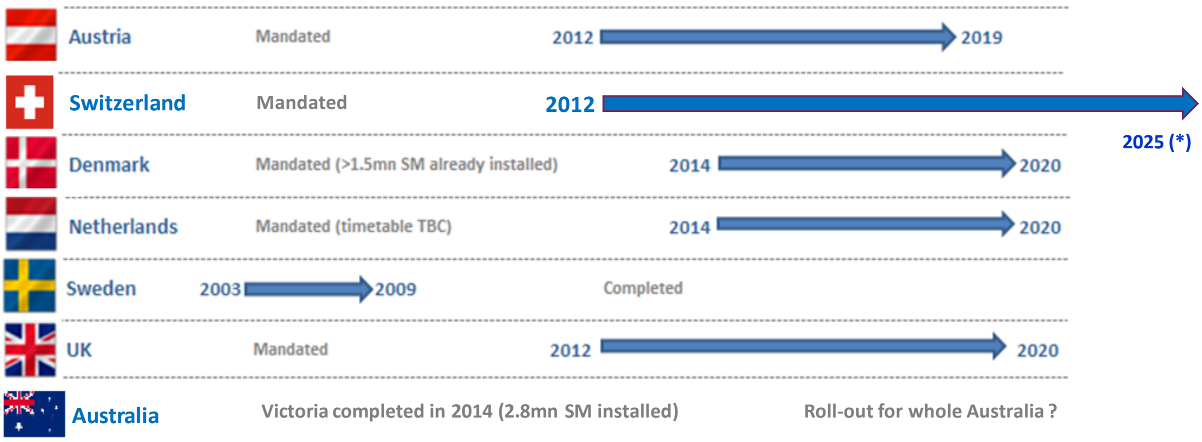


Figure 5: Electricity smart meters roll-out timelines in EDNA Task 1 countries (considering 80% coverage).[9]

In Europe the European Services Directive (2006), the Third Energy Package (2009) and the Energy Efficiency Directive (2012) are the main regulatory drivers promoting the deployment of smart meters in the Member States. The Energy Services Directive laid the foundation for a European legislation for smart metering, by requiring individual energy meters and standards for frequent and understandable energy bills. The Third Energy Package accelerated the penetration of smart electricity metering in the EU, by setting the target of at least 80% of all households having a smart meter by 2020 (given positive cost-benefit assessments). The Energy Efficiency Directive connects the smart meters directly to dynamic pricing and improved feedback programs, and empowers smart meter and consumer feedback regulation.[10]

With respect to energy monitoring systems, there is no mandatory roll-out as such in any of the countries participating in EDNA Task 1. In the UK all smart meter consumers are offered an in home energy display (IHD) as well as web access and apps. Energy monitoring systems are mostly left to the market. There are instances however in which minimum technical requirements of smart meters define a capability of the complete smart metering system to visualize the recorded data online or using a visualization tool.

Regulations addressing efficiency of SMI/EMS

In the EU, the regulatory framework that deals with the energy in use is the EU Ecodesign of Energy Related Products Directive 2009/125/EC. Under this framework, the Regulation (EC) No 801/2013 covers standby, off-mode, and networked standby losses. A "horizontal" regulation was adopted in this case, since networked connectivity is a feature of a large range of products, including products that will appear in the future.

A networked standby condition maintaining a certain level of network connectivity but deactivating main functions could decrease overall energy consumption. Products that are able to be reactivated over a network would typically be IT and consumer electronics equipment, such as personal computers, displays, networked storage, and networked equipment.

9 Adapted from EC, 2014 b. p.13

10 Van Elburg, 2015

According to this EU regulation, this equipment must be designed to provide power management and meet specific levels for power consumption in networked standby (introduced in two stages):

- From 1 January 2015: 12 Watt for products with High Network Availability (HiNA) and 6 Watts for equipment without High Network Availability.
- From 1 January 2017: 8 Watt for products with High Network Availability (HiNA) and 3 Watts for products without High Network Availability [5].

Under the Ecodesign Directive there is also the ongoing preparatory study on smart appliances and meters, which started last October 2014[11]. This preparatory study examines all technical, economic, environmental, market and societal aspects that are relevant for a broad market introduction of smart appliances. Some aspects of smart meters will be considered, but the study is focused almost exclusively on smart appliances, such as large household appliances (e.g., washing and drying machines), domestic lighting, battery storage, space heating, air conditioning, ventilation, and humidity control; and low power chargers. This study will follow in principle a horizontal approach, and focus on functionalities such as energy saving and demand-response features.

In the USA a large number of networked products are covered by ENERGY STAR®[12] requirements. The objective is to minimize overall energy budget for a product in use. US EPA sees a clear trend of network connectivity being integrated in more and more consumer products. For example, 80% of TVs on the US market are shipped with network connectivity. Increasingly demand response-ready appliances and networked climate control is being deployed. The key objective for ENERGY STAR® is to promote the delivery of network connection with the lowest power possible. ENERGY STAR® focuses on total energy consumption and network standby is viewed in this context.[13]

Technical specifications and energy consumption of SMI/EMS

In the context of EDNA Task 1 it is important to understand the (Minimum) technical requirements that governments are adopting for smart metering roll-outs and for energy monitoring systems. This information was gathered primarily from the EDNA member countries and from own research. A summary is presented in this section. The features Austrian smart meters need to comply with are defined in the "Intelligente Messgeräte-Anforderungs-Verordnung" (IMA-VO 2011), which came into force in 2011. Guidelines to accompany the preparation of technical specifications for smart meters are available in Switzerland. For the Netherlands, the UK and Australia detailed technical specifications are available (see Table 2).

Table 2: Summary of technical specification documents for SMI available in selected EDNA task 1 countries.

	AT	CH	NL	UK	AU
Level of technical specifications	Guideline	Preparatory guideline	Detailed guideline	Detailed guideline	Detailed guideline
Reference	IMA-VO, 2011	CH BFE UVEK, 2014	NETBEHEER NEDERLAND, 2014	UK DECC, 2014 a. & b.	NMI, 2012

11 http://www.eco-smartappliances.eu.

12 The US Environmental Protection Agency (US EPA) and the Department of Energy (US DOE) operate this voluntary endorsement labelling program. Their focus is primarily national, however many specifications for consumer electronics and IT equipment are used internationally. ENERGY STAR® has considered network connectivity in its specifications since 1992, covering personal computers and monitors. Further specifications include those of Small network equipment since 2013. [http://www.energystar.gov/products/office_equipment/small_network_equipment/key_product_criteria].

13 https://www.iea.org/media/workshops/2013/networkedstandby/130404workshopreportNetworkStandbyToronto201303.pdf

Within these specifications, the research went deeper into identifying details regarding energy consumption, additional features, and specifications related to visualization and communication, as discussed below:

- **Energy consumption**: in Austria and Switzerland a threshold for the own energy consumption of smart meters has not yet been defined, however, the minimum technical requirements demand for *a system that is designed and operated as efficiently as possible*. In the Netherlands, the maximum allowed average power consumption without and during communication is limited for single phase (2W and 4W, respectively) and for poly-phase meters (4W and 8 W, respectively). In the UK, the average energy consumption thresholds are set at 4W for single phase and 7W for poly-phase meters.
  Detailed measurement data on the own energy consumption of smart meters is not available in the majority of the member countries.
- **Additional features**: the proposed smart meter features in AT, CH, NL and UK largely follow the European Commission Recommendation EC 2012/148/EU of 9 March 2012 on the preparations for the roll-out of smart metering systems.[14]
  In the Netherlands a breaker or valve is not allowed in the meter. In DK and SE the features partly follow the EU recommendations EC 2012/148/EU. In Australia, the features and technical specifications follow largely IEC standards as described in the NMI M 6-1 Electricity Meters Part 1: Metrological and Technical Requirements[15].

Table 3: Country specific minimum functional requirements of smart meters adapted from Table 8. in Commission Staff Working Document SWD 189. [16]

Member States rolling out Smart Meters (SM)	SM MinFun - (a)	SM Min Fun - (b)	SM MinFun - (c)	SM MinFun - (d)	SM MinFun - (e)	SM MinFun - (f)	SM MinFun - (g)	SM MinFun - (h)	SM MinFun - (i)	SM MinFun - (j)
Austria	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Denmark	YES	Partly	YES	YES	YES	YES	YES	YES	YES	YES
Netherlands	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Sweden	YES	Partly	YES	YES	YES	YES	Partly	Partly	YES	YES
United Kingdom - GB	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Description of minimum requirements (adapted) from EC 2012/148/EU
For the customer:
a) *Provide readings directly to the customer equipped with a standardised interface which provides visualised individual consumption data to the consumer and* ***b)*** *Update these readings frequently (e.g., every 15 minutes).*
For the metering operator:
c) *Allow remote reading of meters by the operator.*
d) *Provide two-way communication and control of the metering system.*
e)*Allow readings to be taken frequently enough to be used for network planning.*
For commercial aspects of energy supply:
f) *Support advanced tariff systems.*
g) *Allow remote on/off control of the supply and/or flow or power limitation.*
For security and data protection:
h) *Provide secure data communication.*
i) *Provide fraud prevention and detection.*
For distributed generation:
j) *Provide import/export and reactive metering.*

14 EC 2012/148/EU, 2012

15 NMI, 2012

16 EC, 2014 b. p.16

➔ **Visualization**: The mode of visualization for the smart meter data has not been explicitly defined in Austria. In Switzerland the mode of visualization is left to the market, i.e., to the operators of the smart metering systems. The minimum requirements only demand the technical possibility to visualize the data on a platform if the customer demands it. The specification of the platform includes options such as a smart phone application, a web platform but also in-home displays. In Denmark, the Netherlands, and Sweden frequent readouts are sent to the customers. In Sweden efforts are underway to provide hourly readings to the customers. In the Netherlands, in-home displays are considered most useful for visualization, and the functionality is mandated, but the installation is not mandated. In the UK all customers are offered in-home displays, as well as web access and apps. In Australia the smart meter has to be capable of communicating with the home area network (HAN) and this would suggest the possibility to integrate an in-home display.

Table 4: Summary of visualization modes in the EDNA Task 1 countries.

Visualisation	AT	CH	DK	NL	SE	UK	AU
Physical billing	x	x	x	every 2 months	every month	?	x
Online access		x		?	?	x	
Provision for in-home displays	?	x	?	x	?	x	(x)
in-home displays				(x)		x	(x)

Legend: x - provision is mandatory; (x) - available but not mandatory; ? - unclear

➔ **Communication**: This refers to the technology used to transfer the data from the smart meter, namely, to the other components of the network, such as the data concentrator (DCO). In Switzerland for example, a distribution of about 70% power line communication (PLC) and 30% general package radio service (GPRS) is expected for the configuration of the roll-outs. The smart meter data is planned to be read out daily, but will not be transferred to the distribution systems operator (DSO) in real time. In The Netherlands, the transfer from the smart meter to the supplier is opt-in. The data transfer for 80% of smart meters will be carried out via PLC and for 20% via GPRS. In Sweden the data transfer to the DCO is distributed, with a mix of GPRS, PLC and/or Radio; PLC only; Radio only; and GPRS. From the DCO to the distribution management system (DSM), the technologies used are GPRS, IP (fiber, etc), Radio, PLC and others.
In the UK, the HAN communication is based on ZigBee. Wide area network (WAN) communications are based on cellular or radio transmission. In Victoria (Australia) HAN communication is also based on ZigBee and most of the smart meter data transfer employs radio transmission. More information on specifications regarding communication is shown in Table 5 below.

Table 5: Communication technologies and additional information on SMI roll-outs of EDNA Task 1 countries[17].

	Communication technologies	**Measurement interval**	**Readout interval**	**Comm. synergies across utility meters**
Austria (AT)	SM to DC: 70% PLC and 30% GPRS. DC to DMS: 100% Fiber optics.	15 mins.	Daily readout	Not planned
Switzerland (CH)	70% PLC and 30% GPRS is expected.	15 mins.	Daily readout or upon request	Planned
Denmark (DK)	PLC+GSM/GPRS and wireless radio frequency.	15 mins. For some SM previous to 2011; 1 hour.	Unknown	Unknown
Netherlands (NL)	80% PLC and 20% GPRS. GPRS chosen for small scale roll-outs.	10 secs.	15 mins.	Yes
Sweden (SE)	SM to DCO: 46% GPRS+PLC+RF; 37% PLC; 17% RF & 1% GPRS. DCO to DMS: 86% GPRS; 33% IP; 9% RF; 8% PLC; 17% other.	1 hour	Unknown	Unknown
United Kingdom (UK)	SM to data and comm. company (DCC): 65% cellular (GPRS and 3G); 33% long range radio; and remaining, mesh radio.	10 sec. updates to consumer (HAN).	30 mins readouts (WAN).	Yes
Australia (AU)	HAN communication based on ZigBee. Most of the SM data transfer with DC and mesh system.	30 mins.	Daily readout	unknown

To assess SMI and EMS in detail, the EDNA Task 1 members agreed to the preparation of case studies, looking at their country characteristics in relation to the extent of the deployment of SMI and EMS. Information on demographics as well as average energy use in the residential sector, as shown below in Figure 6, form the basis for these case studies, and provide the starting point for an

17 Based on information and documents provided by member country delegates.

in depth investigation of selected systems, considering the extent of their adoption and the resulting own energy consumption needed for their operation. The approach for this assessment is described in the following chapter dealing with the methodology and the results.

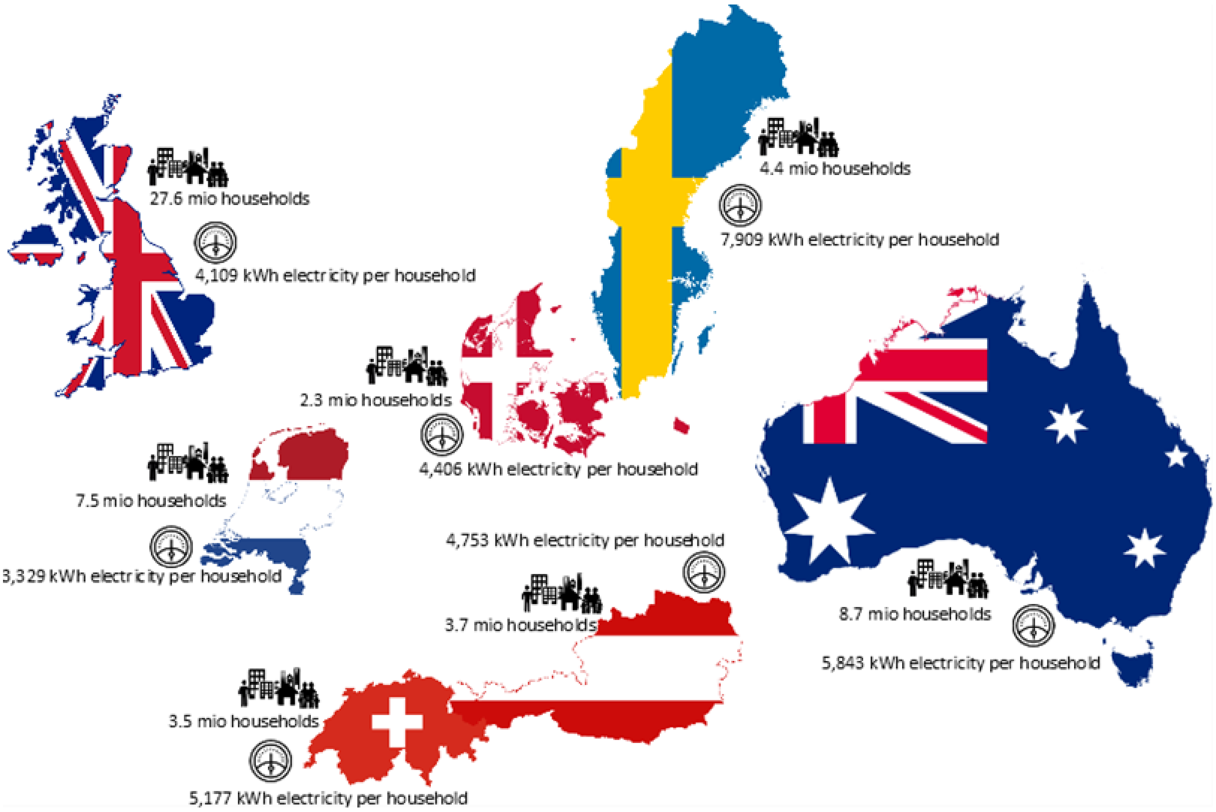


Figure 6: Information on demographics and average energy use in the residential sector for EDNA Task 1 members.

3 Overall description of the approach in Task 1

Starting with a pre-selection of devices and/or systems a prioritization takes place, to further investigate the products or product groups which are representative for a region (e.g., devices available and likely to be installed in significant numbers).

Most smart metering infrastructure (SMI) and energy monitoring systems (EMS) products provide a number of secondary or auxiliary functions. Further, they typically trigger energy consumptions not only at their own site but also at one or more nodes in the network. Hence, the functionalities to be analyzed have to be clearly defined. In the SMART METERING consumption[18] (SMc) project the analysis concentrated on the core functionalities of smart metering systems, namely capturing, logging and transmitting data.

The approach in Task 1 considers the following underlying criteria:

- **Completeness**: A spatial system boundary has to be defined for every product or system to be analyzed. This is necessary for the correct allocation of the (own) energy consumption of devices or processes considered in the analysis.
- **Reliability**: the quality of the single input data used in the modeling shall be assessed. In the best case e.g., when data from real power measurements is used, confidence intervals shall be determined as far as possible.
- **Flexibility**: The methodology is to be built from single contributions to the system´s total energy consumption. Different combinations of the single contributions allow the representation and modeling of diverse systems and/or applications, and allow the comparison between examples and case studies.
- **Comprehensiveness**: The results shall be presented in a general, easily understandable way that provides least possible room for misinterpretations.

18 SMART METERING consumption was a project assessing the own energy consumption aspect of smart metering infrastructure, carried out as a binational study commissioned by the Swiss federal ministry of energy and the Austrian ministry for transport, innovation, and technology (see Preisel, et al. 2012)

Data structure

The graphic in Figure 7 shows the data structure used in the modeling process, sorted in different “data levels”.

These data levels do not represent the chronological sequence of steps to be performed during modeling, but simply indicate the structure of the data, going from the smallest unit of information to the high-level end result. The actual step by step procedures for modeling the SMI and EMS case studies are described separately in subsections 3.1.2 and 3.2.2., as they are different for these different systems. SMI and EMS are brought into the market differently, therefore different reference units are used to keep the logic in alignment to the common thinking in the corresponding industry.

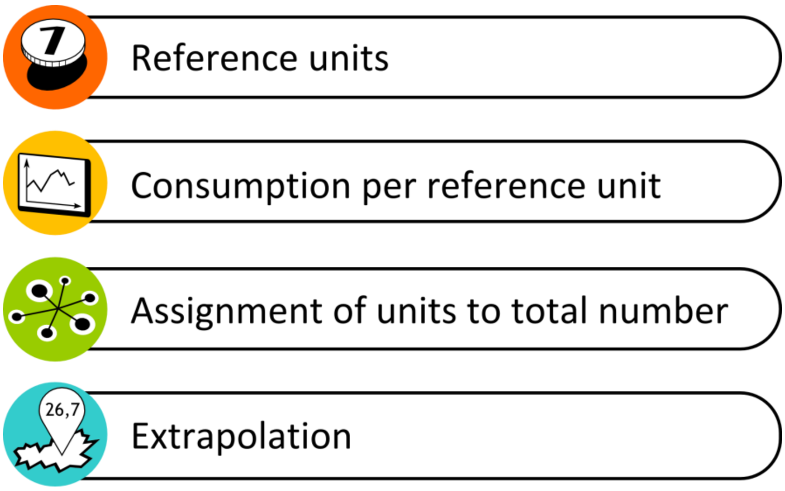
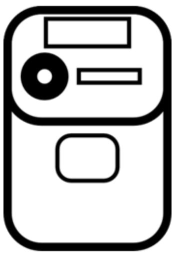


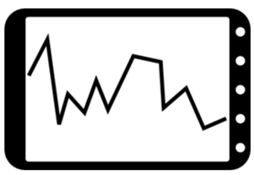
Figure 7: Data levels for the modeling of SMI and EMS.

For better orientation, the corresponding text passages are identified with the following symbols:

SMI
Smart Metering Infrastructure



EMS
Energy Monitoring Systems

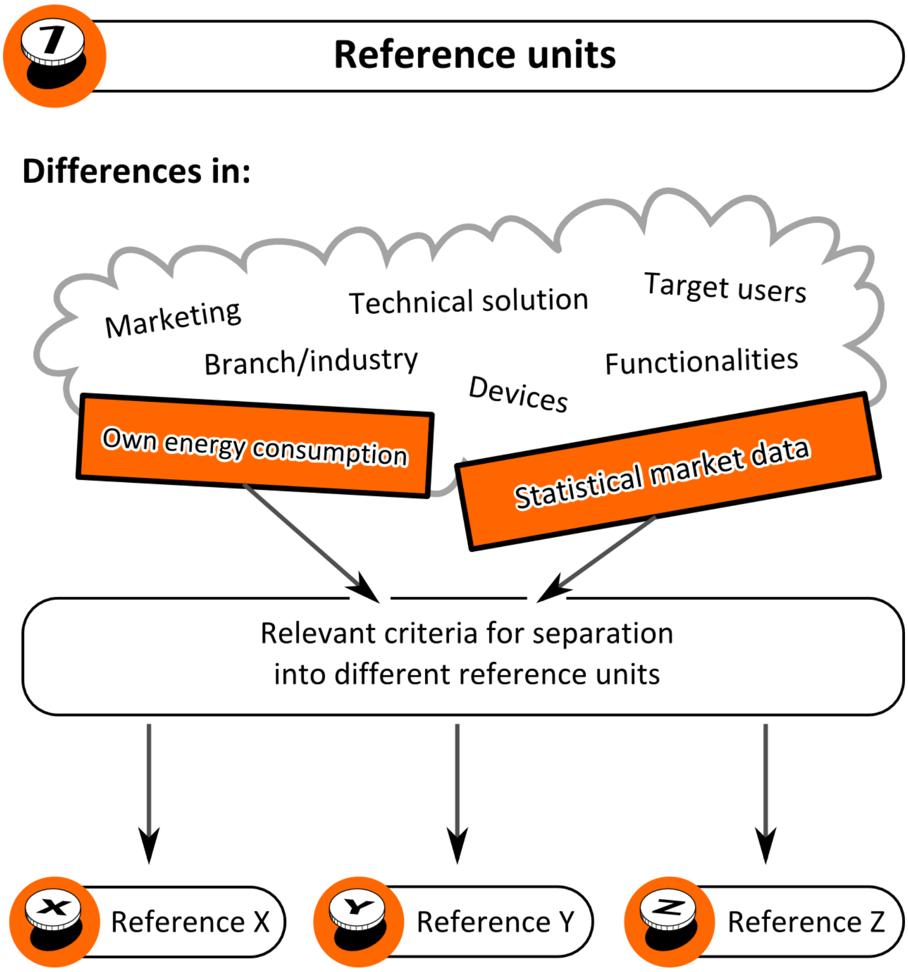


The following four pages of this section describe the quality and type of data, both for SMI and EMS, according to the four data levels in Figure 7.

Reference units

A reference unit should be defined, which considers a reasonable system boundary for the objects to be analyzed. The system boundary for the reference unit can be set around e.g., one household, one metering point, or even a sub-region. By this setup, it will represent a small building block that can be used to perform an extrapolation later on.

To perform extrapolations which combine different technical solutions or product groups, multiple reference units are needed. Following this logic, every single reference unit represents a category of a technical solution or product group, like the exemplary entries X, Y, and Z in Figure 8.
Certain properties of the available products in the market differ significantly. However, differences in the own energy consumption and individual statistical market data must be given to allow for such a categorization and an extrapolation[19].



Example:

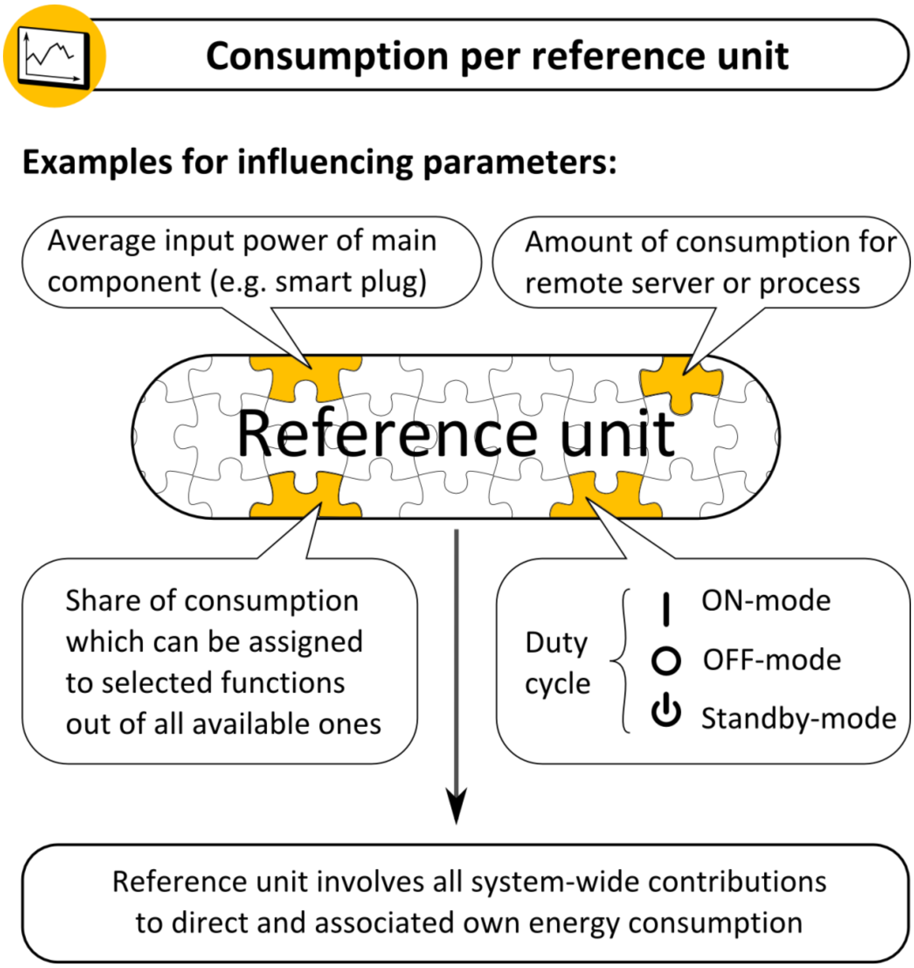
Smart meters are either connected to 1-phase or to 3-phase metering points. 1-phase meters consistently show lower own energy consumption than 3-phase meters. Further, the numbers of metering points for the roll-out region are commonly listed separately for 1-phase and 3-phase metering points. Therefore, it makes sense, to differentiate between these two types of meters and create separate reference units.

Figure 8: Data level "Reference units"

19 If the own energy consumption for all analyzed systems were equal, it would not make sense to split them into sub-categories. Similarly, if the statistical market data does not allow for separate extrapolations according to the chosen sub-categories, it would also not make sense to split them into sub-categories. Therefore, these two characterizations are never negligible.

Consumption per reference unit

To gather data on energy consumption, a reasonable compromise needs to be reached between keeping the necessary level of accuracy on the one hand, and limiting the time burden on the other hand. As such it is necessary to identify the components and/or processes which contribute to the own energy consumption, and which are part of a chosen reference unit. Further, different operational states might need to be identified for these components. In that case, either an average value or detailed information on the different states and duty cycles is required.



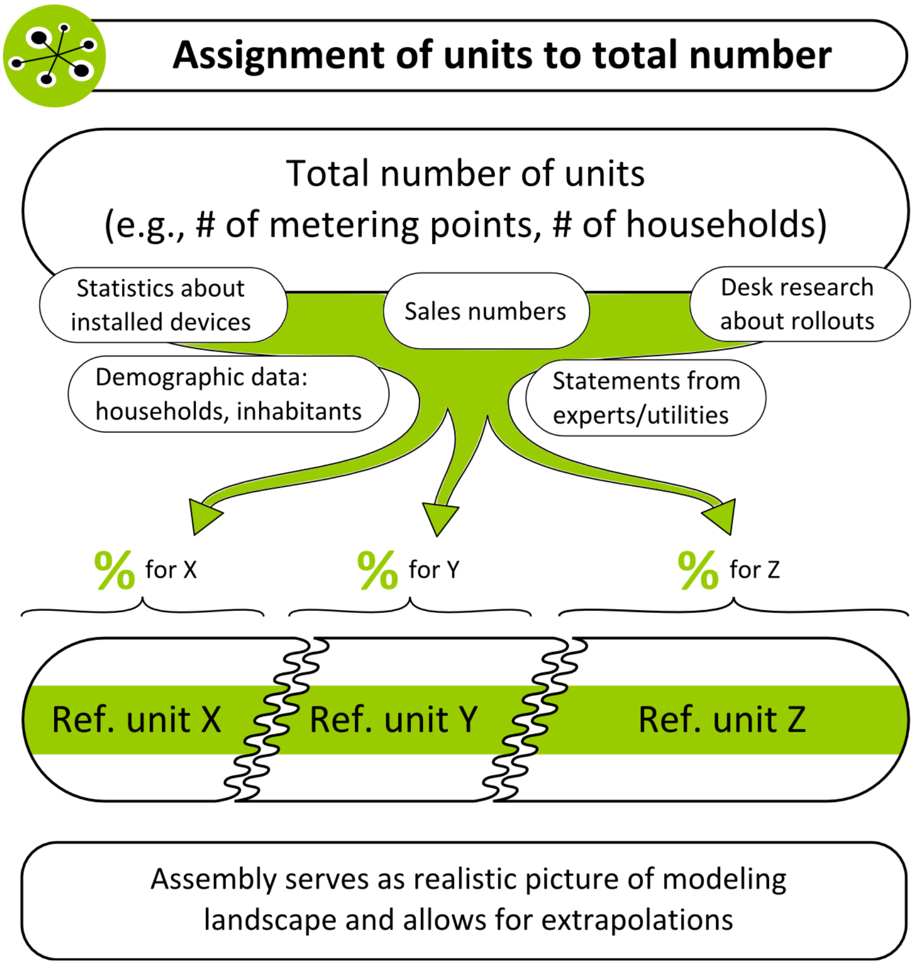
Example:

A fictitious energy monitoring system of a household consists of 3 smart plugs and one base unit. The base unit alternates between different operating states. The actual mix (realistic duty cycle) is a consequence of how it is used – it makes sense to perform measurements on a real installation with a realistic use scenario.

Figure 9: Data level “Consumption per reference unit”.

Assignment of units to total number

It has to be clarified, which kind of data sources can be used to describe the total number of all reference units to a reasonable level of accuracy to allow for representative extrapolations. It has to be kept in mind, that it should be possible to quantify the entities (e.g., number of metering points or number of households) from different reference unit sub-categories separately.
If not, an alternative workaround must be found.



Example:

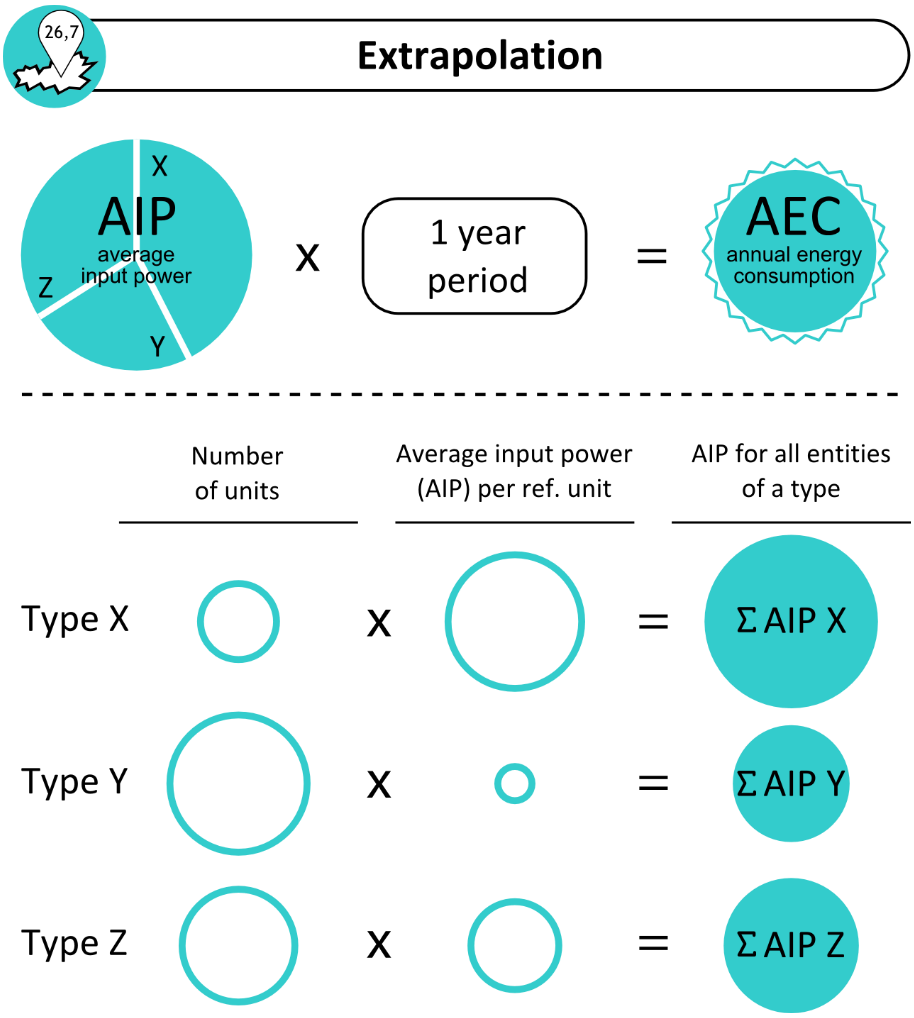
The total number of metering points of a smart meter roll-out region including the split into PLC-, GPRS-, and radio-connected metering points are given.
This enables the quantification of the total number of different units installed, labelled reference units X, Y, and Z.

Figure 10: Data level "Assignment of units to total number"

Extrapolation

For the presentation of the results, the differences and possible future conditions need to be considered, e.g., the resulting data on the own energy consumption for the complete systems under study should be displayed in a compact form using appropriate underlying scenarios.

In the most basic case, the average input power (AIP) value already covers time averaging (respecting duty cycles), weighted averaging over the different systems to be installed in the region or market, and – if applicable – realistic weighting over different use scenarios. In simple terms, this one indicator has to incorporate all notable influences that have a certain effect on the system-wide own energy consumption. If all of these considerations have been taken into account, the extrapolation is just the integration of one "combined" AIP value over the period of one year, giving the corresponding energy demand for one year in operation (AEC). This is shown in the upper part of Figure 11.
The lower part shows a case, where the extrapolation considers a separation into different types (with different reference units). As explained in the data level "reference units", these reference units differ in the AIP (information about the own energy consumption) and may have different market shares or roll-out targets (compare data level "Assignment of units to total number").



Example:

The AIP for all entities is calculated as the AIP per reference unit multiplied by the number of entities. Then, this result times a one year period gives the annual energy consumption which is representative for the total number of installations, the size of a market, a future scenario, etc.

If multiple reference units are given, the AIP for all entities of each types must be calculated separately and summed up.

Figure 11: Data level "Extrapolation".

3.1 SMI: methodology and data issues

This section describes the methodological approach in Task 1, to assess the own energy consumption of the **smart metering infrastructure** (SMI). The own energy consumption is the energy required by the infrastructure to fulfill its basic functions during normal operation.

3.1.1 Definition of SMI in this context

SMI comprises all the devices, from the metering point located at the premises of the consumer (household), up to the head-end located at the center of the network.

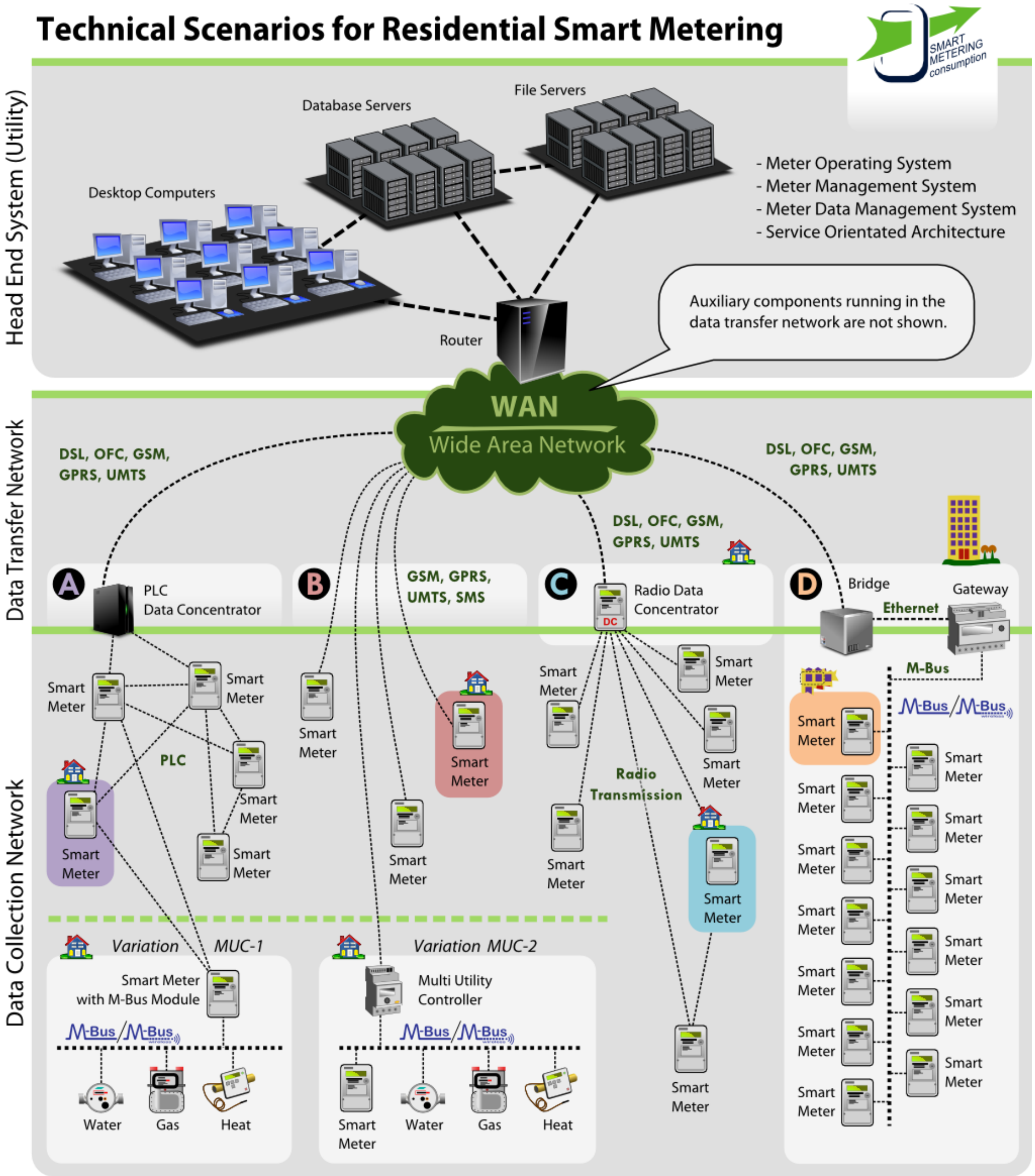


Figure 12: Network model showing four different ways to collect data from smart meters.[20]

20 Preisel et al., 2012

This infrastructure shall measure, compute, and log the electric energy consumption data from the end-users and transfer it to the energy utility. The basic component of the smart metering system is the so-called smart meter, which is a combination of an electricity meter, a small computer, and a communication modem. When there is no direct connection, additional devices such as data concentrators (DCOs) and/or gateways are needed. The network can be operated by the energy utility, by a telecommunications provider, or by other third party service providers.
Figure 12 has been developed for the SMART METERING consumption (SMc) project and gives an overview of the different sections of the network, which components are involved and which different kinds of connections are in practical use (which will be better described in Step 1 of section 3.1.2).

3.1.2 Building a SMI case study

The sequence followed to build the case studies for the assessment of SMI is shown in Figure 13 below. A simplified example is presented in this section to illustrate this process.

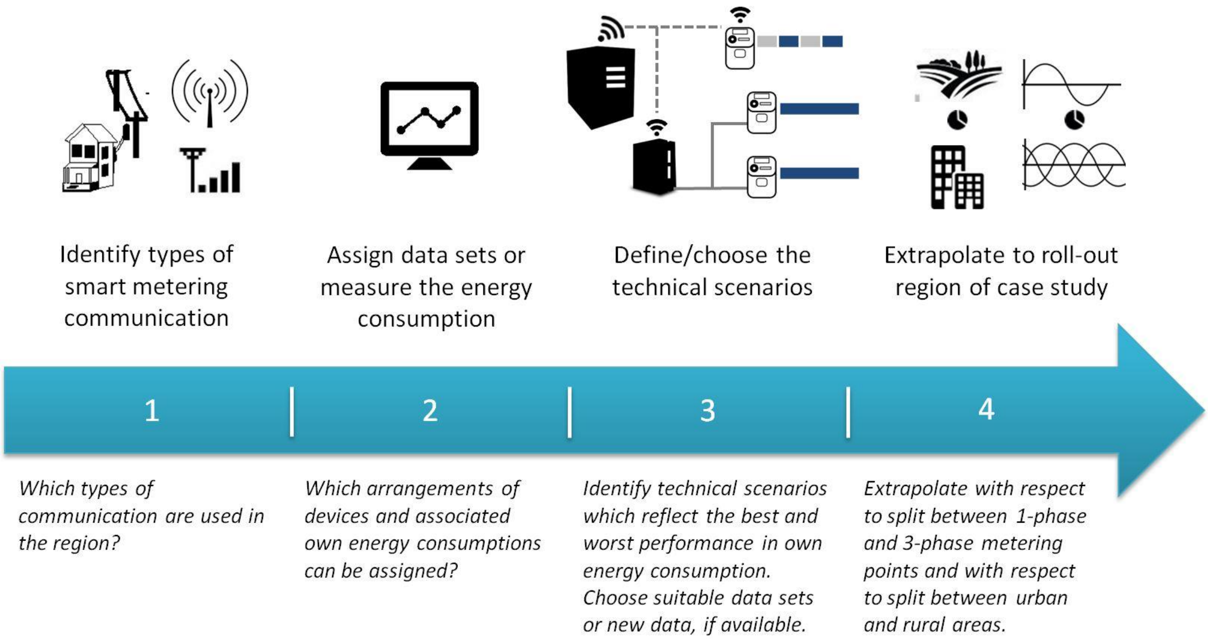


Figure 13: Steps to building an SMI case study

The following source data is needed to build a SMI case study:

Data level	Short description of source data
Reference units	• Overview of available systems and the contained devices • Rough ranges for own energy consumptions of involved devices and processes (illustrative or indicative data) • Anticipation of reference units that are typical for the industry and policies
Consumption of reference unit	• Own **energy consumption** of the meters and the other components of the SM infrastructure, on average and/or for specific operational modes (if available). • Information about duty cycles and operational modes

	Assignment of units to total number	• Data on “meter park”: Total **number of metering points** and their split into sectors e.g., residential, commercial, industrial, agricultural or other. Specific demographics data can also be used, e.g. urban vs. rural household units; detached or semi-detached houses vs. block of flats; single-phase vs. poly-phase meters, and the split into grid regions. • Technical information about the rollout
	Extrapolation	• **Concrete SMI installation**, including present roll-out status and/or plans, and the communication technologies including their split.

The research into the available key data concentrated on three main sources:

- ✓ EDNA member countries
- ✓ Selected companies and their products
- ✓ Existing data base from the SMART METERING consumption (SMc) project

Step 1: Identify types of smart metering communication

There are different technical solutions in place to gather the meter data at the head-end of the smart metering network. As shown in Figure 14, these can be separated into the four big groups of power line communication (category A), GPRS (category B), radio transmission (category C), and wireless M-Bus (category D). These groups differ by the means of communication along the so-called “last mile” which is the distance between the metering point (i.e. the household) and the next following node in the network. This part of the network is also called the “data collection network”. From there upwards (“data transfer network”) often other means of communication are used. In most cases, telecommunication providers run this service using standard technologies like GPRS (as shown in the figure). As a reference, Figure 12 shows the differences between the four categories in more detail.

A) **Power line communication (PLC)** is used along the “last mile”, between multiple smart meters and a data concentrator (DCO). GPRS (general packet radio service) is used to forward the aggregated data from the DCO to the head-end. Around 30 to 200 smart meters are commonly connected to each PLC DCO. This solution allows the energy utilities using their own existing power lines for the data transmission. In this case, the AC voltage signal carried on the power lines is modulated to transmit the information between the smart meters and the DCO.

B) Every single metering point has a **direct GPRS connection** to the head end system. In this case, a telecommunication provider runs the service to read out every single metering point.

C) Along the “last mile”, **radio transmission** is used. There are different types in place, the transmission can be organized using direct connections from each smart meter to the data concentrator, or in form of “meshed radio”, where meters adopt repeating functions (received messages from other meters are being forwarded in order to enhance stability and range of the system).

D) This is a data collection method to be applied in dense settled areas. **Wireless M-Bus** is used to collect meter data which can be reached within a building (residential or office buildings). The collected data is then sent to the head end like for A or C.

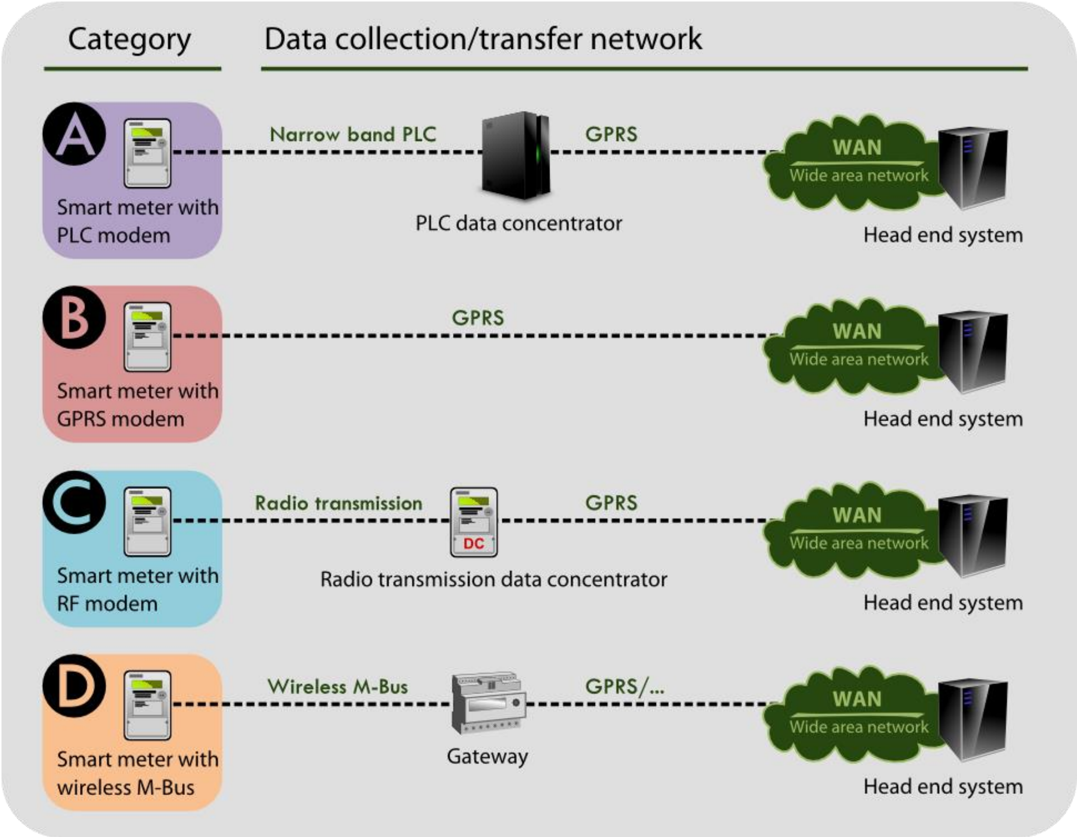


Figure 14: Categorization of SMI after means of communication. The main distinction between different data collection technologies is derived from the priorities a power utility sets for making decisions about its investments, and is not based on their contribution to the total energy consumption.[21]

The primary categorization by the means of communication is the most appropriate one to analyze the own energy consumption of smart metering infrastructure. The sequence in which the modeling is done is not established according to the assumed contribution to the consumption (even though this is all known and accounted for in the calculations).

The chosen path rather follows a similar logic to that of an energy utility in making decisions for deploying a smart metering system in a region. This approach starts with a look at the physical product. When the meter is of a compact type (ready-made combination of meter and communication modem), the communication options are defined.

21 Preisel, et al., 2012

Step 2: Assign data sets or measure the energy consumption

Qualities and sources of data

A challenging part of the modeling work is to obtain all necessary data. Naturally, as many different stakeholders have an influence on the market, the data has to be collected from various sources, as listed below.

For EDNA Task 1 SMI&EMS the main source of information are the responses from a questionnaire by the delegates. The questionnaire asked for technical details on the rollouts, national legal requirements and other aspects with regard to smart metering.

Typically, one or more cost-benefit studies have been carried out in each country planning to roll out smart meters, which are always based on economic data (CAPEX, OPEX costs), but specific, technical input data for rollout descriptions, large pilots, especially own energy consumption are very hard to obtain and sometimes not available.

- **Manufacturers of smart meters**:
    - Technical details about the inner workings (measurement principle, basic information about hardware like semiconductors, breaker unit)
    - Product portfolio (modularity vs. compact solutions) and shipping conditions
    - System solutions – if possible
    - Interfaces and protocols
    - Customers and pilot installations

- **System providers and service providers for smart metering infrastructure**:
    - Cross-compatibility of solutions from different manufacturers
    - Customers and demo installations
    - Organization of readout processes and other regular procedures

- **Utilities, grid operators:**
    - Split of communication technologies in their supply region
    - Concrete rollout plans in their supply region
    - Subjective major criteria for choice of metering solutions
    - Decisions over specific chosen manufacturers and solutions/information about running tenders procedures

- **Regulatory agencies, statistic organizations** or other authorities in the field of the energy sector:
    - Total number of all metering points, categorized after sectors
    - Regulations about mandatory functionalities the SMI has to provide
    - Legal background for smart metering

- **Expert opinions**:
    - Any information about complex relations about communication technologies, approximated numbers for the associated energy consumption of processes

- **Measurement partners** (like research organizations, universities):

- Know-how and facilities for performing measurements of own energy consumption under various conditions (e.g., like secondary load, communication, grid characteristics ...)
- Access to pilot projects or former project partners in the field of the energy business

➔ For the purpose of documentation the quality of data should be classified as follows:

(X) ... Illustrative data: based on conservative estimates. It is not possible to make reliable statements with illustrative data, so the results are to be interpreted with caution, however help to sum up all contributions to a closed picture of the system-wide energy consumptions.
Example: Estimate by an expert for own energy consumption of head-end servers, broken down to one metering point.

(I) ... Indicative data: data derived from other documentation from third parties, such as datasheets, public available studies or other data.

(R) ... Robust data: generated data resulting from (own) measurements carried out during assessments.

Important aspects of the metering infrastructure

To provide a relatively robust approximation, at least, the following two aspects should be considered key when modeling smart metering infrastructure:

- **Distinguish between single- and poly-phase metering points**
  On average, there is a factor of 1.5 between the input power (AIP) of a 3-phase and a 1-phase meter. Unlike the case of Ferraris meters (mechanical electricity meter), the single phases do not require the same amount of energy. One of the phases of a poly-phase meter is used for the metrology and the communication part of the meter.
  The number of phases is given by the existing installations in the region (households are either 3-phase or 1-phase connected). Hence, it is naturally not affected by the change to smart meters. However, the ratio of 3-phase AIP to 1-phase AIP depends heavily on the technical solution to be used. Therefore, it is important to take the number of phases into account.
- **Subdivide metering points into urban and rural areas**
  For the categories A, C, and D (Figure 14), it plays a key role, how many metering points will be connected to one data concentrator or gateway on average. For radio transmission methods, but even more so for PLC this basically depends on the topography of the area and a number of various influences that are capable of disturbing the communication.
  To keep the extrapolation easy, typical average numbers for the meters per data concentrator shall be assumed which apply for urban areas or rural regions, respectively (shown in Table 7 in Step 3).

Measurement procedure

During EDNA Task 1 it was unfortunately not possible to perform new measurements on smart metering infrastructure, although different approaches to cooperate with measurement laboratories and partly together with utilities were explored.

In spring 2015 a meeting with the project leaders of a demonstration project was held to arrange access to smart meter and energy monitoring installations. The cooperation fell through as the installations were been removed prematurely.

Later in 2015 a cooperation with an energy utility with a strong interest in the topic of own energy consumption of their SMI was planned. In fact, the utility companies are still in the decision process for a specific solution and have not yet been able to allocate time to their own energy consumption project so far.
However, it may still be possible to measure a European benchmark low energy smart meter under realistic conditions in cooperation with this utility and communication is ongoing.
The idea behind achieving realistic measurement condition is to install the meter in a pilot project network, so that read-out and communication processes are exactly the same as for every other registered smart meter in the grid. The only difference would be that there is no secondary load (ie. Household) connected to the meter. The measurement would then be one using another meter which has been modified to measure with a resolution of 1/100 with regard to its original factory side condition.

To further progress with the measurements on smart meters two other research institutes contacted. One was fully booked with other projects and the other one could not provide measurement equipment to perform measurements at the necessary accuracy.

After all these efforts and its results the already approved method for performing smart meter AIP measurements developed within the SMc project had been used as reference method and is described in the following.

For the purposes of the SMc project, measurements of the active energy consumptions in the laboratory as well as in field tests had been carried out to support all the modeling work with reliable data. The test series had been set to cover a representative variety of smart metering solutions available on the market. Components which have the greatest occurrence in the metering system had been given priority. These are the smart meters and their corresponding modules, and on second place, the data concentrators. The metrological work had been performed by a competent project partner, the Institute of Electrical Power Systems of the Graz University of Technology.

The measurements were addressing the main drivers for energy consumption which had been previously identified during an experts' workshop with participants from different industries:

- Metering
- Communication
- Hardware design
- Additional features

The measurement work had been completed in four blocks:

1. **Approval of the measurement equipment and arrangement**:
   Figure 15 shows the test circuit which had been used to measure without any load. In that case, only the voltage and current signals located at the net side of the meter had to be registered. As the current is low a simple shunt test circuit is sufficient. This arrangement allows measurements with high accuracy, but can only be used without the presence of load on the user side of the meter.

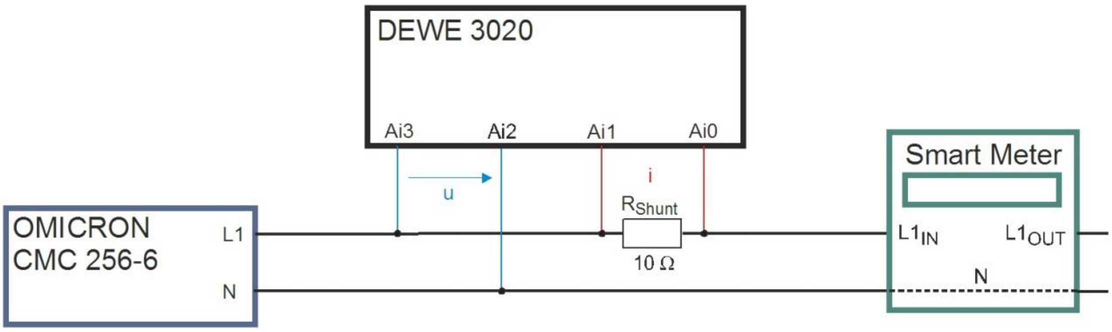


Figure 15: Test circuit using shunts - for power measurements at the meter when it is operated without load.[22]

Figure 16 shows the circuit for measurements with load of up to 16 A. This circuit had been used to analyze the sensitivity in the laboratory, and also for live measurements in the field.

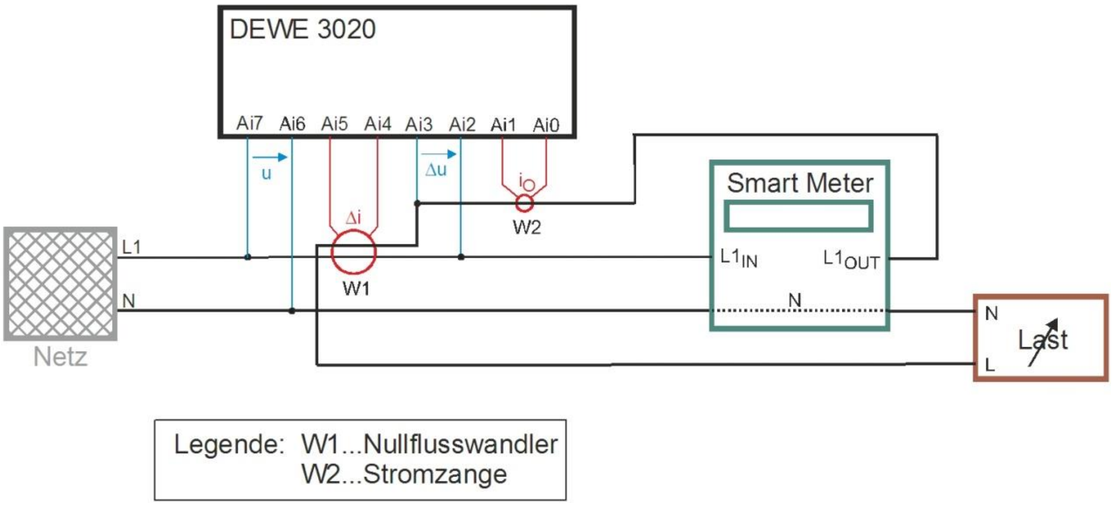


Figure 16: Test circuit using current transducers – for power measurements at the meter in real use cases, when there is a certain load, caused by the end-user.[23] *(Netz = Grid; Last = Secondary load)*

2. **Sensitivity analysis** for the mains voltage, total harmonic distortion (both coming from the net source), load current, and power factor (both caused by different types of loads) was undertaken for two 3-phase smart meter products that are well represented in the Swiss-Austrian market. As an example, Figure 17 shows the relative change of own consumption as a function of load, for smart meter products from different manufacturers. Both circuits, without load and under load, had been evaluated in parallel.

22 Preisel et al., 2012

23 Preisel et al., 2012

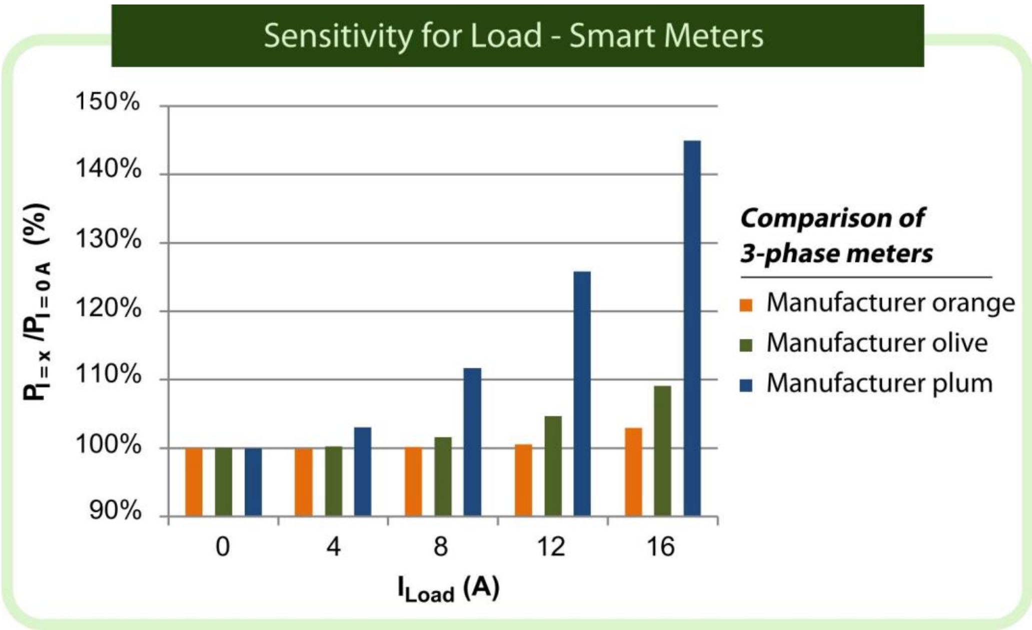


Figure 17: Anonymized comparison of sensitivity for load of different manufacturer-specific mart meter products, normalized to state without load.[24]

3. **Performing measurements** of own energy consumption of different smart meter products without load and under load, in laboratory conditions.

4. **Capturing live measurement data** over 24 hours: Real households situated in regions of power utilities cooperating in the SMc project facilitated this work. The most important additional data coming from these real application cases was the consumption profile over time, in connection to the remote controlled data requests to the meters.

24 Preisel et al., 2012

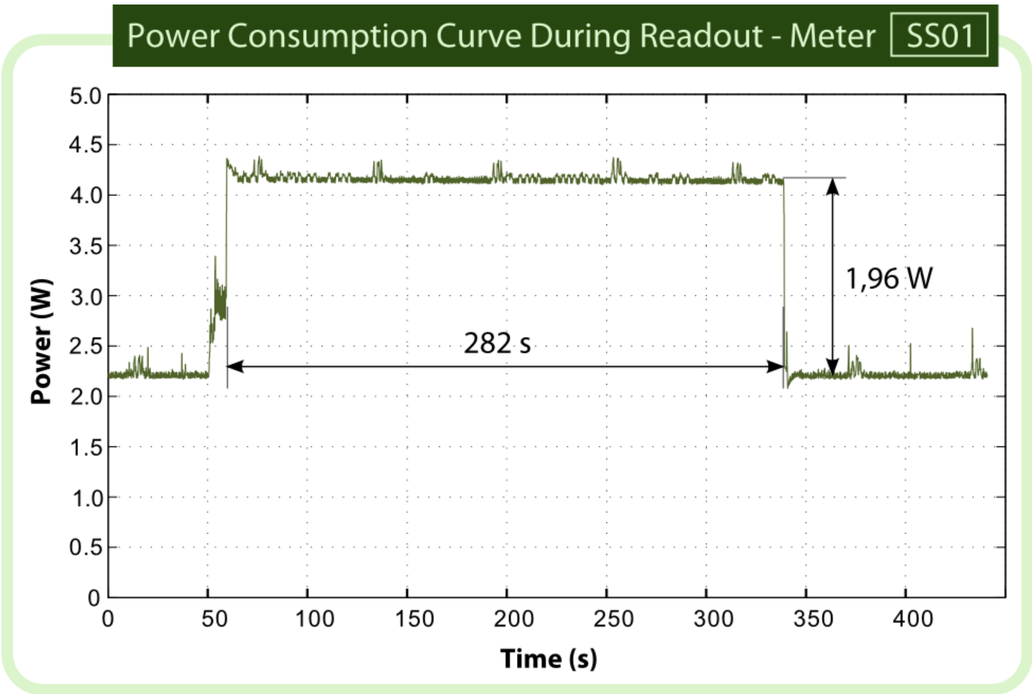


Figure 18: Input power curve of a 3-phase GPRS-connected smart meter - extract of a data transfer event (entire consumption log lasted for 24 hrs.)[25]

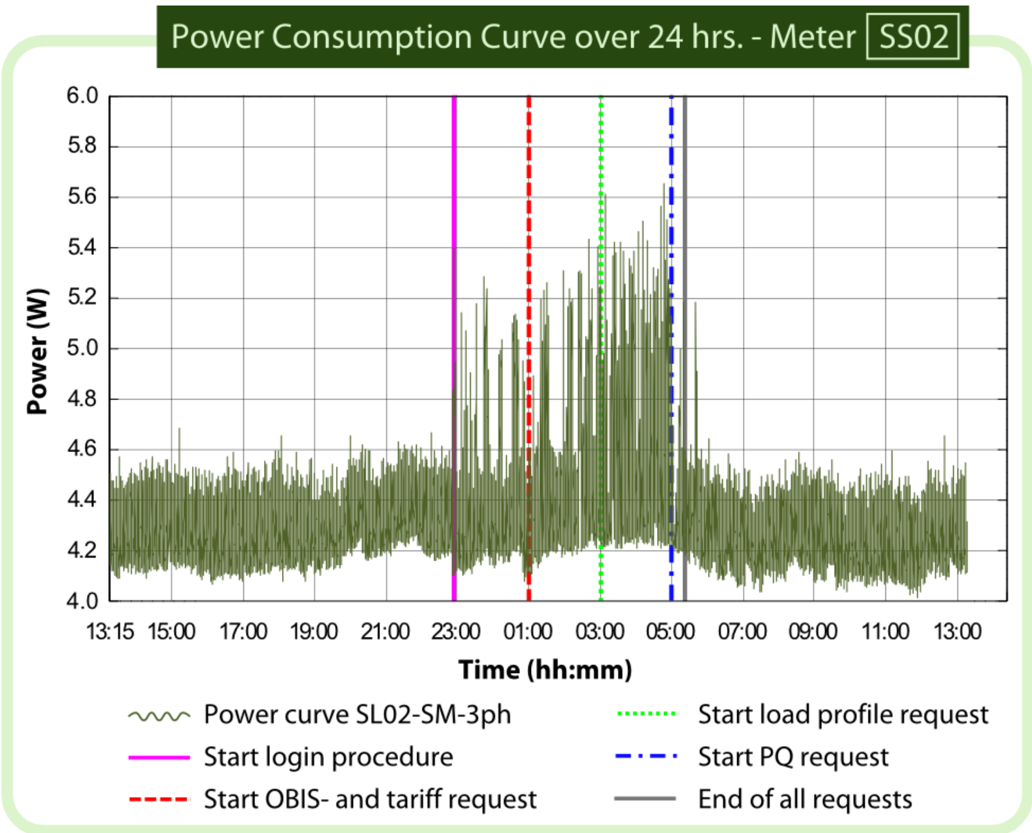


Figure 19: Input power curve of a 3-phase PLC-connected smart meter - during 24 hrs.[26]

25 Preisel et al., 2012

26 Preisel et al., 2012

Figure 18 shows that the readout of data over the tested GPRS system had showed an input power increase during a timespan of about five minutes. The readout process over the tested PLC system had lasted for 6 hrs, as shown in Figure 19.

Step 3: Define/choose the technical scenarios

List of relevant contributions to own energy consumption

The combination of all average input power (AIP) values from associated components and processes which together form a functioning smart metering solution shall be called a “Technical scenario”. The main idea behind that is to obtain the average input power ($\overline{P_{MP}}$) referring to one single metering point and considering all relevant contributions over the whole system.
Table 6 shows the components for the Technical scenario TSC A_1, which belongs to a classic PLC installation. Beside the AIP value $\overline{P}$ (W), the data quality and source are also given as discussed above under step 2.

Table 6: List of technical components (devices and servers) which play a significant role for modeling a "Technical scenario"[27]

TSC A_1 – List of technical components

Aggregated values are estimated for the devices of the data collection network of TSC A_1.

Technical component	Description (reference)	$\overline{P}$ (W)	Data type	Source
One-phase meter	Compact one-phase meter with breaker (SS02-SM-1ph)	3.13	R	Measurements carried out during the project (2011)
Three-phase meter	Compact three-phase meter with breaker (SS02-SM-3ph)	4.68	R	Measurements carried out during the project (2011)
Data concentrator	Data concentrator with power supply unit, to be installed in the transformer station.	11.56	R	Measurements carried out during the project (2011)
Data concentrator modem	A corresponding modem is used for communication with the head-end via GPRS (SS02-DC)	6.42	R	Measurements carried out during the project (2011)
Telecomm-unication operator	For the processes run at the operator, the same power consumption as for a GPRS meter module has been considered.	0.50	X	Conservative assumption based on expert´s opinion (2012)
IT server	Derived from the total server power to which 4300 metering points are allocated.	35 mW	X	Conservative estimate.

This list must not be misunderstood in a way that these contributions should be summed up as is. Rather, feasible combinations out of specific entries and/or shares of entries like the AIP for the data

27 Preisel et al., 2012

concentrator form the AIP per metering point, as shown by Table 7 for the example of the Technical scenario TSC A_1 above.

Table 7: Metering point active input power values for the technical scenario A_1 of the category A connection.[28]

Scenario	Assumptions	Metering point type	$\overline{P_{MP}}$ (W)
A_1 – 200MP	200 metering points per data concentrator	One-phase	3.26
		Three-phase	4.81
A_1 – 100MP	100 metering points per data concentrator	One-phase	3.35
		Three-phase	4.90
A_1 – 35MP	35 metering points per data concentrator	One-phase	3.69
		Three-phase	5.24

Seven different Technical scenarios for which information and data were accessible in Austria and Switzerland had been modeled for the SMc project. The outcomes for the annual energy consumption (AEC), are shown in Figure 20.

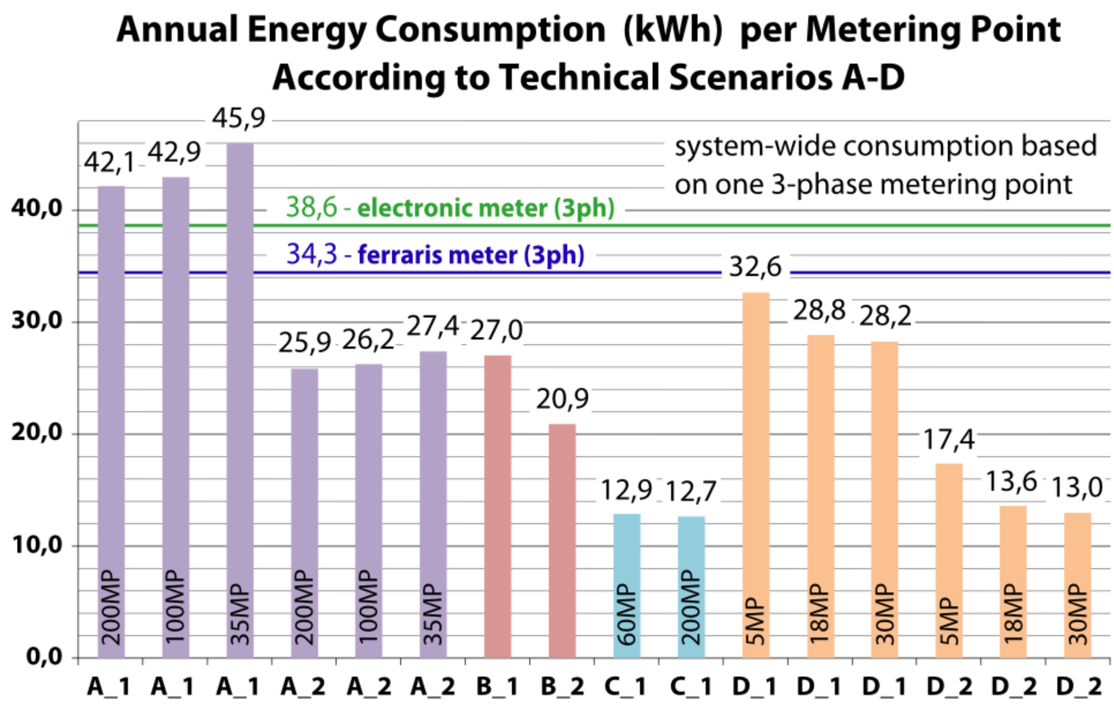


Figure 20 Comparison of energy consumption figures in kWh per metering point and over the time span of one year.[29]

28 Preisel et al., 2012

29 Preisel et al., 2012

Step 4: Extrapolate to roll-out region of case study

An example for a fictitious simple case study is presented here to illustrate how the extrapolations work for a region of 3.5 million metering points, where the rollout goal foresees 70% PLC connected meters and 30% GPRS connected meters. For the PLC meters, 60% urban metering points and 40% rural metering points shall be assumed (GPRS meters do not make use of data concentrators, therefore this differentiation doesn't play a role for them).

Table 8 shows an exemplary selection of technical scenarios and their own energy consumption data per metering point.

Table 8: The average input power consumption per metering point for different Technical scenarios.[30]

Technical scenario	Metering points included	Metering point type	$\overline{P_{MP}}$ (W)
A_1 – 200MP	For **urban** region: 200 metering points per DCO.	1-phase 3-phase	3.26 4.81
A_1 – 35MP	For **rural** region: 35 metering points per DCO.	1-phase 3-phase	3.69 5.24
B_2	Same energy consumption per connection at the operator side as for the communication module of the smart meter.	1-phase 3-phase	1.83 2.38

For a 100% rollout goal, the following linear combination is used to calculate the annual energy consumption for smart metering infrastructure of the region. Taking the system-wide AIP per metering point $\overline{P_{MP}}$ from Table 8 it is easy to extrapolate. The energy consumption E over a time span t is then:

$$E = \left(n_{A\_1-200} \cdot \overline{P_{MP}}_{A\_1,urban} + n_{A\_1-35} \cdot \overline{P_{MP}}_{A\_1,rural} + n_{B\_2} \cdot \overline{P_{MP}}_{B\_2}\right) \cdot t$$

Where:

$n_{A\_1-200} = 3.5 \cdot 10^6 \cdot 0.6 \cdot 0.7 = 1.47\ mio.$ (Number of metering points operated with A_1-200MP)

$n_{A\_1-35} = 3.5 \cdot 10^6 \cdot 0.4 \cdot 0.7 = 0.98\ mio.$ (Number of metering points operated with A_1-35MP)

$n_{B\_2} = 3.5 \cdot 10^6 \cdot 0.3 = 1.05\ mio.$ (Number of metering points being operated with B_2).

Thanks to the work already done in the previous steps 1 to 3, this calculation covers several devices and their allocation of the energy consumption, namely the smart meter and a share of own energy consumption of the remaining components, e.g. 1/200 part of the consumption of the DCO in the case of A_1 – 200MP (for 200 metering points per DCO). It also considers the different functions of the components, especially for the smart meter which alternates between measuring, logging and transmitting data. As a consequence, the average input power values always have to reflect an average value over time, so that practically relevant duty cycles are represented correctly.

30 Preisel et al., 2012

Table 8 shows the own energy consumption of 1-phase and 3-phase meters. To simplify this example let us consider 3-phase metering points only with:

$\overline{P_{MP}}_{A\_1,urban}$= 4.81 W (for PLC connected 3-phase metering points using A_1 in urban areas)

$\overline{P_{MP}}_{A\_1,rural}$ = 5.24 W (for PLC connected 3-phase metering points using A_1 in rural areas)

$\overline{P_{MP}}_{B\_2}$= 2.38 W (for GPRS connected 3-phase metering points using B_2).

Hence, the total own electricity consumption of the SMI for this example of 3.5 million metering points over the time span of one year is:

$$E = (1.47 \cdot 4.81 + 0.98 \cdot 5.24 + 1.05 \cdot 2.38) \cdot 10^6 W \cdot 365 \frac{days}{year} \cdot 24\, h/day = 128.8\, GWh$$

3.2 EMS: methodology and data issues

This section describes the methodological approach followed in Task 1, to assess the own energy consumption of the **energy monitoring systems** (EMS). The own energy consumption is the energy required by the whole system to fulfill its basic functions during normal operation.

3.2.1 Definition of EMS in this context

A residential EMS is a system that visualizes the electrical energy consumption in a household for the end consumer(s). This information has to be accessible to the user in almost real-time and/or on-demand. The data should include the current input power as well as logged consumption data.

3.2.2 Building an EMS case study

The sequence followed to build the case studies for the assessment of EMS is shown in Figure 21 below. A simplified example is presented in this section to illustrate this process.

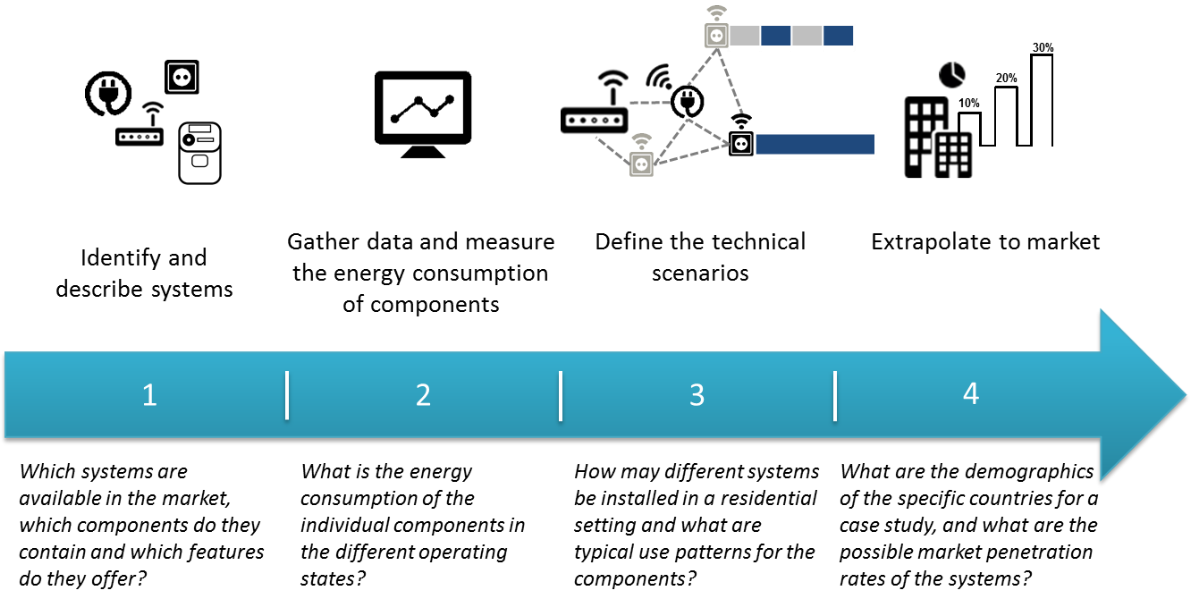


Figure 21: Steps to building an EMS case study

The following source data is needed to build an EMS case study:

Data level	Short description of source data
Reference units	• Overview of available systems and the contained devices
Consumption of reference unit	• Own energy consumption of devices and systems
Assignment of units to total number	• Technical installation data and use scenarios
Extrapolation	• Current and/or projected market penetration of EMS

The research into the available data on these four key aspects concentrated on three main sources:

- ✓ EDNA member countries
- ✓ Selected companies and their products
- ✓ Scientific papers , reports, and general desk research

Step 1: Identifying and describing EM systems

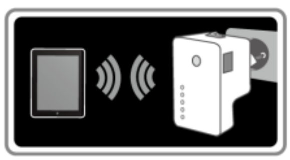
Overview of available systems

The EDNA member countries could only provide rough guidance on which types of systems are available in their respective markets, so general desk research was carried out to identify the different types of systems available. The initial market research showed that there were a great number of different systems available in the market all across the world. New systems were continuously entering the market, with the number of new entries to the market not showing any signs of slowing down during the investigation period March to June 2015. It soon became clear that Energy Monitoring and more broadly speaking, Smart Home solutions, promising energy monitoring functions, could not all be identified and described in the scope of this task. A report by Kotschi Consulting showed over 180 companies involved in the German market alone in 2014.[31]

With the EMS market being very young and diverse, concrete market data was not available. The available information barely allowed for an identification of the big players. It was however possible to distinguish different types of systems available on the market, through the features they offered. To allow for a meaningful assessment within this task, first, systems that did not offer the most basic of functions: "Energy monitoring in consumer households", were excluded from the investigation. Secondly, it became clear that some systems were extremely complex and offered a myriad of functions beside energy monitoring while other systems were single devices offering only very basic energy monitoring. These systems cannot be compared like for like and therefore a distinction had to be made. It came in the form of a classification into three types of systems, respectively labelled Monitoring, Management and Automation.

Classification of systems

Monitoring
Most commonly single point measurement using the smart meter or inductive clamp



Management
Most commonly set of wall plugs, enhanced by simple features like scheduled time profile switching.

Automation
Most commonly full home automation with features beyond energy monitoring.

Cut-off criteria had to be derived, to define which systems would be included in the investigation and which would not. All systems to be included in the investigation would fall within the boundary between simple monitoring and complex automation. The simplest systems were single point, real time monitoring systems and here a cutoff was made to exclude single node measurement devices

31 KOTSCHI CONSULTING, 2014

with an integrated display. The most complex systems were automation systems which were primarily designed to automate processes in the home, with features reaching far beyond monitoring or load switching. These complex systems were also excluded in this investigation.

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 and cannot be used to switch loads. Monitoring systems are intended to allow for energy savings through behavior changes.

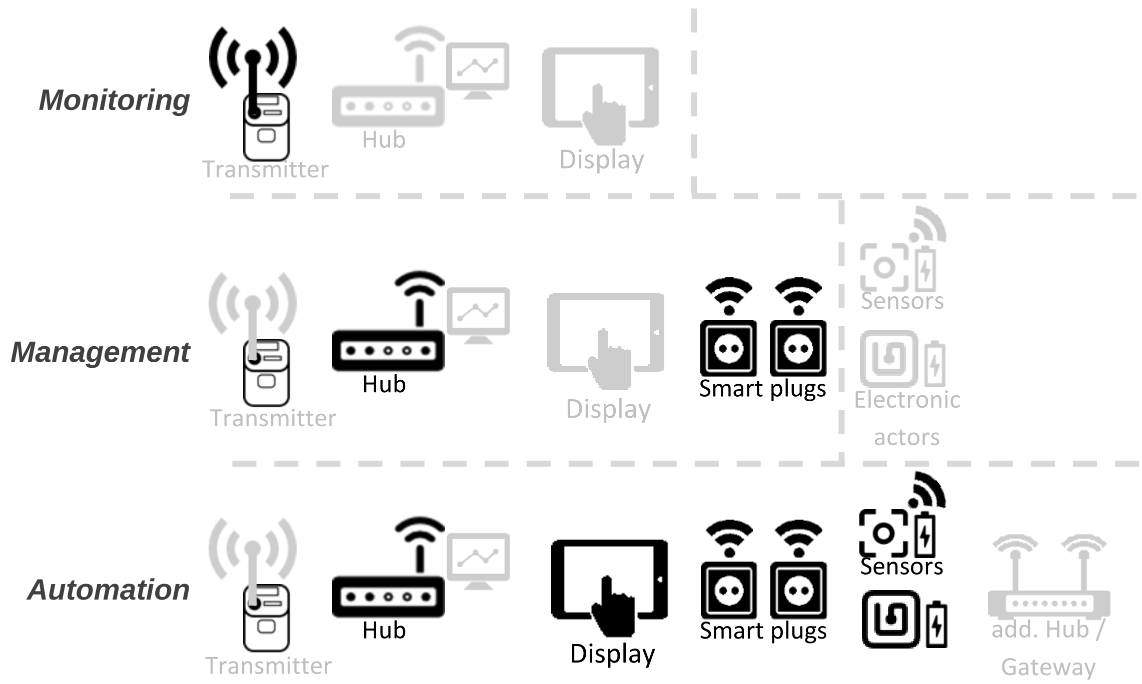
Management systems, usually consists of devices such as a hub, smart plugs and a display, allowing the user to monitor the energy consumption of individual devices in the home and switch these devices On and Off, either in real time or by setting specific time profiles. Management systems also contain monitoring devices and as such, support energy savings through behavior changes and by eliminating unnecessary consumption through scheduled time profile switching.

Automation systems are in general more complex systems, primarily offering a multitude of features besides energy monitoring and management such as security, lifestyle and comfort features. In an Automation system, the actors react autonomously to inputs from sensors within the system. A very simple example is the connection between a movement sensor and a light. These systems are generally composed of a large number of different devices, resulting in diverse installations and uses. In addition to the Monitoring and Management capabilities, Automation systems allow for energy optimization through fully automated reactions to (sensor) inputs. This optimization can lead to substantial savings in residential energy consumption. However, these systems need to be professionally installed, individually programmed and continuously maintained. A survey[32] by Deloitte Germany showed that only 31% of Smart Home customers are interested in “reduced energy cost”, with the majority primarily interested in comfort (47%) and security features (43%). The availability and installation of additional devices offering comfort, security and lifestyle features could possibly offset some of the energy savings achieved.

The initial investigation identified and described five Monitoring systems, nine Management systems and seven Automation systems. The identified system groups are graphically described below in Figure 22.

32 DELOITTE & Technische Universität München, 2015

Simplified description of Systems



* Greyed out devices are optional or selectively included depending on system manufacturer.

Figure 22: Simplified graphical description of devices included in the different types of systems under investigation.

To build case studies on EMS and assess their own energy consumption impact it is important to select systems for further investigation. This is based on various considerations, as explained in this section:

- *Existing market*: a report by BERG Insight indicates "…point solutions outsold whole-home systems in 2014 by a factor of six to one and generated 59 percent of the combined market revenues in North America and Europe."[33] Monitoring and Management systems therefore make up a large part of the current EMS market.
- *Future market penetration*: in general, Monitoring and Management systems cost less than Automation systems, removing an important market barrier for their adoption. Simple systems are generally more user friendly and, in most cases, offer convenient plug and play installation. In comparison, Automation systems may have complex installation requirements. Monitoring and Management systems are often available as add-on solutions, while Automation systems require integration into the existing installations. This is only possible under major refurbishments or in new constructions.
- *Applicability and transferability of systems*: many Monitoring and Management systems use standardized components and/or devices from a small group of manufacturers. It is likely that measurement results from this investigation can be easily transferable and scalable to model similar systems. Automation systems are often composed of more unique components and devices, from smaller manufacturers and therefore measurement results are not easily transferable or scalable as planned in this project.

33 BERG Insight, 2014

- *Complexity of the measurement:* the measurement of single point systems is simpler than the measurement of the own power consumption of sophisticated installations of Automation systems.

For these reasons, the case studies selected in this EDNA task concentrate on Monitoring and Management systems, and Automation systems are excluded from the investigation.

From the Monitoring and Management systems, specific systems offering comparable features and functionalities were grouped in three categories as follows:

- Monitoring system **without** display: composed of a transmitter and a hub only. These systems can be accessed through an external device such as a smartphone or PC.
- Monitoring system **with display**: composed of a transmitter, a hub* and a dedicated display. No further external devices are necessary to access these systems, though some systems offer this feature as well.
  (* one of the investigated systems did not use a hub, the transmitter communicates directly with the display).
- Management system with smart plugs: composed of a hub with smart plugs.

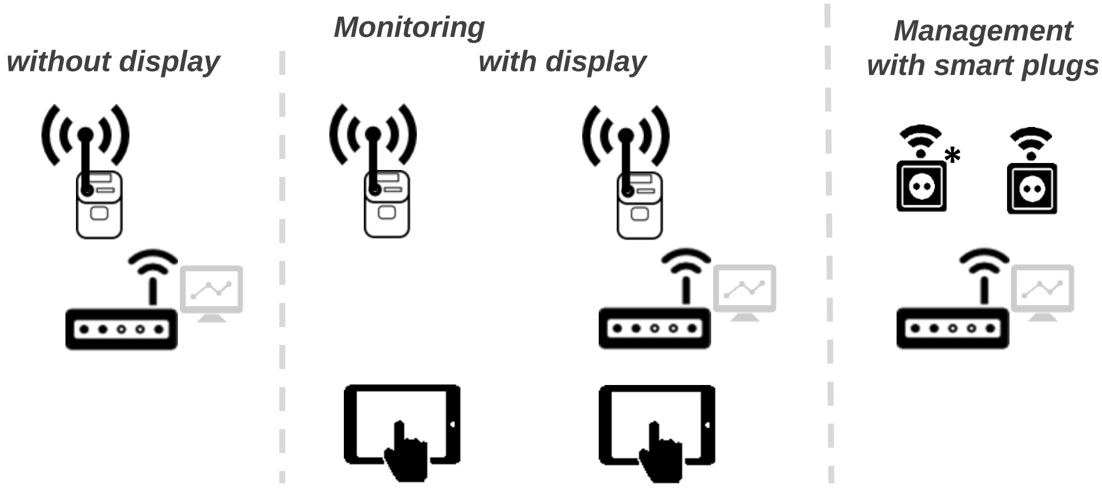


Figure 23: Simple graphical description of the classification and boundaries between different Monitoring and Management systems in this investigation.

Figure 23 shows a simple description of the different types of systems identified.

Within the management group (moving towards the boundary with Automation systems) the systems can be expanded with additional components, offering additional features. This investigation concentrates on a set of management systems composed of smart plugs and a hub, without dedicated displays. In this case, external devices are necessary to access these systems.

The components shown above for each group are used to build the installation scenarios. To allow for extrapolations with these installation scenarios, the energy consumption of the individual components has to be measured or gathered from selected data sources.

Step 2: Gathering data and measuring the own energy consumption of the devices within systems

Data on the own energy consumption of devices of the selected EM systems was obtained from:

- EDNA member countries: e.g. the Swedish Energy Agency completed measurement of several EMS systems and provided these data for the task. The other EDNA member countries could not provide measured data.
- Manufacturers/providers: technical properties of energy monitoring systems, such as the communication technologies, compatibility and features, data on the own energy consumption of the devices, is generally not available. Few data sheets of selected manufacturers provided some insight into the own energy consumption of the devices, though these data came without details on the measurement methodology used.
- Scientific community: technical and scientific publications focus mainly on big data, communication technologies, interoperability and NIALM. Measured data on own energy consumption of EMS and the constituting devices, e.g., from other research projects, could not be found. General desk research did not yield substantial information in this respect.

Therefore measurements of the own energy consumption had to be carried out to fill this data gap, as the main part of the Task. Research on applicable measurement standards was completed to create a structured measurement approach, and ensure the robustness of the results.

Measurement standards & measurement approach

Amongst the relevant standards identified, the most broadly applicable and relevant international standard is IEC 62301:2011 “Household electrical appliances - Measurement of standby power”. The equivalent (slightly modified) European Norm, derived from this standard is the EN 50564:2011 “Electrical and electronic household and office equipment - Measurement of low power consumption”.

Other pertinent standards and test methods were also investigated. These included the European Norm EN 50563:2014 “External a.c. - d.c. and a.c. - a.c. power supplies - Determination of no-load power and average efficiency of active modes” [34]; the ENERGY STAR® test method for displays, small network equipment and electronics and office equipment[35]; the measurement procedures for computers and monitors as well as external power supplies described in the Australian MEPS[36].

The measurement procedure developed for this EDNA task follows where possible the approach outlined in EN 50564:2011, as summarized in the text box below. Some aspects related to the measurement equipment and the laboratory setup differ from the standard. For details on the measurement procedure see the Guidance document in the APPENDIX.

34 EN 50563:2014 describes specific requirements for measuring and determining the no load power and average efficiency of active modes for external ac/dc and ac/ac power supplies. EN 50563:2014 includes test method provisions based on those published by the US EPA and under Australia/New Zealand Standard AS/NZS 4665.1.(http://www.newelectronics.co.uk/electronics-technology/european-standard-set-to-improve-energy-performance-of-external-power-supplies/37060).

35 http://www.energystar.gov/products/spec

36 http://www.energyrating.gov.au/products

Steps for undertaking measurements in EDNA Task 1:

- Setup the system according to the supplier's instructions
- Adhere to the maximum distances between devices as defined in the instruction manual
- Record a layout plan
- Check the ambient temperature and ensure its stability
- Ensure that the system is operating as intended and allow it to stabilize
- Record the own energy consumption by logging the long term energy consumption using continuous sampling
- Identify periodic behavior and determine appropriate measurement period
- Analyze measured data
    - Divide the measurement period in three equal parts (each at least 15 min. long)
- Ensure stability criteria are satisfied
    - Linear regression within the second and last period combined, must be less than 1% of the average over this same period (Depends on load)
    - A logging period of 60 minutes is acceptable (without periodic behavior) if the cumulative average of each data point within the second and last period lies within 0.2% of the overall average of this same period
- Calculate average consumption of device as average over second and third period

Two systems available in Austria were measured by the ECODESIGN company GmbH. Following a similar approach, the Swedish Energy Agency also measured seven EM systems. The resulting individual energy consumption ranges of all these measurements are shown in Figure 24 below.

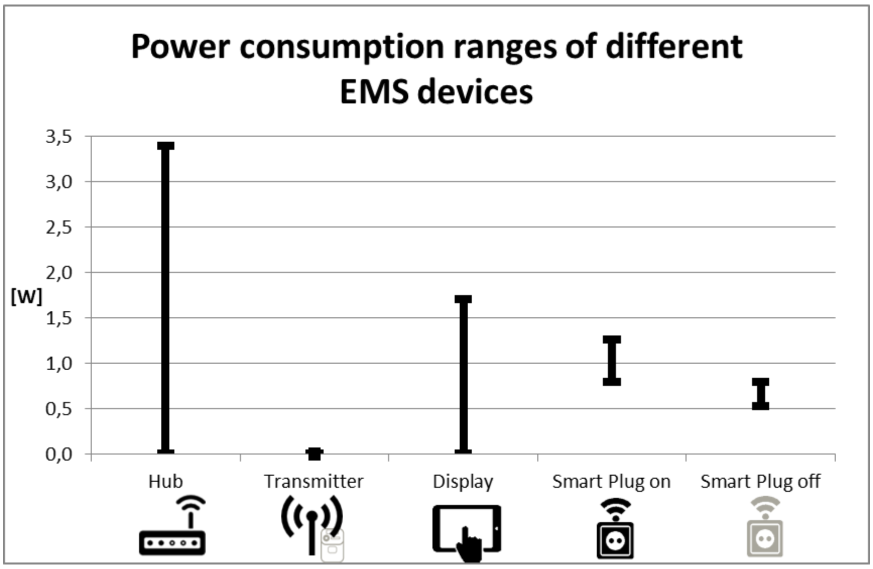


Figure 24 Measured own power consumption of selected devices in Task 1.

The energy consumption of individual devices shown in Figure 24 differs greatly, with the hub showing the largest values, the displays and the smart plugs follow in terms of own power requirements, with the transmitter (battery powered) showing the lowest value of own energy consumption. There was a large difference between battery powered and mains connected devices as shown in Figure 25 below.

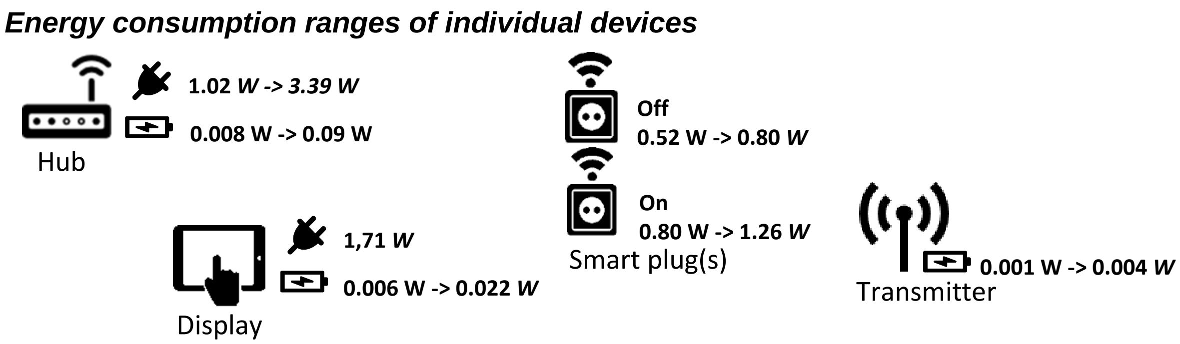


Figure 25: Consumption figures for different devices split up for battery and mains powered devices

Simple possible combination of devices allowed the identification of best and worst in class. Since the most efficient system may not combine all the most efficient devices or these may not be compatible, it is not possible to simply sum the figures of all the most efficient devices to get the values for the most efficient system. Table 9 shows the input power values for the combination for simple systems, as well as the AIP over those compatible devices. Greyed out components are not included in the simple systems.

Table 9: The own power consumption of various simple system compositions.

System Type	Monitoring						Management				
	Basic			Complex			Single Node Management				
Devices	Transmitter Hub Display Smart plug(s)			Transmitter Hub | Hub Display Smart plug(s)			Transmitter Hub Display Smart plug(s) [*1 on + 1 off*]				*Unit*
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**	***W***
	best in class --> worst in class			*best in class --> worst in class*			*best in class -----> worst in class*				

The possible combinations of devices given in Table 1 shows again that the AIP differs greatly between different systems.

Step 3: Defining the technical scenarios

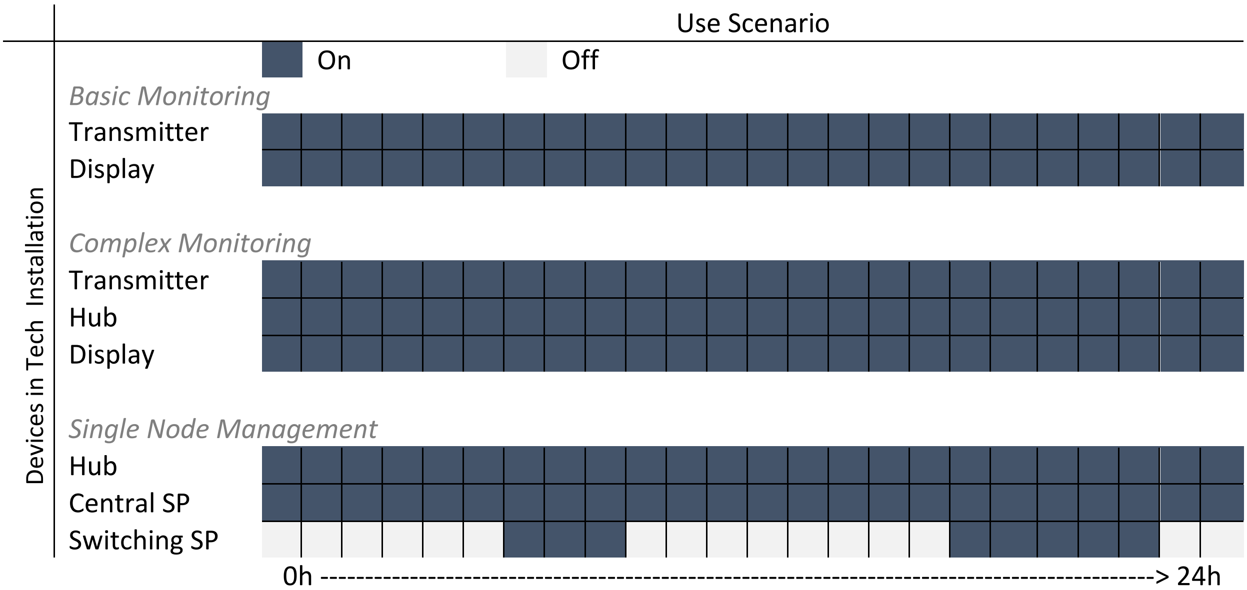
A technical installation scenario describes a specific combination of devices, with each of the devices having been assigned a specific use scenario. Data on the technical installation scenarios and use scenarios of EMS was mainly obtained from:

- Scientific sources: various publications and projects investigated the user adoption of systems and achievable consumption reductions, and provided information on typical EMS installations and number of devices.
- Manufacturers/providers: information from ready-made systems, composed of several devices were used to estimate the characteristics of technical installations. It is plausible that customers would purchase such ready-made systems as offered by the EMS companies.

Defining the use scenarios

Before combining the devices to systems in the installation scenarios the use scenarios for each device must be defined. The use scenario is defined as a combination of "On" and "Off" modes at the level of the devices. As shown in Table 10, 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 (SP) are On for 8 hours per day, and Off for the remaining 16h to mimic a likely schedule for a load as described in detail in the technical installation scenarios below.

Table 10: Use scenarios of the individual devices in the three different technical installations



Defining the technical installation scenarios

A technical installation scenario describes how the devices may actually be installed in a household to form a system which provides the required functionality and features. Monitoring and Management systems were considered, as indicated before.

The technical installation scenarios for Monitoring systems differentiate between those systems with and those without dedicated displays.

The technical installation scenarios for Management systems with a hub and smart plugs differ only in the number of such smart plugs to be installed. A basic Management installation would be composed of two smart plugs[37], one a central smart plug and one a switching smart plug, as defined in the use scenario above. Other sources indicate that a complex Management installation would be composed of nine smart plugs[38], one central smart plug supplemented by eight switching smart plugs. These scenarios for possible installations seem realistic according to expert judgement of a member of the REFIT project[39] . In addition this is supported with information from ready-made starter packages offering a basic system (composed of two smart plugs) and the more advanced system, encompassing nine smart plugs[40].

37 Correspondence with Mr. M Jansen - Swedish Energy Agency.

38 Correspondence with Mr. W. Elmenreich - Monergy Project.

39 http://www.refitsmarthomes.org/

40 https://www.plugwise.com/products/appliances-and-lighting/starter-packages

The technical installation scenarios were named “Basic” and “Complex”[41]. In this context basic refers to a system that a consumer may purchase first and upgrade or expand later, especially in the case of Management systems. The terms basic and complex in this context do not describe the quality, quantity or depth of data and information recorded or visualized to the customer.

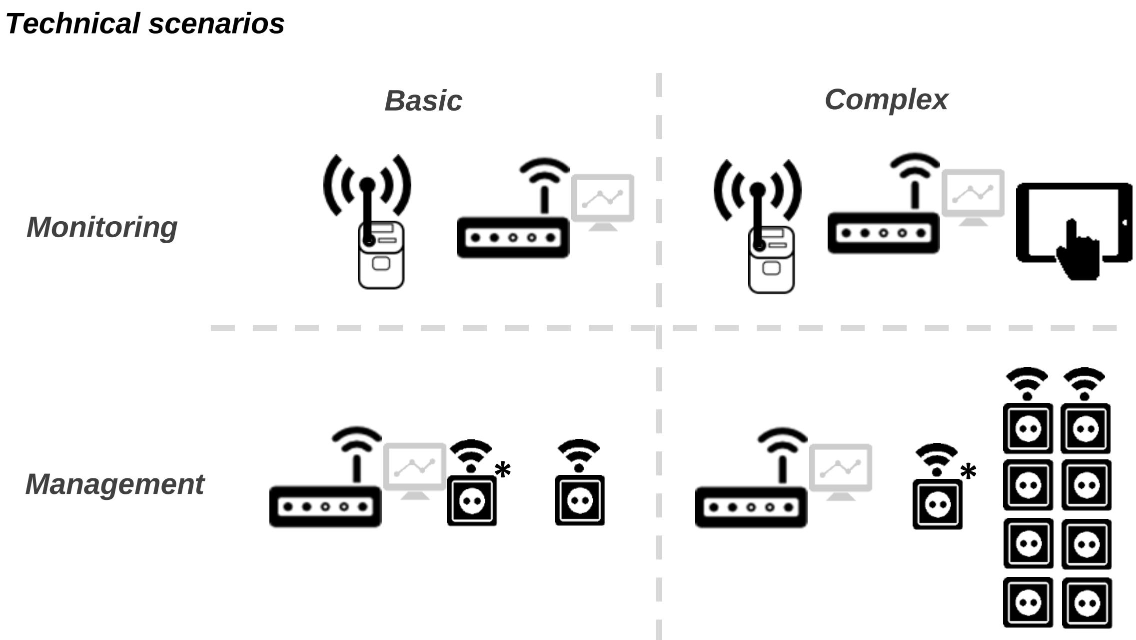


Figure 26: Simplified graphical depiction of the different technical installation scenarios defined for this investigation.

Technical installation scenarios for monitoring systems

As described in step 1, for the monitoring systems the basic installation is defined as 1 transmitter and 1 hub (without a dedicated display); while the Complex installation consists of 1 transmitter, 1 hub* and 1 dedicated display.

(* one of the investigated systems did not employ a hub, the transmitter communicates directly with the display).

The greyed out PC screen in the background indicates the possibility to access the system using a PC or a handheld device. For the case of no dedicated display, a handheld device such as a mobile phone or a PC is necessary to interact with the system. Mobile phones and PCs are not included in the overall energy impact calculation of the technical installation scenarios and case studies. Their own energy consumption is considered negligible compared to the EM systems entire consumption, due to their low power consumption and the rather low use time[42]. Although these devices might be necessary peripheral devices in some of the scenarios considered, and it is appropriate to mention them in the system description, they are not the subject of this investigation. Moreover, it is unlikely

41 Basic and complex do not refer to the quality, amount, or depth of information recorded and displayed by the EM systems, and does not indicated the level of sophistication of the systems as such.

42 Carroll et Heiser, 2010, suggest the power consumption of smart phones to be approximately 500 mW when operating web-applications via GPRS. Assuming that the smart phone would be active for 5 minutes per day to interact with the EMS, the additional energy consumption would be 0.015 kWh per system per year. The use of a PC to access the information and interact with the EM system could also be estimated in a similar fashion. Sticking to the use scenario of 5 minutes of activity per day (35 minutes per week for the entire year) this would result in an additional energy consumption of approx. 0.6 kWh/y to 2.4 kWh/y, depending on the device i.e., Laptop (taking 20 W) vs. PC (taking 80 W).

that a user will purchase, install and permanently run a device such as a laptop only for EM purposes and this is not necessary for any of the systems investigated.

Use scenario with dedicated displays

In this project it is assumed that dedicated displays are always on. The assumption is reasonable, for example 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.

This use scenario is different to that of the smart phones or PCs which are thought to be used 5 minutes per day for this purpose.

Technical installation scenarios management systems

Two technical installation scenarios have been defined according to expert views consulted for the project.

The basic installation consists of 1 hub, 1 central smart plug* and 1 switching smart plug. The system described in this technical scenario requires one central smart plug (denoted by a * in Figure 26 above). This central smart plug establishes the network and provides information to the hub, and is complemented with a number of switching smart plugs, acting as "endpoints" of this network. These two types of smart plugs have slightly different energy consumptions.

The assumption is that the central smart plug is used to monitor the energy consumption of certain devices, such as a fridge, while the switching smart plug(s) are used to switch loads that can be managed according to a time schedule e.g., to avoid standby losses from a TV or switching periodic loads from an electric heater.

- The **Basic** technical installation consists of 1 hub, 1 central smart plug (always ON) and 1 switching smart plug (with a defined use pattern).
- The **Complex** technical installation consists of 1 hub, 1 central smart plug (always ON) and 8 switching smart plugs (with a defined use pattern).

These technical scenarios are now combined to form the basis for the system consumptions over the period of one year. The energy consumption figures of the devices are calculated according to their use scenarios, and the devices are then combined in the installation scenarios to form technical scenarios. This gives an indication of the possible ranges of overall annual energy consumption of individual systems when installed in a household. The results are presented in Table 3 and were used to build the country specific case studies.

Table 11: Annual electricity consumption of different energy monitoring and energy management systems

		Basic	Complex	
Monitoring	*worst in class*	20.6	32.1	*kWh/y*
	best in class	8.9	0.1	*kWh/y*
Management	*worst in class*	48.3	101.5	*kWh/y*
	best in class	14.3	62.7	*kWh/y*

There is a large difference between energy consumption of 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.

These data on the household level can be used to estimate ranges of energy consumption of EMS at the level of the country, considering specific market penetration data for such countries. This is described in the next step.

Step 4: Extrapolating country scenarios using demographic, energy and market data

To identify current and project future market penetration of EMS the following sources were investigated:

- EDNA members: could not provide substantial data on the EMS market in their respective countries. This information was not readily available.
- Scientific institutions: publicly available publications on the EMS market could not be found. Research institutions, working on smart home applications mainly focus on topics of expected reductions in consumption in households, user experience and privacy.
- Companies: Professional research and market research companies such as Navigant research and GfK were contacted to find out if market research data for EMS was available. Even these companies had to concede that their current data is limited in scope, geography, and timeframe, making it unsuitable for this Task.

A report by Waide Strategic Efficiency Limited[43] found "*In the residential sector, penetration of EMS is projected to rise from 2% of homes today to 40% by 2034 without additional intervention.*" A report by BERG Insight[44] projects 37% annual growth in the EMS market from 2014 to 2019. Investigations by Deloitte[45][46], Kotschi Consulting[47], and Icontrol Networks[48] indicate that the *smart home* market is a growing market. Due to lack of additional data, this report compares system consumption figures to individual household consumption and extrapolates overall consumption of these systems up to a maximum of 50% market penetration.

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43 Waide Strategic Efficiency Limited, et al, 2014

44 BERG Insight, 2014

45 Deloitte, 2013

46 Deloitte et Technische Universität München, 2015

47 KOTSCHI CONSULTING, 2014

48 Icontrol Networks, 2015

4 Case studies for SMI and EMS

Underlying information for the EDNA member countries

SMI and EMS deployments are completely decoupled in all EDNA member countries, with the UK as the only exception.

Australia is preparing legislation to facilitate the further national roll-out based on customer choice of smart metering. Australia consists of six states. In Victoria, there has been a government directed mandatory roll-out of smart meters by the distribution company to all users with consumption below 160 MWh per year. This process is already completed and covers 2.8 mio. metering points. The other five states follow another policy and mainly support a "customer-led" smart metering agenda.[49] The following functionalities are required in smart meters installed in Victoria in addition to the measurement requirements:

- Supply relay
- Load control
- Bi-directional for distributed generation
- Supply failure and restoration notifications
- Quality of supply event recording
- Supply capacity control
- Enabling a Home Area Network (HAN) based on ZigBee radio
- Metering installation asset management (for example tamper detection)
- Remote firmware upgrade and self-registration of meters

In New South Wales metering service providers can provide different meters, ranging from basic devices to customers that provide real–time information and detailed billing to sophisticated devices allowing remote control of household appliances.[50]

For EMS, technical performance requirements or energy consumption thresholds could not be identified. The Australian regulation includes MEPS[51] for computers and monitors, as well as for external power supplies. In terms of possible regulation, the features of Energy Monitoring Systems are not clearly defined, as these systems are not yet widely purchased in the country.

In Austria, small scale pilot roll-outs have been completed. Currently, most utilities in Austria are on their way to decide for specific smart metering products (tenders are in many cases finished or ongoing). Based on the EIWOG 2010 (Elektrizitätswirtschafts- und -organisationsgesetz), utilities had to deliver a step-by-step plan for introducing smart meters in their region. On top of the EU target of an 80% roll-out until 2020, Austria follows a goal of 95% roll-out by the end of 2019. The actual installation progress is supervised by the Austrian regulatory agency E-Control.
The features Austrian meters have to provide are defined in the "Intelligente Messgeräte-Anforderungs-Verordnung" (abbrev. IMA-VO 2011). This directive came into force in November 2011 and requires smart meters to be capable of acquiring, logging and transferring active power values through a bidirectional communication system. It requires further, that these values are obtained

49 Sweeney, 2015 p.4

50 Sweeney, 2015 p.3

51 http://www.energyrating.gov.au/products

every 15 minutes and stored for at least 60 days inside the meter. For the communication process the time span is limited to 12 hrs. There are further requirements to connect with other utility meters and to provide an interface for sending out data to external devices located in the home area.

The visualization of the energy consumption to the consumer is not bound to the smart meter roll-out plans. The penetration of EMS is unknown though the large number of market players and start-ups suggests growing adoption, further driven by the (EU) energy efficiency law. Under the national implementation of this law, the utility companies can claim the associated savings expected from a widespread installation of these systems, as a specific energy efficiency measure. Therefore many utility companies have launched their own line of EMS on the consumer market.

In Denmark, 1.63 million metering points have been equiped with a smart meter, following a voluntary roll-out led by the distribution system operators. A recently introduced law (June 2013) mandates the full smart metering roll-out to all 3.28 mio. metering points in Denmark. Projected energy savings are 2% of total electricity consumption[52].

Regarding EMS, no technical performance requirements, energy consumption thresholds, nor information on the spread or consumer acceptance could be found.

In the Netherlands, a small scale roll-out was carried out to install up to 500.000 SM (electricity & gas) from 2012 to 2014. There are a total of 7.6 million metering points in the country. The national goal is a 100% coverage by the year 2020[53]. In the case of new construction and renovations it is compulsory to install a SM. Information transfer to the supplier by the customer is “opt-in” which creates problems for the business case[54].

The functionality of visualization to the customer (e.g., in-home display and live energy data) is required through the Dutch Smart Meter Requirements – Main Document v4.2.2.[55] Smart meters have to be equipped with a P1 port, a standardized interface for data output to the in-home area. The implementation or provision of devices capable of visualizing this data is left open. The customer therefore has the option of connecting an EMS to the smart meter. The utility company, which installs and owns the smart meter is however not required to provide such an EMS.

In Sweden, due to mandated monthly invoicing (entered in force on 1st July 2009) a full smart meter roll-out with 5.2 mio. metering points has already been completed.

Most of it has been carried out without EMS installations from the start. The commonly available EMS that appeared afterwards were tested in 2015 for their usability, and measurements of the own energy consumption of the systems were also performed.

In Switzerland, there are 4.998 million metering points, which are 3-phase only. The government plans to implement 80% SM coverage by 2025, including a protection duration of 10 years for older

52 EC, 2014 a. p. 29f

53 EC, 2014 a. p. 80f

54 Hiscock et Kang, 2014 p. 74

55 NETBEHEER NEDERLAND, 2014

meters.[56] The full current status of a SM roll-out in CH is unclear. Few Smart meters have so far been installed[57]. Small scale SM pilot projects & roll-outs (e.g. >27.000 SM in Zürich by EKZ) have been implemented.

The situation regarding EMS is similar to the Netherlands. An interface is required in the smart meter, which allows the transmission of (quasi) real time data. The interface must be open, uni-directional and documented. The choice of purchasing and connecting an EMS is left to the end consumer, and the owner of the smart meter is not required to provide such a system.

In the UK, energy suppliers are responsible to roll-out 97% SM (31.95 mio. Electric SM) by 31st Dec 2020 (100% by 2030) which will replace the total 32.94 million electricity meters in the UK (GB) (All domestic and smaller non-domestic). As of May 2015, approximately 1 million compliant smart meters have been deployed.
The expected energy savings are given as 2.2% of total electricity consumption.[58]

The smart meter roll-out approach and its technical specifications include EMS, by requiring online access to real-time energy data, and the provision of an in-home display. The own energy consumption limits for the smart meter and EMS have been defined in technical specifications: the in-home display should on average consume no more than 0.6 W.

Based on this preliminary research, and information, SMI and EMS case studies were drafted for each EDNA country. These case studies are presented in a standard template/format developed for this task.

4.1 Case studies on smart metering infrastructure (SMI)

The SMI case studies for each EDNA member country were derived according to the methodology described in section 3.1.2 above. Further details on the underlying measurement methodology, referenced data sources, and documentation are available in the project report to the SMART METERING consumption study (binational study of Switzerland and Austria).[59]

To sum it up briefly, the most important influencing factors to be taken into account for the own energy consumption of a region are:

- The number of metering points to be rolled out
- The share of 3-phase metering points (complementary to the 1-phase metering points)
- The means of communication along the so-called last mile (connection to the household)
- Split into urban and rural areas

56 CH BFE UVEK, 2014 p. 31

57 Brüniger, R., 15.01.2015 email to Diaz, A.

58 EC, 2014 a. p.113-p.115

59 Preisel et al., 2012

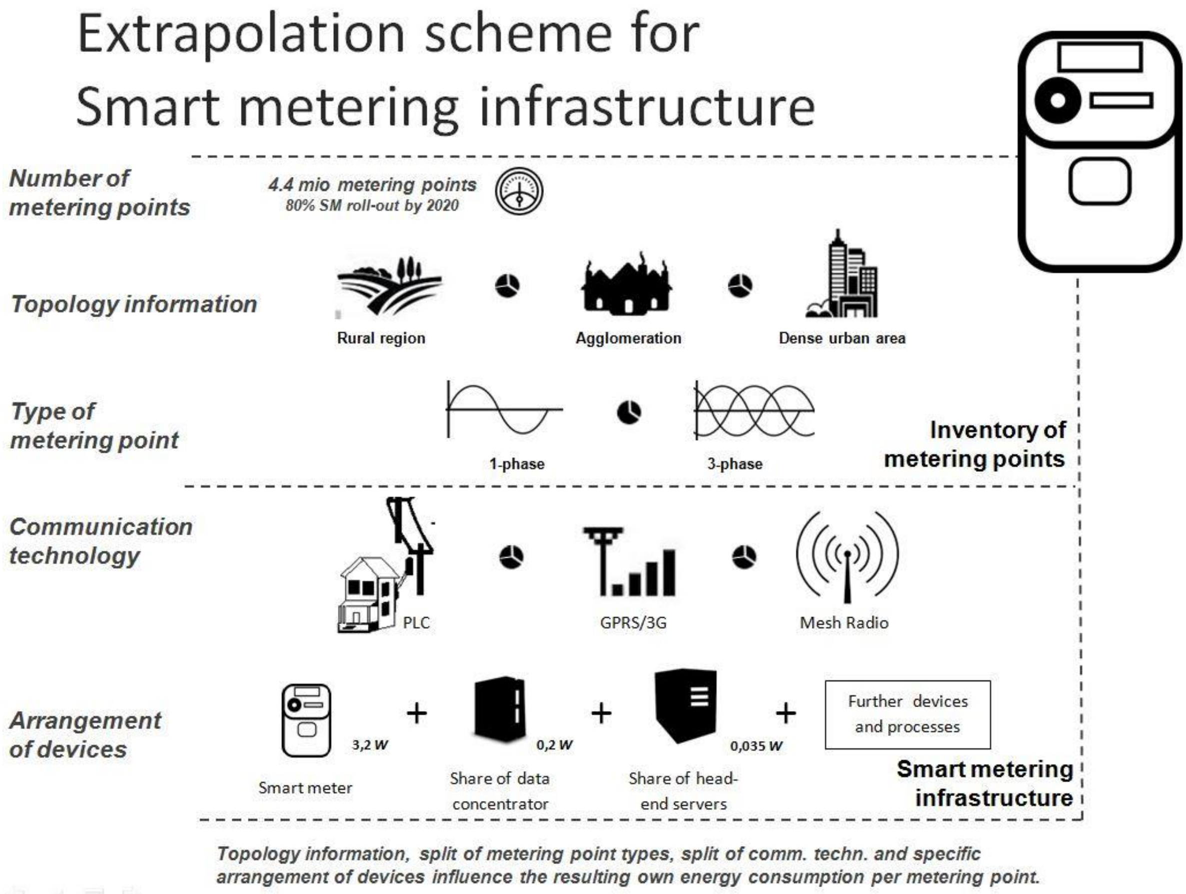


Figure 27: General SMI extrapolation scheme for a fictitious region, featuring sample numbers

Figure 28 shows how this input data has to be applied.

SMI extrapolation scheme

MPs are metering points in thousands

Input	*Abbreviations:*	MP	metering point	PLC	power line communication
Calculated		AIP	average input power	GPRS	general packet radio service
Information		AEC	annual energy consumption		
Comment		A_2, etc.	SMc technical szenario		

Distribution of metering points

Total number of metering points → 3500 MPs

Split according to topology			**Split according to**			**Split according to communication**				
			1-phase	3-phase		PLC	GPRS	Radio	specify	
			33%	67%	100%	70%	20%	10%	0%	100%
dense urba	33%	1167	389	778	MPs	817	233	117	0	MPs
			33%	67%	100%	70%	30%	0%	0%	100%
agglomerat	33%	1167	389	778	MPs	817	350	0	0	MPs
			33%	67%	100%	70%	20%	10%	0%	100%
rural regior	33%	1167	389	778	MPs	817	233	117	0	MPs
	100%	MPs								

Figure 28: Input mask for SMI extrapolations

The extrapolation of own energy consumption per metering point (*average input power = AIP*) is then based on data sets that are already available from the SMART METERING consumption project. Only for the Swiss case study, new data has been fed into the database.

Beside the four influencing parameters as mentioned above, further possible influences shall be kept in mind. Basically, these are:

- Customized parametrization decides which auxiliary functions the meters shall perform (e.g. power quality control, communication schedule or protocol details) and defines the regular intervals in which operations are triggered, according to the needs of the utilities.
- Additional devices like gateways or auxiliary interface modules etc. may contribute with a considerable extra average input power.
- Further product-specific differences in the hardware design

This information was not available for the case study countries. Further, it is hard to address a specific consumption value when the parametrization is not clear down to the very last detail and when possible extra devices as mentioned above have not been measured.

Although these uncertainties are already known from the experiences in the SMART METERING consumption project, it would not make sense to understand all these details in the depth of device parametrization but rather focus on real live measurements in concrete installations.

As there are different technical solutions available in the market, depending on the efficiency performance the manufacturers achieved with their implementations, this report does not provide single value results, but instead a certain bandwidth of possible AIP values (Figure 29). According to the split into different communication technologies, the split into 1-phase and 3-phase metering points, and the characterization of the network topology (classified after the habitat densities), linear combinations of particular technical solutions that could be used and for which own energy consumption data is available, must be calculated. The result is an upper bound and a lower bound value, as illustrated in Figure 29.

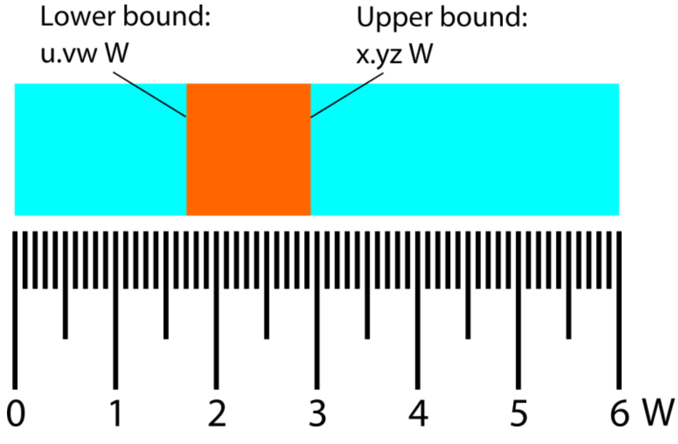
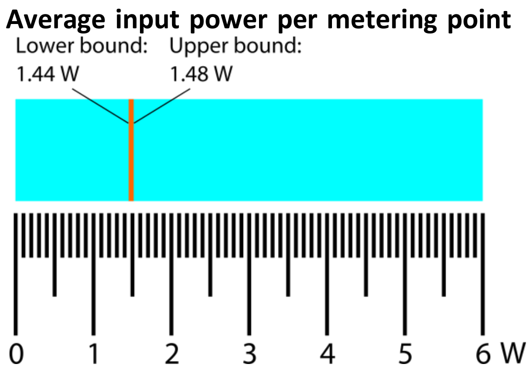


Figure 29: Bandwidth of possible values for the average input power, according to linear combination of appropriate technical solutions.

In the following section, the country specific results are presented in detail using the above described representation.

Australia

Extrapolated own energy consumption of smart metering infrastructure
Key facts and figures



The Australian grid area + metering aspects

9 052 000	total of electricity metering points (MPs)
5 %	amount of 3-phase MPs
GPRS, Radio	last mile communication technologies

Main results and key findings

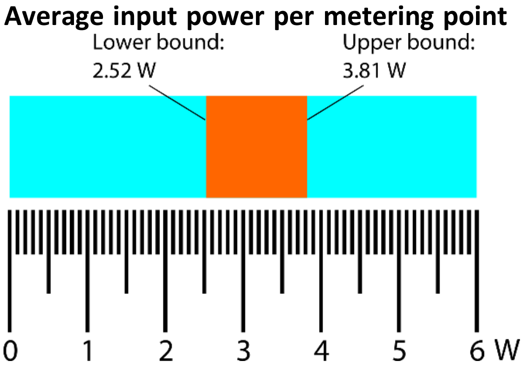
1.44 – 1.48 W	range for average input power (AIP) per metering point (including all system-wide contributions from associated power demand)
117.6 GWh	extent of annual energy consumption (AEC), based on maximum AIP
1.9 %	amount of energy demand for smart metering in whole Australia, related to the energy production of the Hazelwood power station.

The stock data for available smart metering systems with radio communication is limited to one sample. Therefore the resulting bandwidth is very narrow and only depends on the different ratios between meters and DCOs.
The calculated AEC must be understood as a rough approximation. In fact, the Australian meters feature home area network (HAN) based on ZigBee. Most of the smart meters' data transfer employs radio DCOs in conjunction with meter mesh radio networks (SSN). A smaller number of meters employ WiMAX and 3G data transfer. In the state of Victoria, the readout of data is required daily. The energy consumption data is collected from the SMI daily and has a resolution of one data point per 30 minutes (48 values per day).
To get more precise consumption data for these configurations, own energy consumption measurements would have to be carried out.

Smart meters must meet the metrological standards of IEC 62052.11, IEC 62053.21, IEC 62053.22 and any pattern approval requirements of the National Measurement Institute (Australia). Technical specifications are available in NMI, 2012.

Austria

Extrapolated own energy consumption of smart metering infrastructure
Key facts and figures



This document briefly describes how the Austrian case study of EDNA Task 1 is set.

The Austrian grid area + metering aspects

5 805 000	total of electricity metering points (MPs)
71 %	amount of 3-phase MPs
PLC, GPRS, Radio	last mile communication technologies

Main results and key findings

2.52 – 3.81 W	range for average input power (AIP), per metering point (including all system-wide contributions from associated power demand)
193.8 GWh	extent of annual energy consumption (AEC), based on maximum AIP
18.4 %	amount of energy demand for smart metering in whole Austria, related to the energy production of the Viennese hydro power station Freudenau.

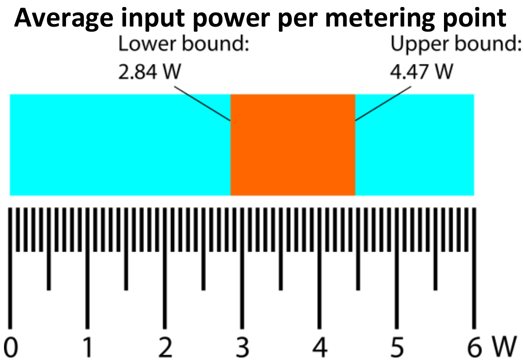
The stock data for available GPRS and especially PLC systems shows a certain bandwidth of efficiency in terms of own energy consumption.

In Austria, there are no energy consumption thresholds set in legal requirements. The upper bound set by the international standard IEC62053 -21 (2003) foresees maximum input power levels of 2W (10VA) for each phase (this means 6W for a three-phase meter). However, this definition only applies to the MID-part of the meter and does not include the communication premises. Definitions as in Germany, where strict peak-power limits are set for the whole counted area (this means everything that belongs to the metering system at the metering point and beyond towards the home area) are not set in Austria.
It is widely unclear how “real-time” meter readings will be prepared for end-user feedback when it comes to large-scale roll-outs. Currently it is more likely that private energy monitoring systems will be used instead of the grid operator infrastructure (smart metering systems). However, these systems sometimes include add-on sensors to be attached to smart meters and potentially provide timely information about the most recent energy consumption profile.

Denmark

Extrapolated own energy consumption of smart metering infrastructure
Key facts and figures

This document briefly describes how the Danish case study of EDNA Task 1 is set.



The Danish grid area + metering aspects

3 280 000	total of electricity metering points (MPs)
90 %	amount of 3-phase MPs
PLC, GPRS	last mile communication technologies

Main results and key findings

2.84 – 4.47 W	range for average input power (AIP), per metering point (including all system-wide contributions from associated power demand)
128.5 GWh	extent of annual energy consumption (AEC), based on maximum AIP
3.9 %	amount of energy demand for smart metering in whole Denmark, related to the energy production of the Studstrup power station

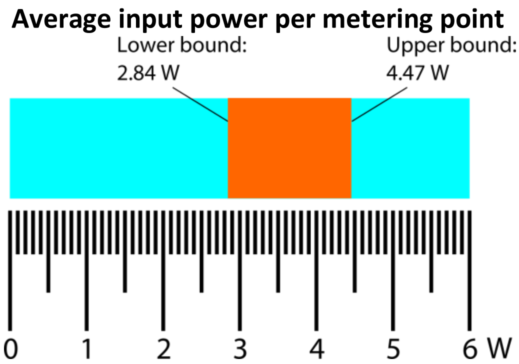
The stock data for available GPRS and especially PLC systems show a certain bandwidth of efficiency in terms of own energy consumption.

The amount of PLC communication systems, but also the given high amount of 3-phase metering points explains the relatively high value for the average input power per metering point.

The Netherlands

Extrapolated own energy consumption of smart metering infrastructure
Key facts and figures

This document briefly describes how the Dutch case study of EDNA Task 1 is set.



The Dutch grid area + metering aspects

7 600 000	total of electricity metering points (MPs)
90 %	amount of 3-phase MPs
PLC, GPRS	last mile communication technologies

Main results and key findings

2.84 – 4.47 W	range for average input power (AIP), per metering point (including all system-wide contributions from associated power demand)
297.8 GWh	extent of annual energy consumption (AEC), based on maximum AIP
9.1 %	amount of energy demand for smart metering in the whole Netherlands, related to the energy production of the Borssele power station

The stock data for available GPRS and especially PLC systems show a certain bandwidth of efficiency in terms of own energy consumption.
The amount of PLC communication systems, but also the given high amount of 3-phase metering points explains the relatively high value for the average input power per metering point.

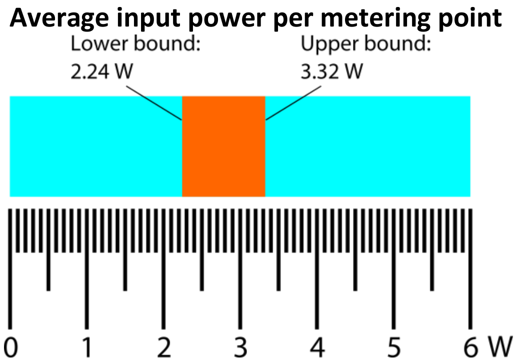
The maximum allowed power consumption without communication and unconnected P1 device for single phase meters is set at 2 W / 10 VA and for poly phase meters at 4 W / 20 VA. For single phase meters, average power consumption shall not exceed 4 W during communication. For poly phase meters, average power consumption shall not exceed 8 W during communication.[60]

60 Netbeheer Nederland, 2014

Sweden

Extrapolated own energy consumption of smart metering infrastructure Key facts and figures

This document briefly describes how the Swedish case study of EDNA Task 1 is set.



The Swedish grid area + metering aspects

5 200 000	total of electricity metering points (MPs)
90 %	amount of 3-phase MPs
PLC, GPRS, Radio	last mile communication technologies

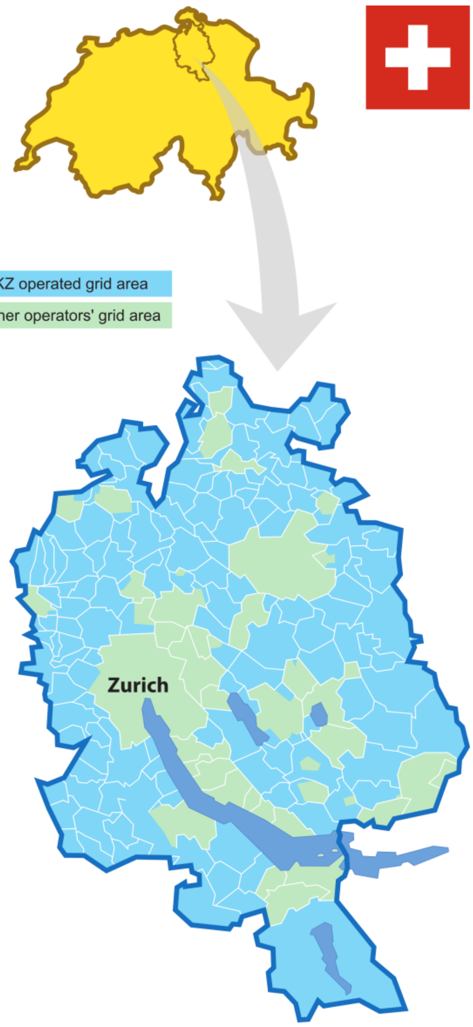
Main results and key findings

2.24 – 3.32 W	range for average input power (AIP), per metering point (including all system-wide contributions from associated power demand)
151.4 GWh	extent of annual energy consumption (AEC), based on maximum AIP
0.6 %	amount of energy demand for smart metering in whole Sweden, related to the energy production of the Ringhals nuclear power plant

The stock data for available GPRS and especially PLC systems show a certain bandwidth of efficiency in terms of own energy consumption.

Switzerland

Electricity smart metering rollout of the energy utility of the Canton Zurich (EKZ) Key facts and figures



This case study briefly describes the planned rollout of electricity smart meters, including information on the technology and its benefits as well as future perspectives on energy monitoring along with this rollout.[61]

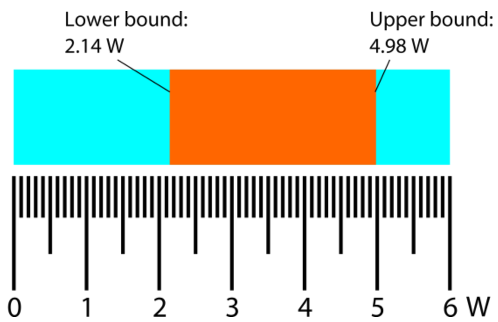
The EKZ grid area + metering aspects

360.000	total electricity metering points (EMPs)
84%	residential MPs
100%	3-phase MPs
PLC	last mile communication technology
20%	of residential smart meters are installed
2033	estimated year for complete rollout

Implications on SMI own energy consumption

2.14 W	average input power (AIP) per metering point
94%	of that, only for the meter
13.00 GWh	annual energy consumption (AEC) before 2010 (EKZ operated grid area)
6.75 GWh	AEC when all res. meters are exchanged by smart meters (EKZ operated grid area)

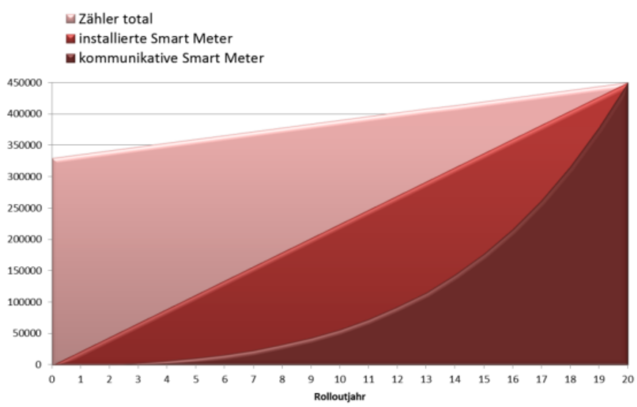
Average input power per metering point



The figure to the left shows the bandwidth of AIP according to different technical solutions for PLC smart metering infrastructure. According to the data that has been provided by the manufacturer, the currently installed solution marks the lower bound, compared with existing data from the SMART METERING consumption project.[62]

Legislative requirements and EKZ´s strategy for the smart meter rollout

In Switzerland, there is no fixed, mandatory rollout "deadline" for the utilities. EKZ are one of the first adopters of smart metering in



61 Based on Röthlisberger/Gmür, 2015

62 Preisel, et al, 2012

Switzerland and began rolling out smart meters in 2010. As such EKZ established a continuous process which they call “Smart smart meter rollout”. For regional subdivisions of the size of 5.000 electricity metering points, the smart meters will be installed once the existing meters reach their end of life or no longer fulfill the legal requirements. Based on testing results, the decision is taken if the meters of each sub-region shall be exchanged by new smart meters or not. 25.000 meters are exchanged on average per year, and 2033 is the estimated year for the process to be completed.

Technology choice of EKZ for electricity smart metering

EKZ decided to install a PLC system from a European provider of smart metering solutions. The reasons for choosing PLC were the independence from telecommunication providers, and a projected better performance of the smart meters by avoiding communication failures associated with radio transmission.

Only one type of electricity smart meter is to be rolled out in the residential sector, consisting purely of 3-phase MPs. The chosen product shall fit all possible installation and operation conditions. Tenders for manufacturers are carried out every two years, and a second, compatible manufacturer has been chosen as a parallel backup option. The most important criteria for the selection process in these tenders are the robustness and performance of the smart meters in binding to the head-end system, the hardware and quality of the SMs as such, and the price per unit.

Future perspective of smart metering

EKZ experts believe that smart metering will make it possible to perform most administrative processes in an automated way, using end-to-end communication between the customer and the head-end. The economic benefits relate to the reduction of manpower, for example, for dealing with 40.000 relocations of residents per year, solely in the canton Zurich. Switching from one electricity provider to another will be easier for the customers and possibly more frequent.

Future perspectives on energy monitoring systems[63]

In 2010 EKZ started a pilot project to examine energy saving effects along with different ways of providing energy consumption feedback to end users. The possible development of additional customer services was planned after evaluation of the pilot project results. The results did not meet the original expectations. Accordingly, the only new service for end users is a web portal called “MyEKZ”. This portal will visualize the energy consumption profile of the previous day, and it is not intended to display real-time information. However, the next generation of smart meters will include a so-called HAN interface (Home Area Network). This interface will make it possible for (other) energy service providers but also for the end-users themselves to connect the smart meter to an EMS.

This interface for easy connection is likely to facilitate the adoption and use of other systems, providing energy consumption feedback.

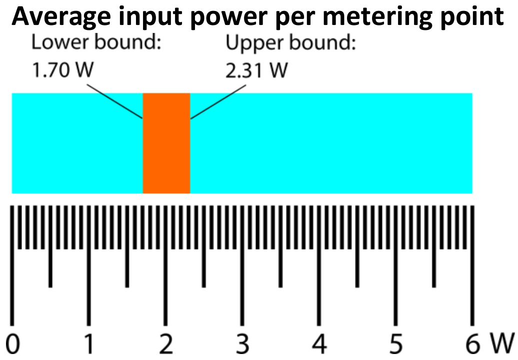
EKZ would be technically prepared to install multi-utility-control in the future. In this way it would be possible to connect additional meters like water, heat, and gas to the existing electricity smart meter, and perform synchronized, combined read-outs.

63 EKZ

United Kingdom

Extrapolated own energy consumption of smart metering infrastructure Key facts and figures

This document briefly describes how the United Kingdom case study of EDNA Task 1 is set.



The United Kingdom grid area + metering aspects

32 940 000	total of electricity metering points (MPs)
3 %	amount of 3-phase MPs
GPRS, Radio	last mile communication technologies

Main results and key findings

1.70 – 2.31 W	range for average input power (AIP), per metering point (including all system-wide contributions from associated power demand)
667.7 GWh	extent of annual energy consumption (AEC), based on maximum AIP
8.0 %	amount of energy demand for smart metering in whole United Kingdom, related to the energy production of the Wylfa nuclear power station

The stock data for available GPRS and especially PLC systems show a certain range of efficiency in terms of own energy consumption.
Detailed technical specifications for smart meters are available in UK DECC, 2014 a. and UK DECC, 2014 b. Data on own energy consumption is not available, however the specifications for smart meters state, that the own energy consumption should on average not exceed 4 Watts for single and twin element electricity meters and 7 Watts for poly phase meters[64]. The majority (>97%) of meters will be single phase meters.[65] Further, these technical requirements comply with all common minimum functional requirements recommended in EC 2012/148/EU.[66]

In the UK, all consumers are offered an in home energy display as well as web access and apps.

64 UK DECC, 2014 a. p. 39, p. 73, p. 86

65 Morgan, P. 20.01.2015 email to Diaz, A.

66 EC, 2014 b. p. 16

4.2 Case studies on energy monitoring systems (EMS)

The Case studies for each EDNA member country were derived as described in Chapter 3.2.2 above and further details on the underlying measurements methodology and documentation are available in APPENDIX A and APPENDIX B respectively. The country specific case studies focus on two, distinct but complementary, important issues:

1. The own power consumption of different systems as a share (%) of the country specific household electrical power consumption as shown in Figure 30 below. Lower and upper bounds of possible energy consumption from the investigated systems are provided. This information can be used to evaluate the trade-off when considering the expected savings from the implementation of such systems.

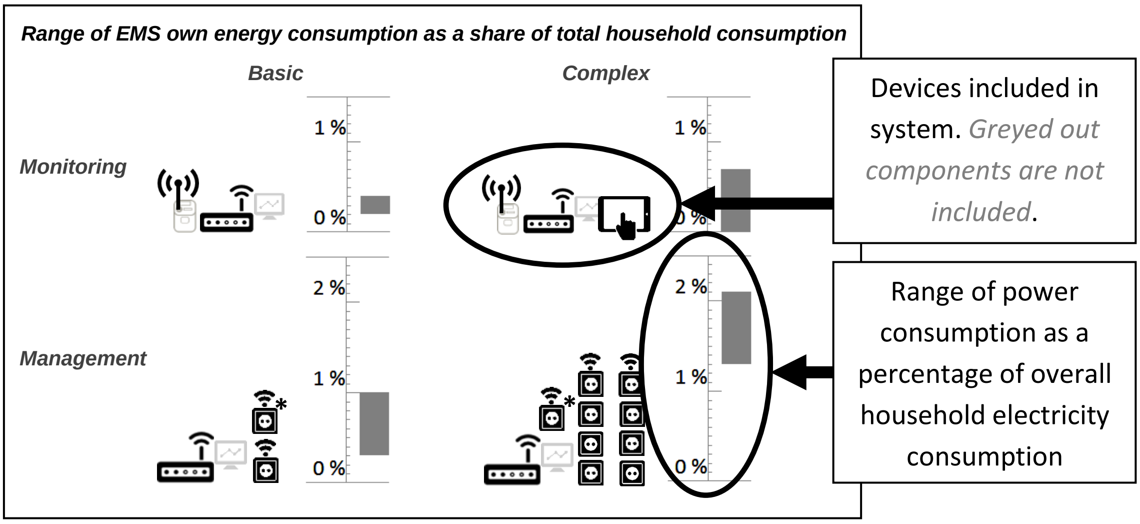


Figure 30 Example of the graphical representation of the own power consumption on household level used in the case studies.

2. The energy implication of a widespread installation of EMS according to different market penetration scenarios in the EDNA countries, an example of which is shown in Figure 31. This information helps understand the potential magnitude of the overall parasitic energy consumption of such systems.

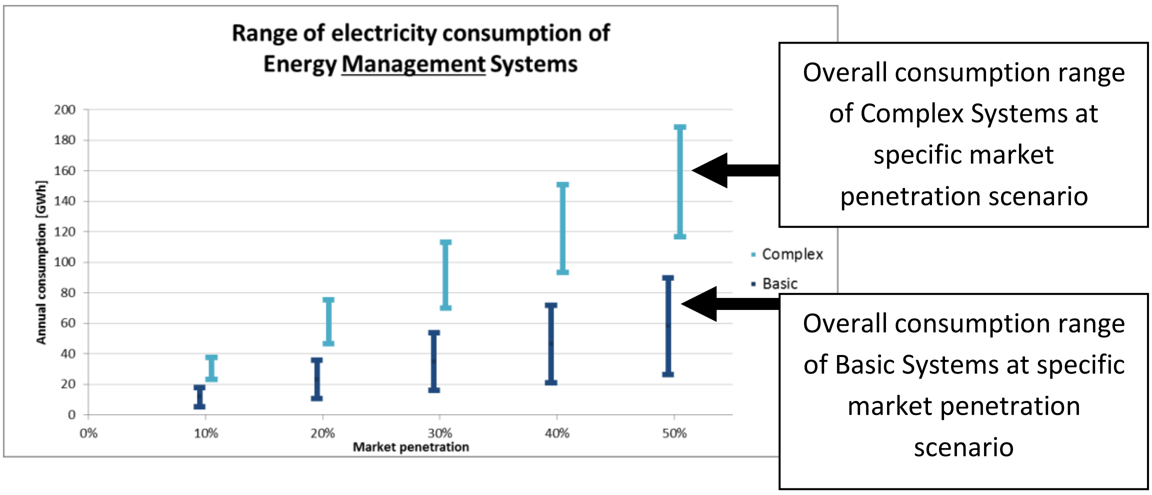


Figure 31 Example of the graphical representation of the own power consumption on the country level used in the case studies.

Australia

Energy Monitoring Systems and their own energy consumption Key figures

8.73 million households

51,031 GWh total annual household electricity consumption

5,843 kWh average annual electricity consumption per household

The impact of an installation of EMS on a single household's energy consumption are shown below, indicating the possible ranges of electricity consumed by the EMS as a share (%) of the household's total annual electricity consumption:

EMS own energy consumption as a share of household electricity consumption

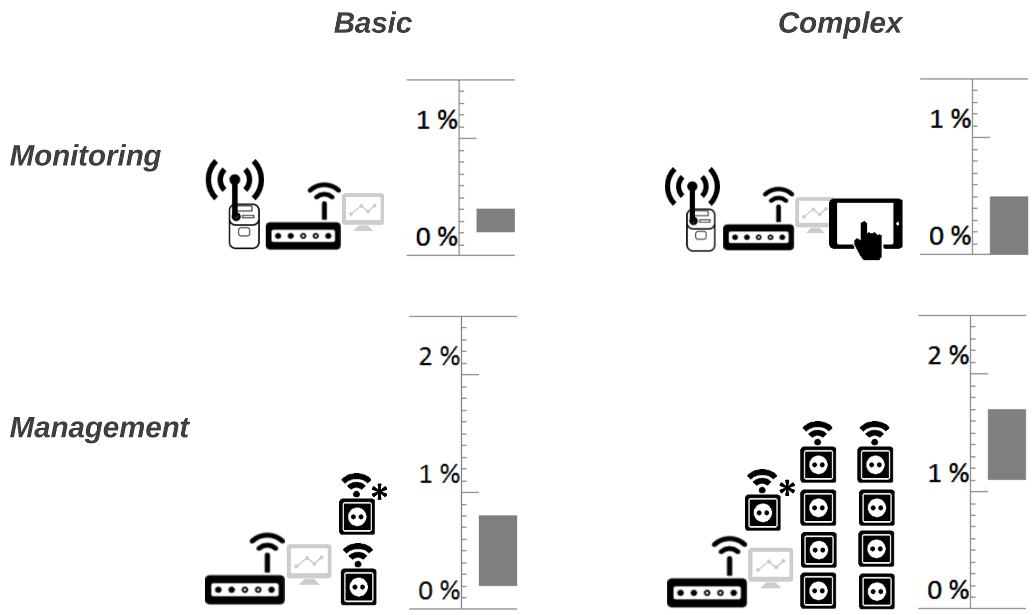
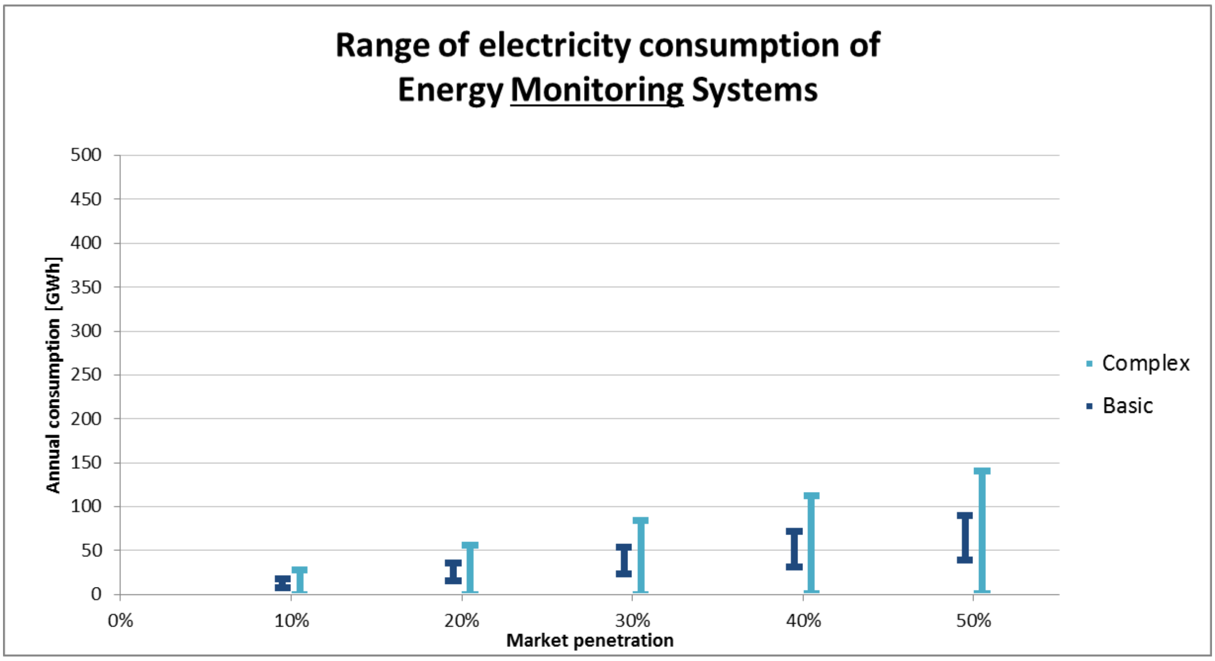


Figure 32 Depiction of the range of own electricity consumption of EMS as a share (%) of the annual electricity consumption of a household in four different technical installation scenarios

To provide electricity monitoring of the entire household, the systems considered require between 0.001% and 0.5% of the household's consumption. Basic management systems require between 0.2% and 0.8% while complex management systems require between 1.1% and 1.7% of the average household´s consumption.

To evaluate the country wide energy implications from the widespread installation of EMS, the following two figures show the range of the own electricity consumption of the monitoring and management systems, as a function of their market penetration in the country.



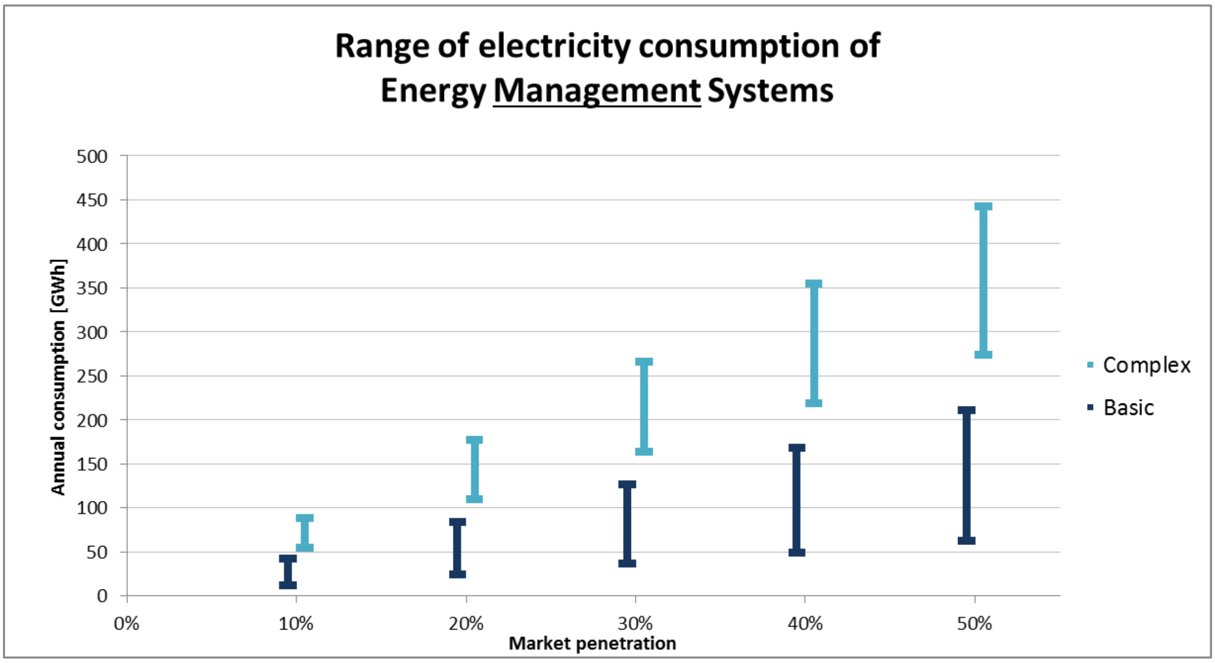


Figure 33 Lower and upper bound of total electricity consumption of energy monitoring and management systems in Australia as a function of their market penetration.

Key findings:

Different systems require substantially different amounts of electricity to provide similar or even identical features. The installation of EMS can add up to 1.7% to the energy consumption in single homes. For a 50% penetration scenario of EM systems, namely when 50% of the households in Australia would install such a system, the energy consumption of the residential sector could increase by up to 443 GWh/year, which is equivalent to 7 % of the annual electricity generated by the Hazelwood power station. This additional consumption would offset part of any expected savings from the installation of these systems and should therefore be minimized. Further key findings which are more widely applicable to EMS are discussed in Section 5.2.

Austria

Energy Monitoring Systems and their own energy consumption Key figures

3.72 million households

17,687 GWh annual household electricity consumption

4,753 kWh average annual electricity consumption per household

The impact of an installation of EMS on a single household's energy consumption are shown below, indicating the possible ranges of electricity consumed by the EMS as a share (%) of the household's total annual electricity consumption:

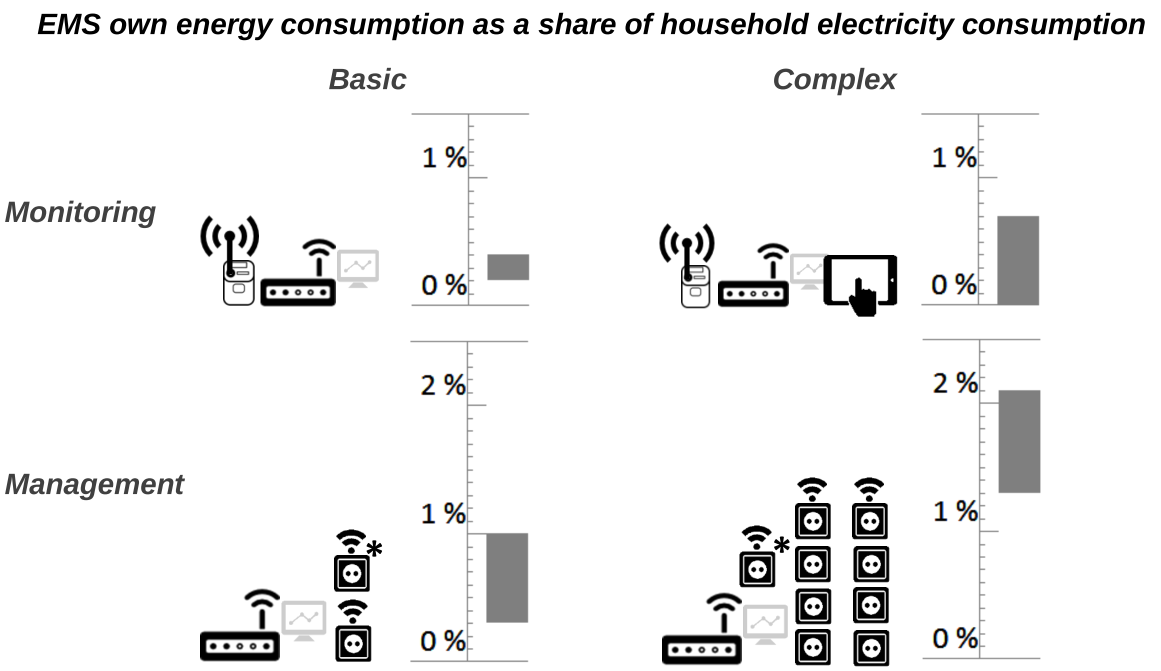
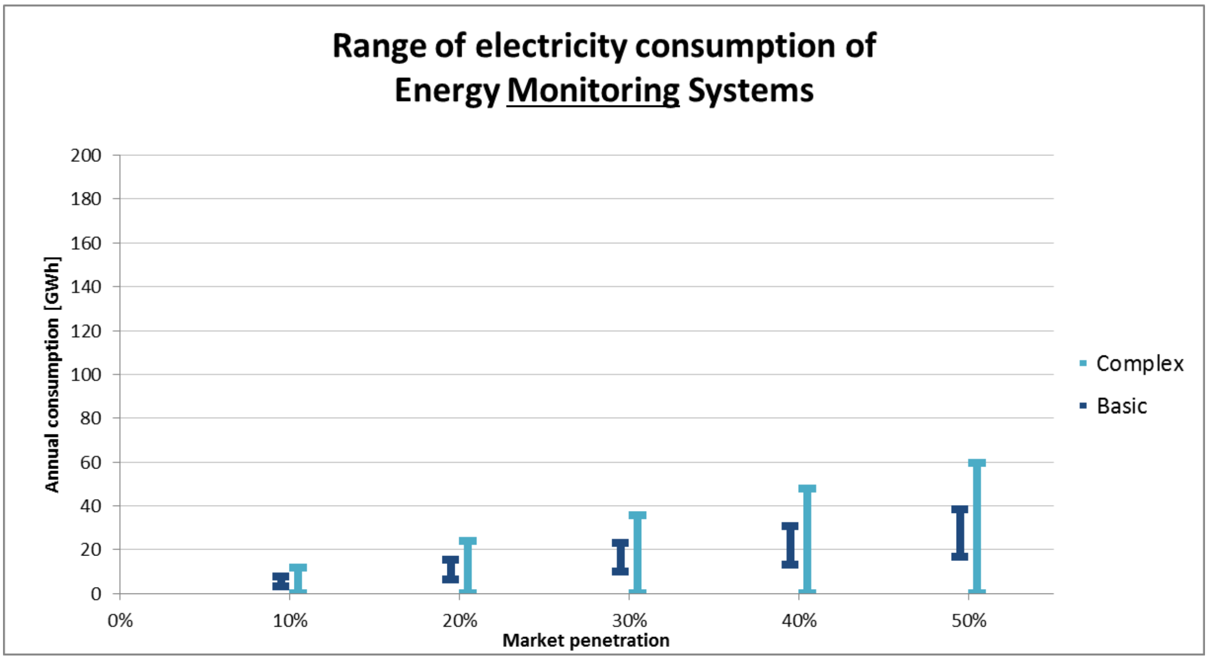


Figure 34 Depiction of the range of own electricity consumption of EMS as a share (%) of the annual electricity consumption of a household in four different technical installation scenarios

To provide electricity monitoring of the entire household, different systems require between 0.002% and 0.7% of the household's consumption. Basic management systems require between 0.3% and 1.0% while Complex management systems require between 1.3% and 2.1% of the average household´s consumption.

To evaluate the country wide energy implications from the widespread installation of EMS, the following two figures show the range of the own electricity consumption of the monitoring and management systems, as a function of their market penetration in the country.



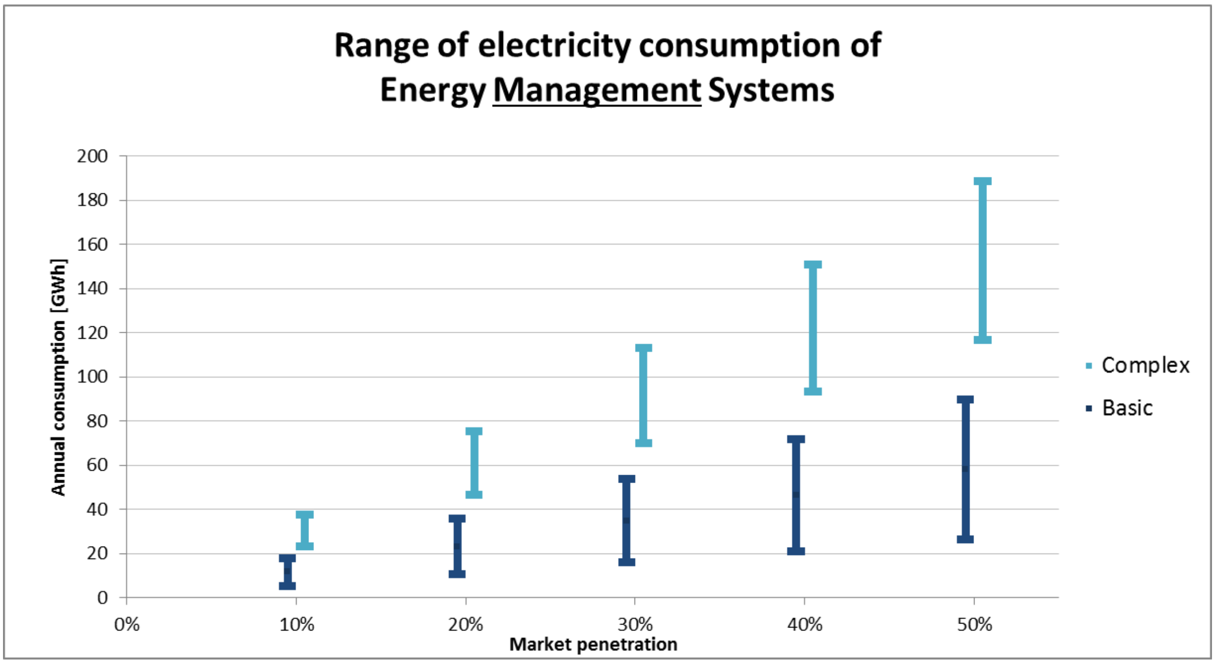


Figure 2 Lower and upper bound of total electricity consumption of energy monitoring and management systems in Austria as a function of their market penetration.

Key finding:

Different systems require substantially different amounts of electricity to provide similar or even identical features. The installation of EMS can add up to 2.1% to the energy consumption in single homes. For a 50% penetration scenario of EM systems, the energy consumption of the residential sector could increase by up to 189 GWh/year, which is equivalent to 18 % of the annual electricity generated by the Danube Hydropower plant Freudenau. This additional consumption would offset part of any expected savings from the installation of these systems and should therefore be minimized. Further key findings which are more widely applicable to EMS are discussed in Section 5.2.

Denmark

Energy Monitoring Systems and their own energy consumption Key figures

2.34 million households

10,307 GWh annual household electricity consumption

4,406 kWh average annual electricity consumption per household

The impact of an installation of EMS on a single household's energy consumption are shown below, indicating the possible ranges of electricity consumed by the EMS as a share (%) of the household's total annual electricity consumption:

EMS own energy consumption as a share of household electricity consumption

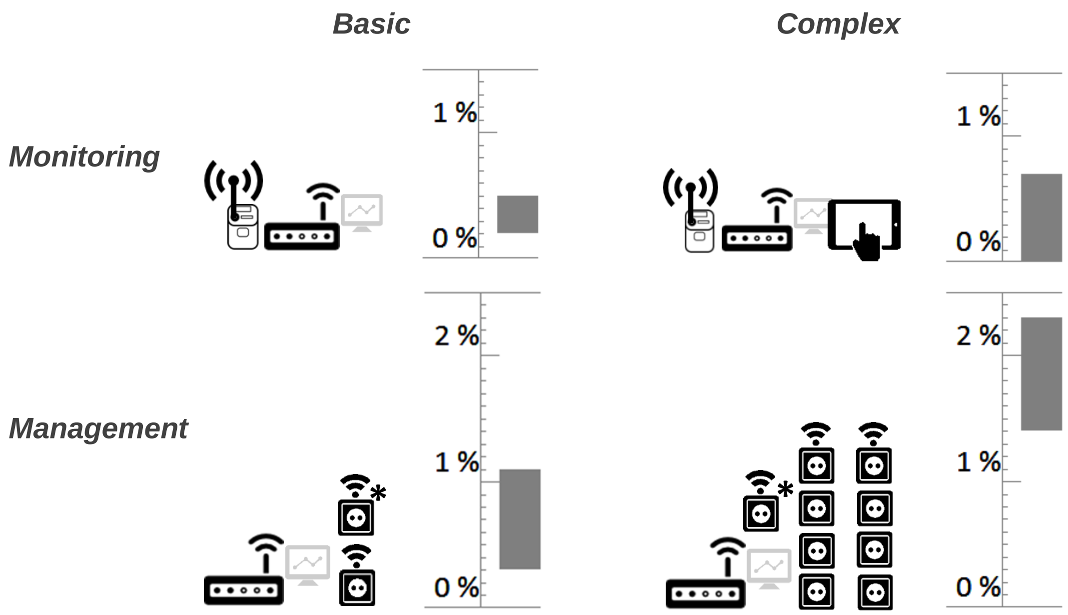
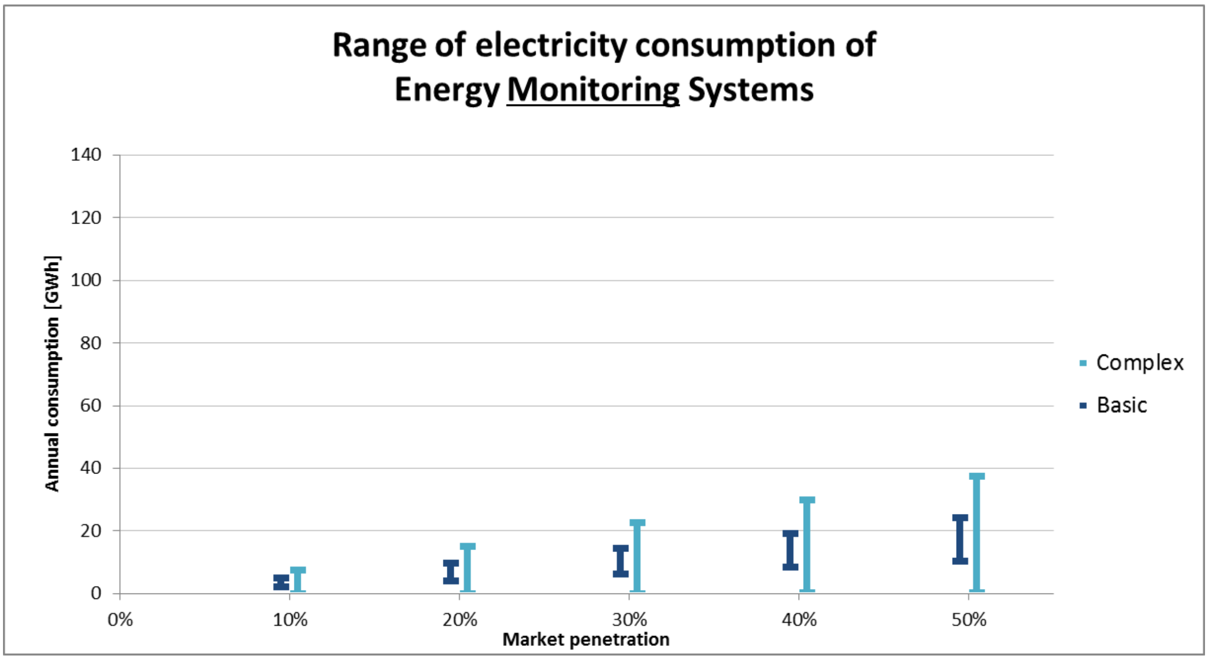


Figure 35 Depiction of the range of own electricity consumption of EMS as a share (%) of the annual electricity consumption of a household in four different technical installation scenarios

To provide electricity monitoring of the entire household, different systems require between 0.002% and 0.7% of the household's consumption. Basic management systems require between 0.3% and 1.1% while Complex management systems require between 1.4% and 2.3% of the average household´s consumption.

To evaluate the country wide energy implications from the widespread installation of EMS, the following two figures show the range of the own electricity consumption of the monitoring and management systems, as a function of their market penetration in the country.



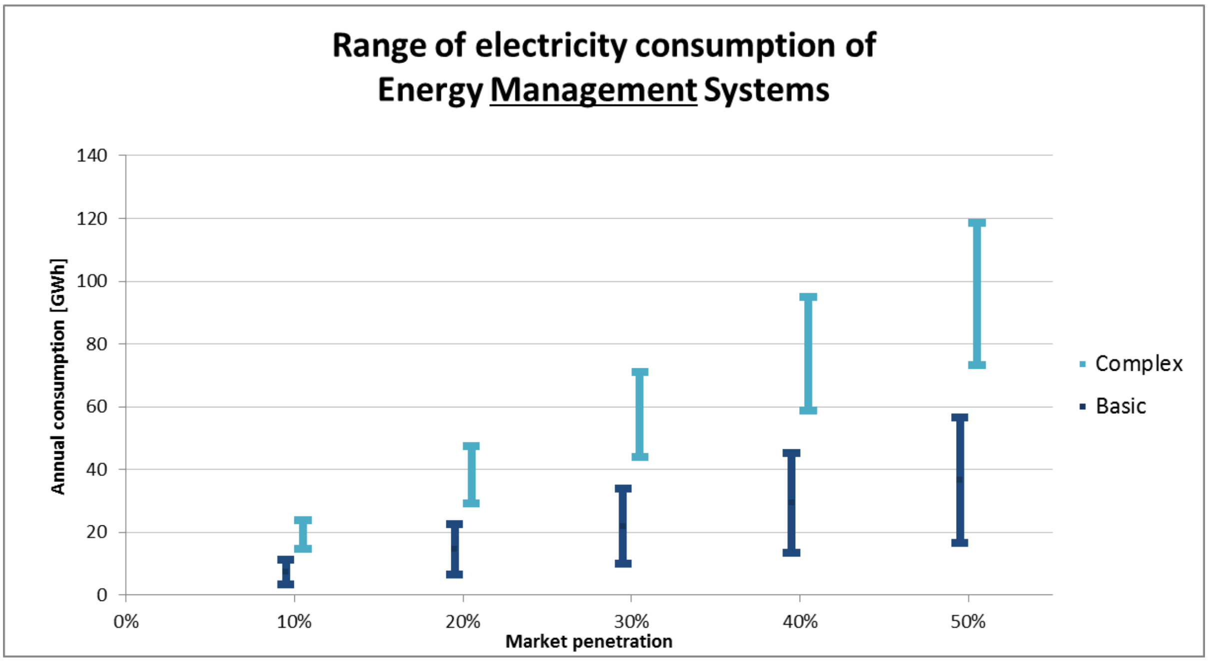


Figure 36 Lower and upper bound of total electricity consumption of energy monitoring and management systems in Denmark as a function of their market penetration.

Key finding:

Different systems require substantially different amounts of electricity to provide similar or even identical features. The installation of EMS can add up to 2.3% to the energy consumption in single homes. For a 50% penetration scenario of EMS, the additional energy consumption of the whole residential sector could increase by up to 119 GWh/year, which is equivalent to approximately 4 % of the annual electricity generated by the Studstrup power station. This additional consumption would offset part of any expected savings from the installation of these systems and should therefore be minimized. Further key findings which are more widely applicable to EMS are discussed in Section 5.2.

The Netherlands

Energy Monitoring Systems and their own energy consumption Key figures

7.55 million households

25,132 GWh annual household electricity consumption

3,329 kWh average annual electricity consumption per household

The impact of an installation of EMS on a single household's energy consumption are shown below, indicating the possible ranges of electricity consumed by the EMS as a share (%) of the household's total annual electricity consumption:

EMS own energy consumption as a share of household electricity consumption

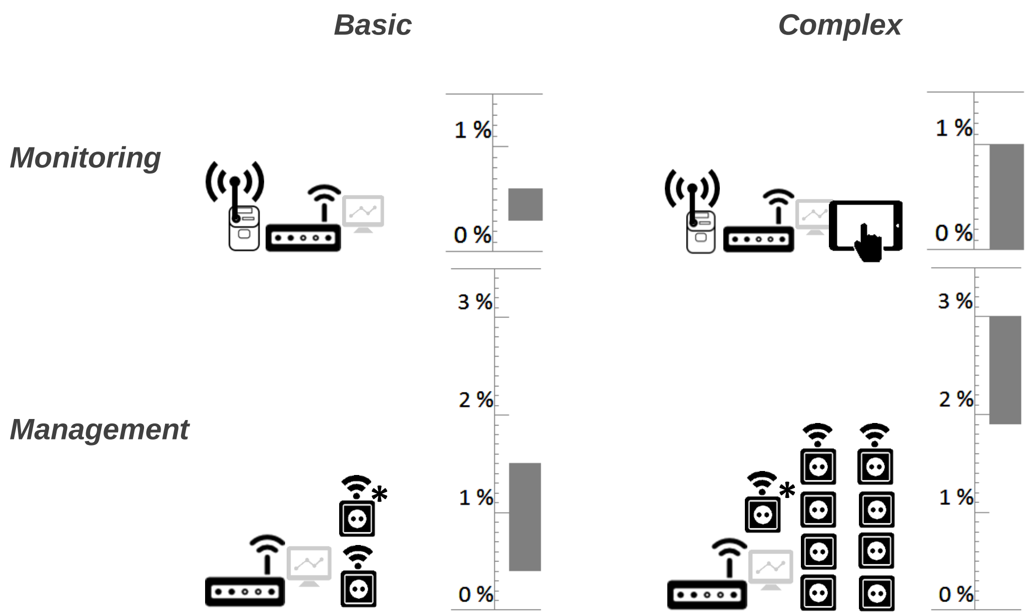
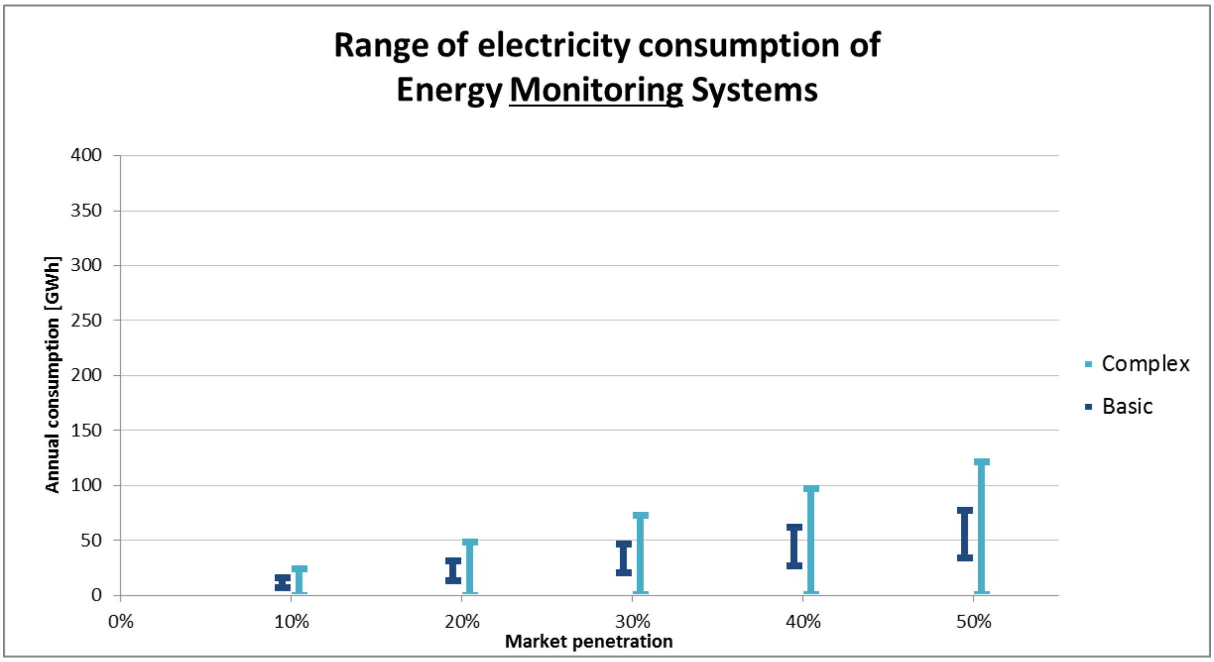


Figure 37 Depiction of the range of own electricity consumption of EMS as a share (%) of the annual electricity consumption of a household in four different technical installation scenarios

To provide electricity monitoring of the entire household, different systems require between 0.003% and 1,0% of the household's consumption. Basic management systems require between 0.4% and 1.5% while Complex management systems require between 1.9% and 3.0% of the average household´s consumption.

To evaluate the country wide energy implications from the widespread installation of EMS, the following two figures show the range of the own electricity consumption of the monitoring and management systems, as a function of their market penetration in the country.



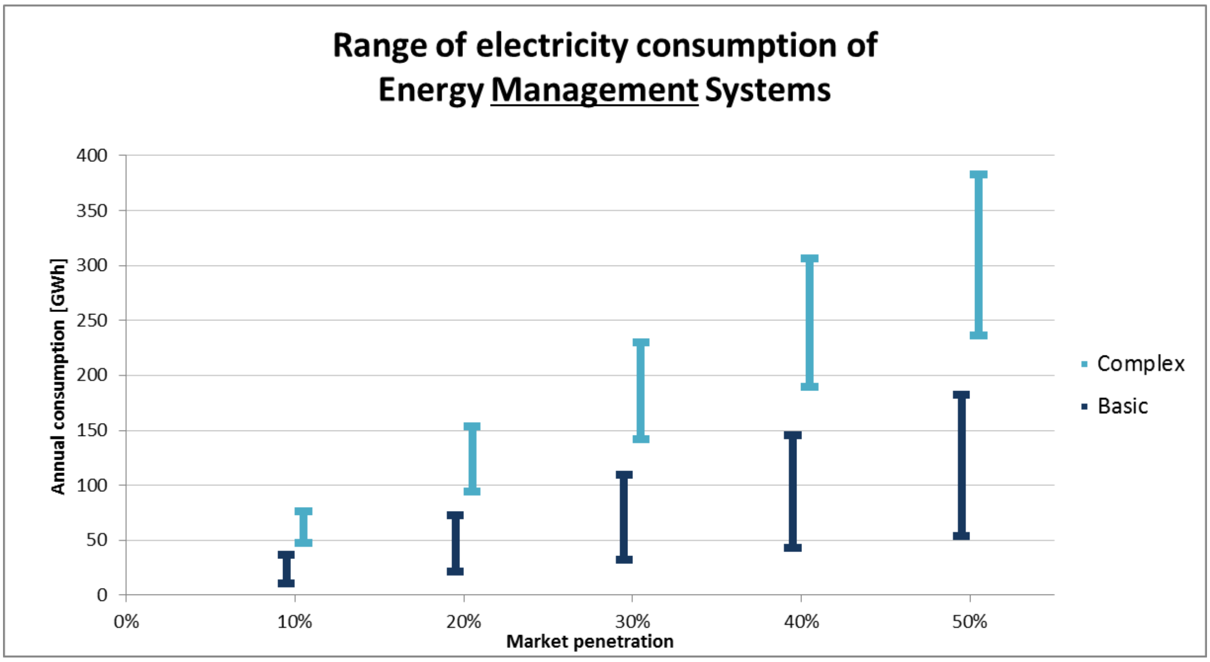


Figure 1 Lower and upper bound of total electricity consumption of energy monitoring and management systems in the Netherlands as a function of their market penetration.

Key findings:

Different systems require substantially different amounts of electricity to provide similar or even identical features. Considering the already rather moderate average household energy consumption in the Netherlands, the installation of EMS can have an impact on this consumption and, depending on the system, could add up to 3% to the household´s consumption. For a 50% penetration scenario of EMS, the additional energy consumption of the whole residential sector could increase by up to 383 GWh/year, which is equivalent to nearly 12 % of the annual electricity generated by the Borssele power station. This additional consumption would offset part of any expected savings from the installation of these systems and should therefore be minimized. Further key findings which are more widely applicable to EMS are discussed in Section 5.2.

Sweden

Energy Monitoring Systems and their own energy consumption Key figures

4.4 million households

2.4 million apartments

2 million detached homes

34,800 GWh annual household electricity consumption

7,909 kWh average annual electricity consumption per household

3,542 kWh/y average consumption in apartments.

13,150 kWh/y average consumption in detached homes.

In Sweden there are 4.4 million households, which are commonly split into apartments and detached houses. The overall electricity consumption in 2014 was reported to be 24,800 GWh, giving an average household consumption of 7,909 kWh of electricity per year. The consumption is however very different for apartments and detached homes. This is especially true for detached homes which use electricity for heating and hot water generation. The average electricity consumption in detached homes is 13,150 kWh/y while the average consumption in apartments is only 3,542 kWh/y. The energy impact of an EMS installation therefore is evaluated separately for apartments and for detached homes, as shown below, indicating the possible ranges of electricity consumed by the EMS as share (%) of the household's total annual electricity consumption:

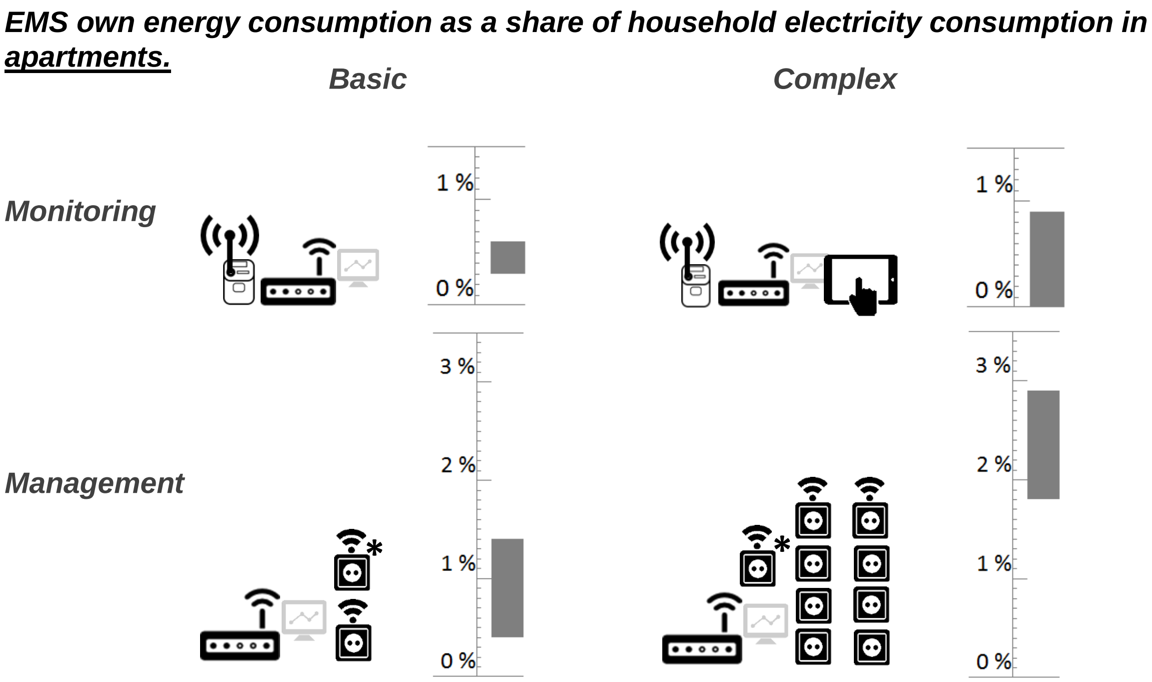


Figure 38 Depiction of the range of own electricity consumption of EMS as a share (%) of the annual electricity consumption of an apartment household in four different technical installation scenarios

to provide electricity monitoring of an apartment , different systems require between 0.002% and 0.9% of the apartment's consumption. Basic management systems require between 0.4% and 1.4% while Complex management Systems require between 1.8% and 2.9% of the apartment´s average consumption.

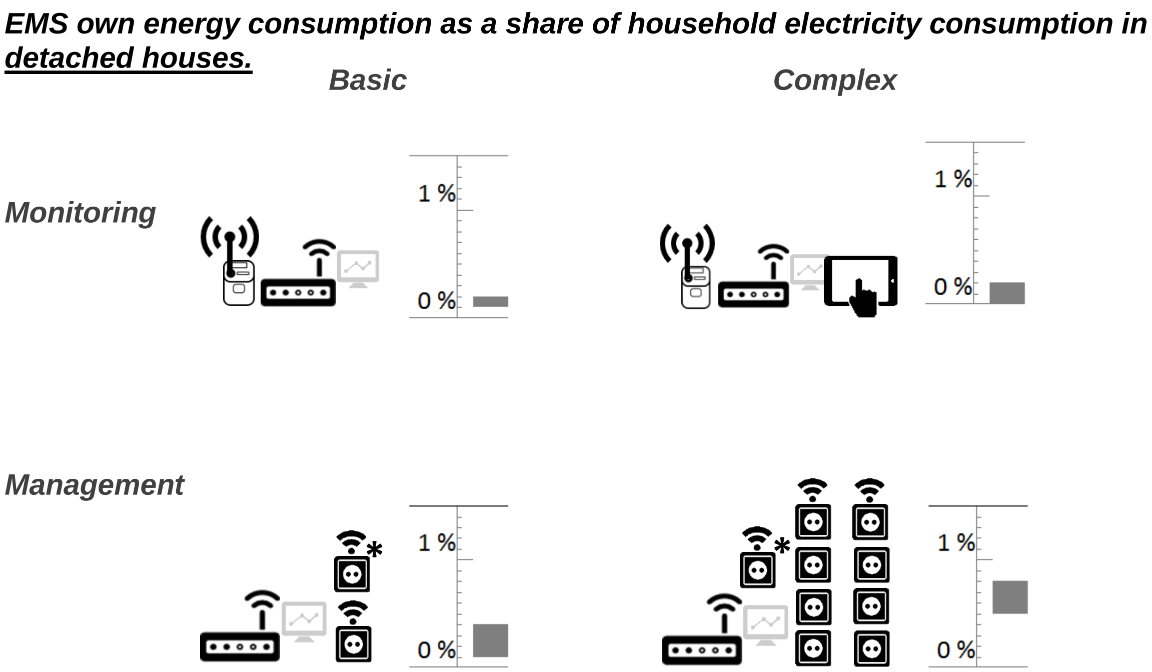
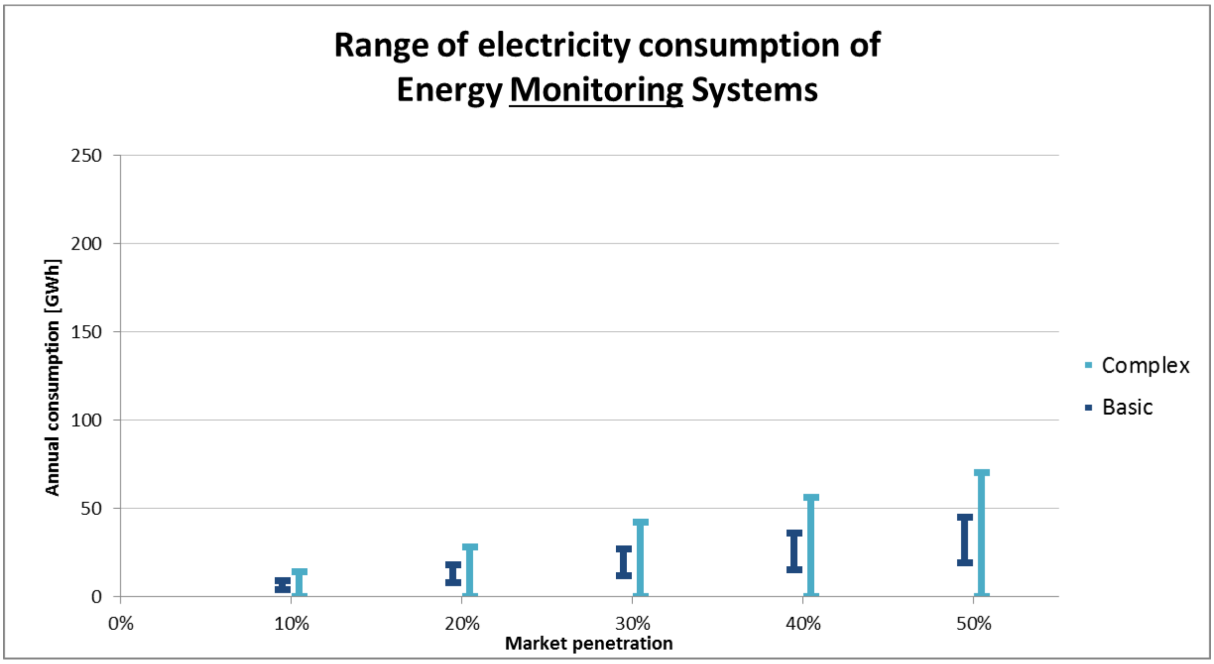


Figure 39 Depiction of the range of own electricity consumption of EMS as a share (%) of the annual electricity consumption of a detached house household in four different technical installation scenarios

For a detached home the EM systems considered require between 0.001% and only 0.2% of the detached home's consumption. Basic management systems require between 0.1% and 0.4% while

Complex management systems require between 0.5% and 0.8% of the detached home´s average consumption.

To evaluate the country wide energy implications from the widespread installation of EMS, the following two figures show the range of the own electricity consumption of the monitoring and management systems, as a function of their market penetration in the country.



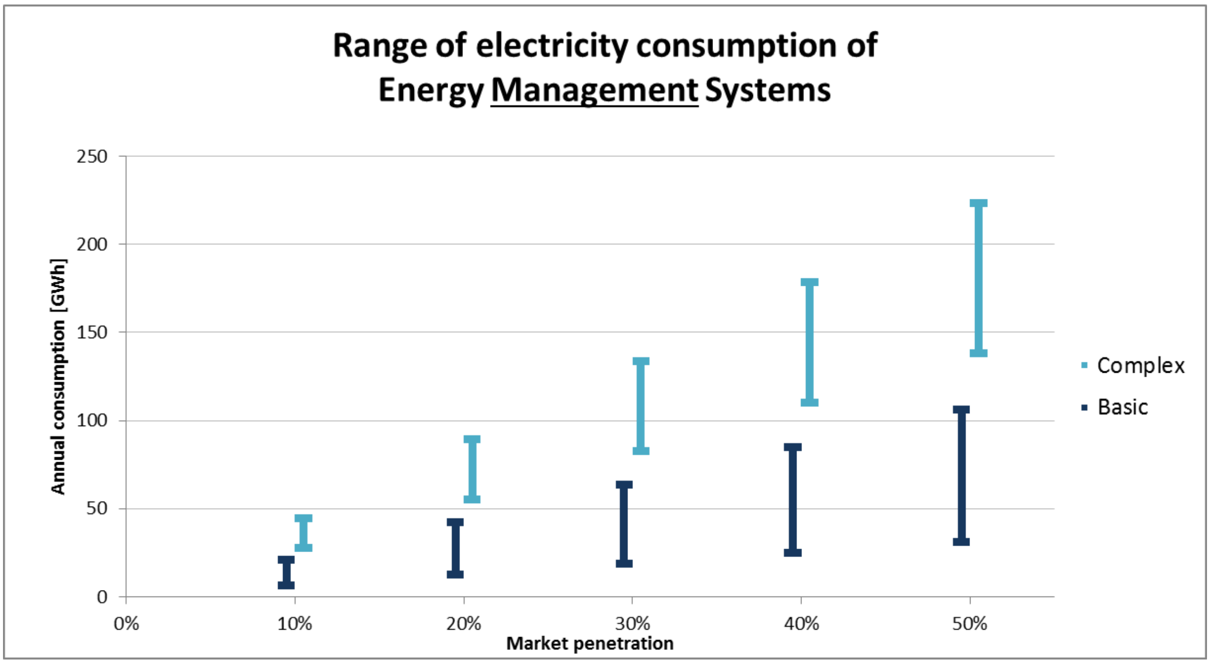
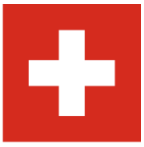


Figure 2 Lower and upper bound of total electricity consumption of energy monitoring and management systems in Sweden as a function of their market penetration.

Key finding:

Different systems require substantially different amounts of electricity to provide similar or even identical features. The installation of EMS can add up to 2.9% to the energy consumption in apartments, and up to 0.8% in detached homes. For a 50% penetration scenario of EMS, the energy consumption of the whole residential sector could increase by up to 223 GWh/year, which is equivalent to nearly 1 % of the annual electricity generated by the Ringhals nuclear power plant. In light of the comparably large residential electricity consumption in Sweden, especially for detached homes, and the associated savings potential, the own power consumption of EMS may be less relevant than in other EDNA member countries. Nonetheless, this additional consumption will offset part of any expected savings from the installation of these systems and should therefore be minimized. Further key findings which are more widely applicable to EMS are discussed in Section 5.2.

Switzerland



Energy Monitoring Systems and their own energy consumption Key figures[67 68]

3.53 million households

18,287 GWh annual household electricity consumption

5,177 kWh average annual electricity consumption per household

The impact of an installation of EMS on a single household's energy consumption are shown below, indicating the possible ranges of electricity consumed by the EMS as a share (%) of the household's total annual electricity consumption:

EMS own energy consumption as a share of household electricity consumption

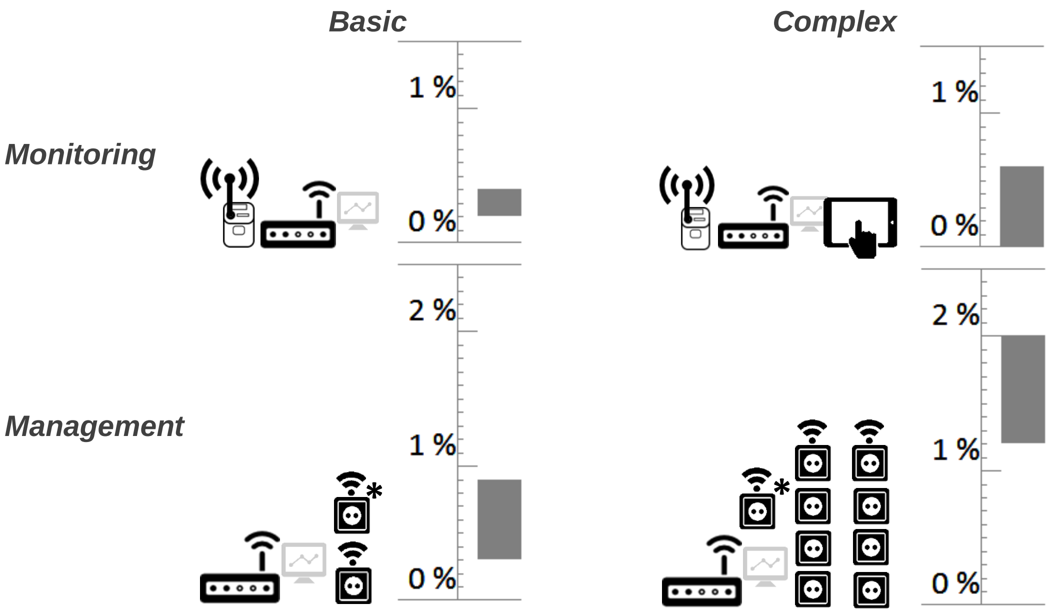


Figure 40 Depiction of the range of own electricity consumption of EMS as a share (%) of the annual electricity consumption of a household in four different technical installation scenarios

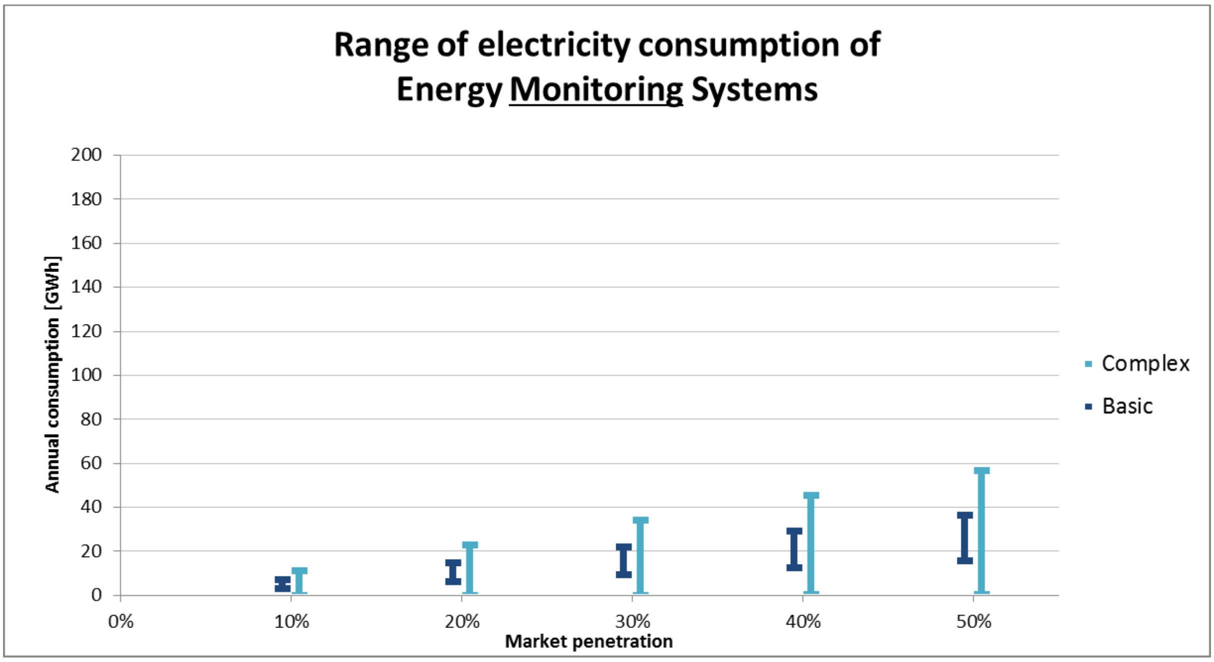
To provide electricity monitoring different systems require between 0.002% and 0.6% of the household's consumption. Basic Management systems require between 0.3% and 0.9% while

67 Statistik Schweiz, 2013

68 Bundesamt für Energie BFE, 2014

Complex management systems require between 1.2% and 2.0% of the average household´s consumption.

To evaluate the country wide energy implications from the widespread installation of EMS, the following two figures show the range of the own electricity consumption of the monitoring and management systems, as a function of their market penetration in the country.



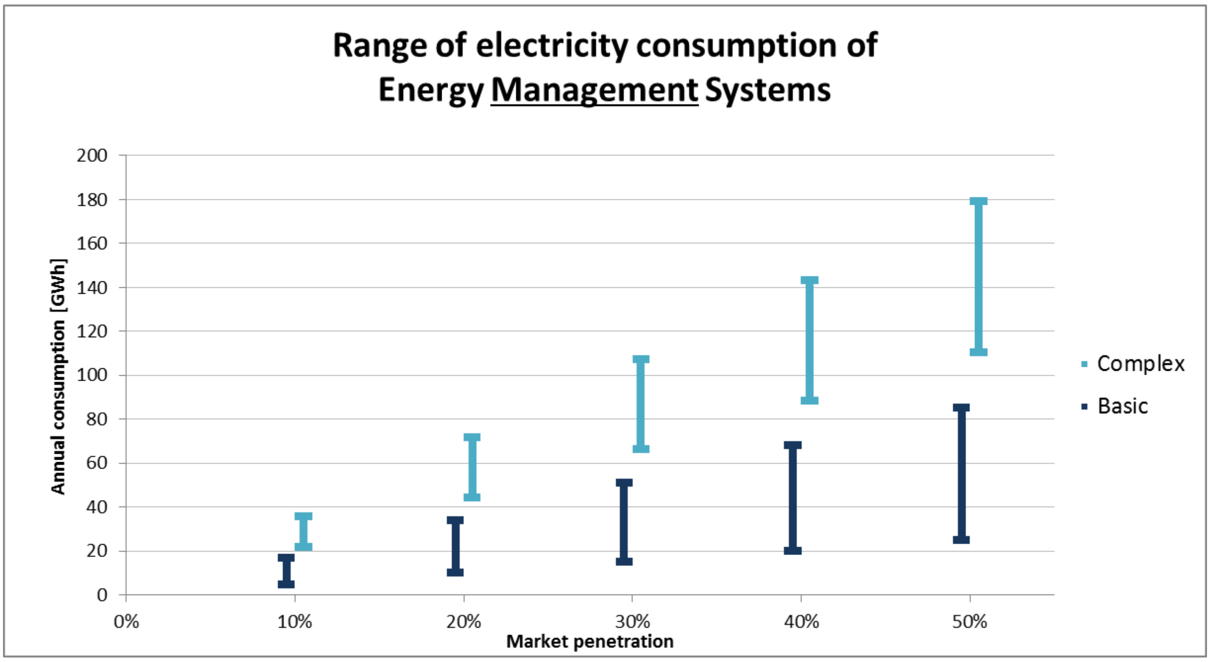


Figure 3 Lower and upper bound of total electricity consumption of energy monitoring and management systems in Switzerland as a function of their market penetration.

Key finding:

Different systems require substantially different amounts of electricity to provide similar or even identical features. The installation of EMS can add up to 2 % to the energy consumption in the household. The additional energy consumption from the use of handheld devices and PCs is not included in this estimate. For a 50% penetration scenario of EMS, the additional energy consumption of the whole residential sector could increase by up to 179 GWh/year, which is equivalent to nearly 28 % of the annual electricity generated by the Rheinkraftwerk Albbruck-Dogern. This additional consumption would offset part of any expected savings from the installation of these systems and should therefore be minimized. Further key findings which are more widely applicable to EMS are discussed in Section 5.2.

The United Kingdom

Energy Monitoring Systems and their own energy consumption Key figures

27.61 million households

113,453 GWh annual household electricity consumption

4,109 kWh average annual electricity consumption per household

In The impact of an installation of EMS on a single household's energy consumption are shown below, indicating the possible ranges of electricity consumed by the EMS as a share (%) of the household's total annual electricity consumption:

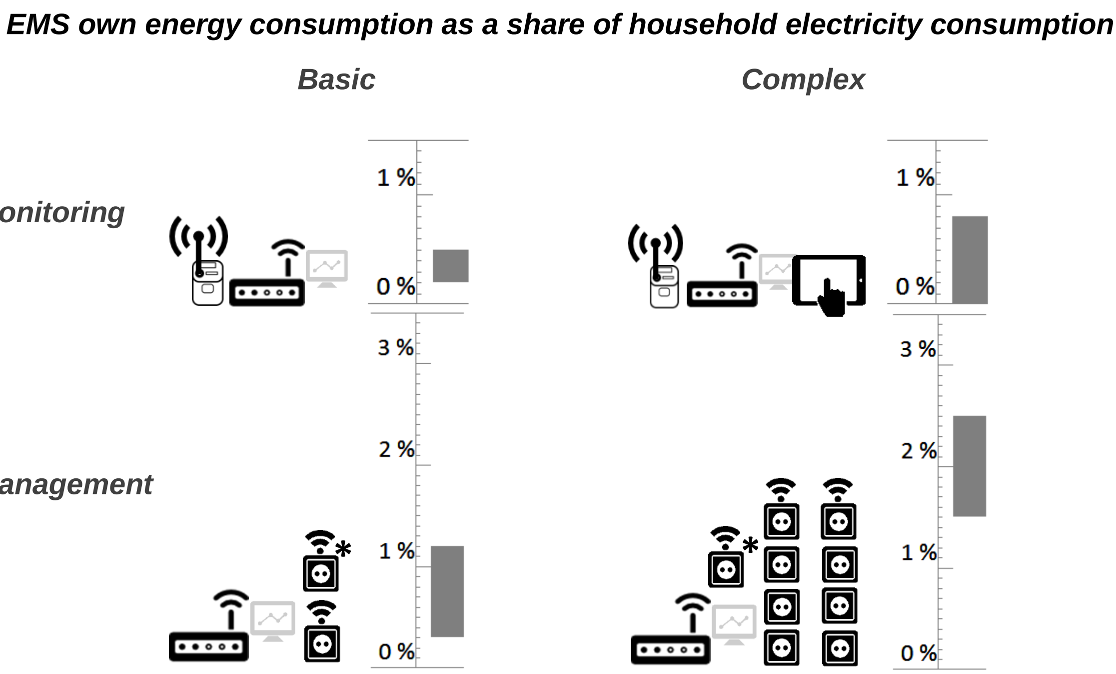
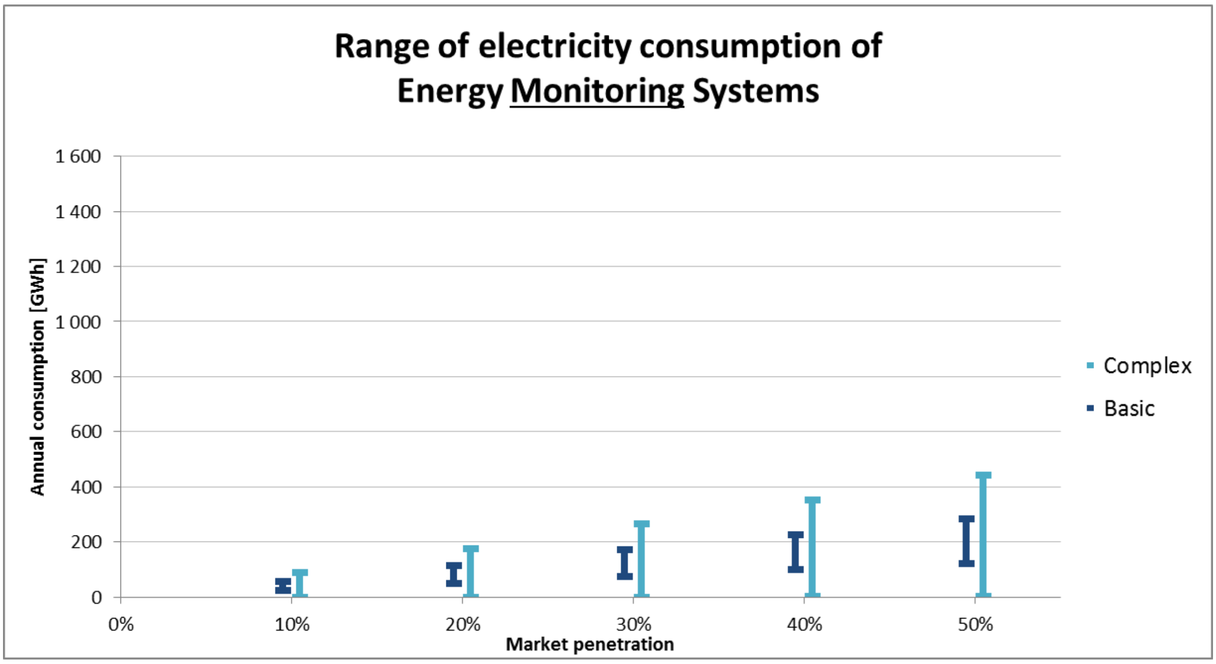


Figure 41 Depiction of the range of own electricity consumption of EMS as a share (%) of the annual electricity consumption of a household in four different technical installation scenarios

To provide electricity monitoring for the homes, different systems require between 0.002% and 0.8% of the household's consumption. Basic management systems require between 0.3% and 1.2% while Complex management systems require between 1.5 % and 2.5 % of the average household´s consumption.

To evaluate the country wide energy implications from the widespread installation of EMS, the following two figures show the range of the own electricity consumption of the monitoring and management systems, as a function of their market penetration in the country.



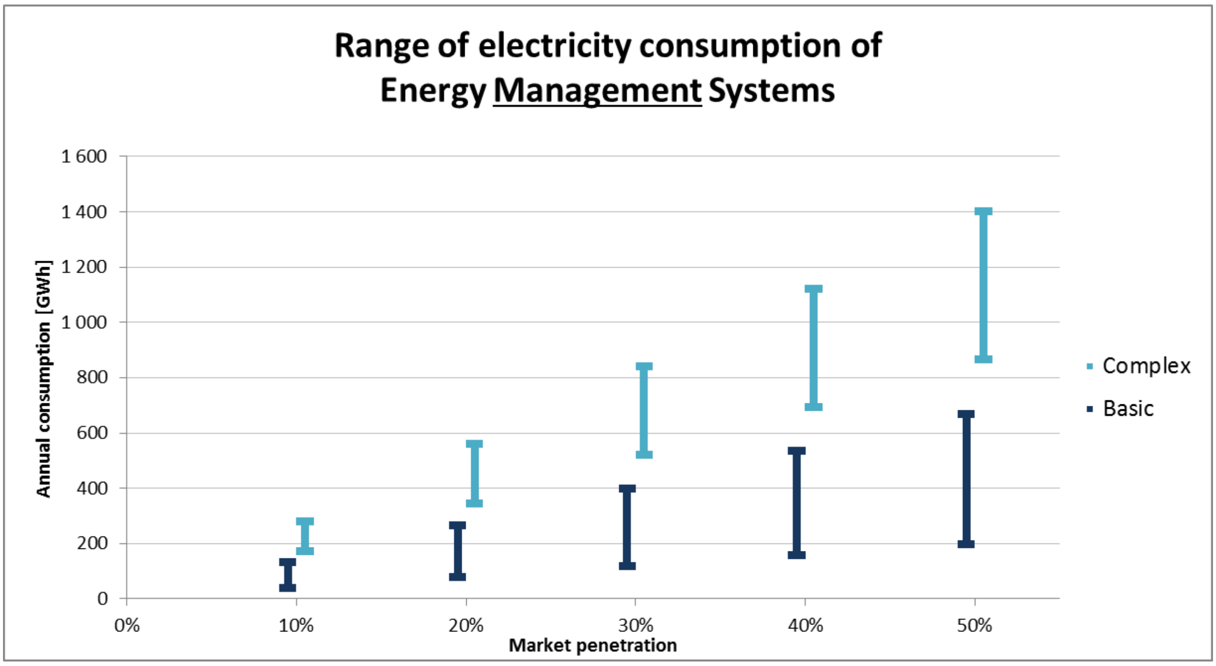


Figure 4 Lower and upper bound of total electricity consumption of energy monitoring and management systems in the United Kingdom as a function of their market penetration.

Key findings:

Different systems require substantially different amounts of electricity to provide similar or even identical features. The installation of EMS can add up to 2,5% to the energy consumption in the household. For a 50% penetration scenario of EMS, the additional energy consumption of the whole residential sector could increase by up to 1401 GWh/year which is equivalent to nearly 17 % of the annual electricity generated by the Wylfa nuclear power station. This additional consumption would offset part of any expected savings from the installation of these systems and should therefore be minimized. The UK has already started to define maximum power consumption thresholds for in-

Home displays.[69] Measurement results indicate that an expansion or more detailed specification of this threshold could lead to consumption benefits. Further key findings which are more widely applicable to EMS are discussed in Section 5.2.

69 UK DECC, 2014 a. p. 96 „… operating at a nominal voltage of 230VAC without consuming more than an average of 0.6 watts of electricity under normal operating conditions.”

5 Key findings

5.1 SMI – Key findings

Awareness is still low on the issue of own energy consumption

Through the results of the questionnaire that was distributed to the member countries it became clear, that the awareness for the own energy consumption of smart metering infrastructure has not substantially grown since 2012 when the SMc project was concluded. In the field of smart meter rollouts other topics seem to be more prominent.

Further, it seems to be unclear for governments which kind of meters there will be or are being favored by the utilities. Most of the EDNA members could not share information on the meters. The delegates were therefore not able to provide extensive and precise information on this issue. The decision makers would benefit from clearer and extensive data and information.

With respect to energy consumption, the meter is the most relevant component of the infrastructure

Data from the SMc project and recently gathered data for the own energy consumption of devices showed, that the meter is still by far the single most important energy consuming component of the SMI. It contributes between 76% and 98% to the system-wide average input power (AIP) of SMI. This applies to all listed installation scenarios in this report, as researched and reported by the EDNA member countries. These results show that the communication technology is the key factor influencing the energy consumption of the meter. According to Figure 14 and Figure 20, PLC connected meters (category A) tend to have the highest own energy consumption, whereas radio transmission meters (category C) tend to be much more efficient. To achieve a low SMI system-wide energy consumption it is therefore centrally important to install an energy efficient communication technology, which ensures low meter consumption and subsequently low system-wide consumption.

Choice of technology has long-term effects

From the investigation it became clear that several different communication technologies are currently being implemented by utilities in EDNA member countries. These different communication technologies are GPRS, PLC, direct radio transmission or meshed radio. Within each of these coarse categories there are many more sub-solutions being implemented (different standards for PLC, proprietary solutions). Most of these technologies are not compatible to each other and cannot easily interact. In some cases, the geographical constraints only permit (or favor) a specific communication technology, though in most cases, several technologies compete. It is paramount to understand that once a specific technology has been rolled out, the technology pathway for the next 20-30 years is set and cannot be reversed, except with very large investments. This pathway will determine not only the own consumption of the infrastructure for the years to come but also the features, interoperability, and expansion options available to utilities and the end-consumers.

Policies for SMI and EMS are currently decoupled

The investigation shows that there are very few cases, where smart metering roll out plans are coupled to the distribution of EMS or even mandate specific feedback provisions. The only country, where this path has been consequently taken, is the United Kingdom.

The EMS are likely to penetrate if not inundate all markets in the near future. Smart meters can partly be understood as enablers for energy monitoring. However, the current provisions are in most cases limited to the provision of optical interfaces or the parallel service of online platforms, operated by utilities. While in some countries utilities are simply required to operate web portals to serve end-consumers with timely information reflecting the previous day.

Expected change of user behavior mandates real-time feedback

The introduction of smart meters alone will not result in a change of user-behavior. It is necessary to provide appropriate means of feedback to the end-users. According to a variety of research projects and field trials of utilities this works best under the following circumstances:

- The feedback shall be prepared in a mostly simplistic form and avoid abstract indicators or too much confusing peripheral information.
- Feedback shall be given as close to "real-time" as possible. Only in that case, users have the chance to compare the status before and after introducing new improvement measures (e.g. exchange of the refrigerator)
- Improvements are not a permanent process. Therefore it is questionable if permanent information is actually helpful. Many research projects showed that behavior changes take place right after the new monitoring feature is available, but do not continue working in the long term.

"Soft" phase-out strategies are in place

A key finding exclusively coming from the Swiss case study is that there are ways to account for the energy effort for the raw material, the manufacturing, distribution, installation and end of use phase of the smart meters' product life. Further, it is possible to integrate the exchange process into the regular re-calibration processes, the grid operators are carrying out within their meter park.

Meters that are still working properly and fully functioning are kept as long as possible. Decisions of complete exchanges within a lot are made upon a statistically representative sample of a few meters.

Low power smart meters – synergy of infrastructure

The strikingly low AIP of battery powered SM devices as well as the substantial differences between the AIP of different communication technologies demonstrates that there is a large improvement potential which could be tapped into with intelligent policy.

As further metering technology may be updated in the next few decades, synergies in communication and visualization technologies may exist which may further increase the efficiency of the installed infrastructure. This should be taken into account when devising policy for the introduction of electricity SM. In the UK for example, the electricity SM roll-out does take into account that future gas- and water- meters may also be replaced with smart technologies, whose communication technology should be compatible with the electricity smart meters currently under consideration. Smart policy is needed to ensuring that these synergies can be exploited in later installations.

5.2 EMS - Key Findings

The investigation clearly showed that the own power consumption of EMS can be significant and can substantially offset the expected efficiency gains. In this context, it is therefore necessary to understand the EM system as a whole to decide what specific features are necessary and identify the devices or components which carry the greatest efficiency improvement potential.

The systems should be fit for purpose

A system does not need to record everything but should provide the user only with the necessary information. EMS manufacturers have to 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 allows manufacturers to define exactly which devices are necessary to provide the required function and which are not. To distinguish relevant from irrelevant data, EMS manufacturers and installers should be able to argue the intended benefits of each dataset within the wider context of the desired service. Here 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.

Practically this means that manufacturers should consider carefully which functions the system should fulfil and which devices are necessary within this system. Sticking with the functions highlighted above, a system needs to measure, log and visualise the consumption. Different systems use different devices to provide these functions.

Measurement: There are different approaches to measurement. One of the approaches uses a sensor or interface with the electricity meter to transmit the overall consumption to a hub or directly to a display, using a transmitter. Most transmitters relay their information to hubs. In one of the three investigated monitoring systems with displays the transmitter communicated directly with the display, eliminating the need for a hub. This model of eliminating the hub is very interesting due to the large constant power consumption of the hub. An investigation could look into the most energy efficient technologies to link transmitters not only with dedicated displays but possibly directly with an existing infrastructure to eliminate the need for a dedicated hub and possibly a display.

A different measurement approach uses single node measurement points such as smart plugs which also transmit the information to a hub. The number of smart plugs installed greatly influences the total power consumption, increasing with every additional device installed. Users should make informed decisions on exactly how many smart plugs are necessary and how they will specifically be used. Additionally, direct rebound effects may offset the potential savings. When the off consumption of smart plugs exceeds the standby consumption of products the expected savings will be fully offset by the additional parasitic energy consumption of the smart plug. This applies to low standby products such as (but not limited to) TV sets, power supplies such as phone chargers or kitchen appliances such as coffee machines.

As a concrete example, a TV set, sold in the EU is required to have a standby consumption of less than 0.5 W through the Ecodesign Directive. All of the measured smart plugs have an equivalent or greater own consumption in the off mode. The installation of a smart plug, with the hope to eliminate the standby consumption from such TV sets, would add the parasitic energy consumption of the smart plug in on mode, to the standby and on mode of the TV, while offsetting the expected savings in the off mode due to the own consumption.

These cases must be clearly distinguished from cases where the installation of an EMS can lead to substantial savings such as for submersion heaters or heat pumps.

Logging: Both described approaches require (with the mentioned exception) a dedicated hub, with substantial constant power consumption. Research into the possibility of eliminating this hub or replacing it with existing infrastructure could lead to substantial savings in the overall system consumption.

It should also be considered that the huge amount of data generated in these systems has to be stored, protected and analysed. 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 and brings us to our third function, visualisation.

Visualisation: Some of the investigated systems had dedicated displays which on first sight do not seem necessary system components, considering that this function can be provided by existing infrastructure. However, the energy efficient technologies available, low use times and the benefit of such devices to specific user groups, such as the elderly, mean that the benefits of these devices can outweigh the additional energy consumption if smart power management is implemented.

One of the main benefits of dedicated displays is that the data can be stored locally easing any security and privacy issues. Sensors can transmit their information directly to display units with minimal energy requirements. The alternative to dedicated displays is the use of smart phone apps or software which requires additional infrastructure and energy to link the Sensors with the web.

Having identified the necessary devices to build a system one can then look at the operating mode of these devices. Systems should be fit for purpose not only on the system level but also on the device level.

Ensure appropriate network availability

In this context it became clear that most devices only require low network availability and the communication protocol should allow for a “wake from sleep” command. The EMS devices are generally programmed to a time profile once and can then run autonomously. The data only needs to be available on demand and the system can wake from sleep to transfer data or switch consumption as required. Some security or home automation devices may require high network availability but these can be separately defined and should not be considered together with EMS. To allow for this functionality, communication protocols have to be able to send a wake up signal, so that devices can be activated from sleep upon demand. This would reduce the energy consumption of these devices considerably by cutting their high network availability time.

Measurement: All investigated transmitters were battery powered and therefore consumed very little energy. This was due to two factors, efficient components and energy management settings such as less active “light”-sleep modes where the transmitter reduces its transmission frequency when the consumption on the Smart Meter remains constant. As soon as a change in consumption is detected, the transmission frequency increases again. These devices, though efficient, require batteries to run. A widespread penetration of these devices in the market could lead to considerable increases in battery waste.

Smart plugs are used to measure and switch loads in energy management applications. Large differences in consumption were found between different devices. The large consumption difference between the different components suggests, that technologies do exist, which would greatly reduce the power consumption of these devices, especially in the off mode. These devices have two distinct operating modes, switching the attached devices on and off. It may be possible to issue own consumption thresholds, for the on and off modes of these devices.

Logging: Hubs play a central part in nine of the ten investigated systems. The hubs measured by ECO transmit the measured data from the internal network to a wifi network, enabling users to access the information online. In management systems, they relay commands back to actors. These hubs are therefore constantly on and communicating in the network. Along with the smart plugs they therefore form one of the most relevant components of EMS from an energy consumption standpoint. There is a great difference in the own energy consumption between battery and mains powered devices, though it is not fully clear if these hubs all provide the same functionality. Stringent thresholds for these types of devices would greatly influence the overall parasitic electricity consumption of EMS in cases where these devices cannot be eliminated.

The two hubs measured by ECO in detail over long operating periods, did not show any periodic change in its own energy consumption, indicating that they are constantly communicating and relaying information. This suggests that smart power management features may offer great saving potentials. Especially since the systems only need to be communicating and relaying information on demand, i.e. when the user requests the information or orders an action in the network.

Visualization: Displays as such can be very energy intensive in use and the most pertinent question becomes one of energy management. Displays, as defined by their primary function, are generally required for very short periods of time, to visualize information for the user. 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. Due to the small active period, the choice of display technology plays a subordinate role to smart power management. Especially battery powered displays can be very efficient, though again leading to an increase in battery waste. With mains connected displays, the power losses in the power supply unit may become relevant when these power management features are implemented and should be taken investigated. This idea that peripheral component of devices, such as the power supply may become relevant when smart power management and efficient technologies are applied brings us to the next key finding.

Focus improvement effort on relevant components

To further ensure that the systems are fit for purpose the manufacturers should continuously assess their devices and systems to ensure that their improvement focus lies on the correct components and devices within the systems. The reduction of the own power consumption of components means that other components, which had not previously been considered may now become relevant. This may be components such as the device's control unit or power supply as mentioned above. Product developers are often surprised to find that previously negligible components come to the foreground when efficiency measures reduce the own consumption of the main components. Iterative assessment ensures that product developers continuously focus their efforts on the most relevant components.

Enable energy efficient settings by default

To ensure that users can take full advantage of the products, the energy efficient settings should be enabled by default. This simply means that devices are shipped with energy efficiency settings enabled, forcing manufacturers not only to integrate these functions but actually ensure that the intended benefit reaches the customer.

Measurement example: Sensors and smart plugs do not need to be constantly measuring and communicating if they can wake from sleep on demand or according to a pre-programmed time schedule. This operating mode should be set as default and taken into account when designing the system.
Logging example: The hub does not need to be constantly communicating. It can be programmed to adhere to periodic wake up events and wake from sleep upon demand if the communication protocol allows for this. This should be the default setting for the setup of the hub for EMS.
Visualization example: Displays only need to be available on demand. They can have a physical on switch combined with a programmed shut off after a few minutes of inactivity. Shipping displays with this default setting does not diminish the function or attractiveness of the device.

Train the installers and maintenance professionals to ensure continued effectiveness

Once the products have been shipped, it is important they are installed correctly. In this context it is important to offer dedicated training, not only on installation but also on maintenance and optimization. There is a lack of knowledge on how to install and especially maintain more complex systems.[70] This means that the maximum savings potential is in most cases not achieved with complex installations. Training and courses may be required to bring electricians up to speed on these installations. This would in turn make these classical jobs more appealing to young apprentices. In terms of maintenance it is paramount to ensure the continued effectiveness of the systems. This applies to complex automation systems as well as to simple EMS. Results on the frequency of interaction with the systems[71] show that the users lose interest after an initial setup and optimisation period. 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.

70 Harnisch, J. 2016

71 Reisinger, M. 2016

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