Energy Efficient Smart Metering Infrastructure

Scoping Study within the IEA Implementing Agreement „4E“

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Berichte aus Energie- und Umweltforschung

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Scoping Study within the IEA Implementing Agreement „4E“

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Vienna, May 2012

Ein Projekt im Auftrag des Bundesministeriums für Verkehr, Innovation und Technologie

Vorbemerkung

In der Strategie der österreichischen Bundesregierung für Forschung, Technologie und Innovation ist deutlich verankert, dass Forschung und Technologieentwicklung zur Lösung der großen gesellschaftlichen Herausforderungen beizutragen hat, wobei die Energie-, Klima- und Ressourcenfrage explizit genannt wird. In der vom Rat für Forschung und Technologieentwicklung für Österreich entwickelten Energieforschungsstrategie wird der Anspruch an die Forschung durch das Motto „Making the Zero Carbon Society Possible!“ auf den Punkt gebracht. Um diesem hohen Anspruch gerecht zu werden sind jedoch erhebliche Anstrengungen erforderlich.

Im Bereich der Energieforschung wurden in den letzten Jahren die Forschungsausgaben deutlich gesteigert und mit Unterstützung ambitionierter Forschungs- und Entwicklungsprogramme international beachtete Ergebnisse erzielt. Neben der Finanzierung von innovativen Forschungsprojekten gilt es mit umfassenden Begleitmaßnahmen und geeigneten Rahmenbedingungen eine erfolgreiche Umsetzung der Forschungsergebnisse einzuleiten. Ein wesentlicher Erfolgsfaktor für die Umsetzung ist die weitgehende öffentliche Verfügbarkeit der Resultate. Die große Nachfrage und hohe Verwendungsquoten der zur Verfügung gestellten Ressourcen bestätigen die Sinnhaftigkeit dieser Maßnahme. Gleichzeitig stellen die veröffentlichten Ergebnisse eine gute Basis für weiterführende innovative Forschungsarbeiten dar. In diesem Sinne und entsprechend dem Grundsatz des „Open Access Approach“ steht Ihnen der vorliegende Projektbericht zur Verfügung. Weitere Berichte finden Sie unter www.NachhaltigWirtschaften.at.

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Vorbemerkung zur Smart Grids Begleitforschung

In den letzten Jahren setzt das BMVIT aufgrund der Aktualität des Themas einen strategischen Schwerpunkt im Bereich der Weiterentwicklung der Elektrizitätsversorgungsnetze. Dabei stehen insbesondere neue technische, aber auch sozio-technische und sozio-ökonomische Systemaspekte im Vordergrund.

Im Rahmen der „Smart Grids Begleitforschung“ wurden daher Fragestellungen von zentraler Bedeutung für die Weiterentwicklung diesbezüglicher F&E-Strategien identifiziert und dementsprechende Metastudien, Detailanalysen und Aktionspapiere initiiert und - zum Teil gemeinsam mit dem Klima- und Energiefonds - finanziert. Der gegenständliche Bericht dokumentiert eine in diesem Zusammenhang entstandene Arbeit, die nicht zwingend als Endergebnis zur jeweiligen Fragestellung zu verstehen ist, sondern vielmehr als Ausgangspunkt und Grundlage für weiterführende Forschung, Strategieentwicklung und Entscheidungsfindung.

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1. Introduction and Motivation

The IEA 4E "Efficient Electrical End-use Equipment" Implementing Agreement is an international program to cooperate on technical and policy issues for increasing the efficiency of electrical equipment, and to initiate projects set up to meet the participants´ needs.

Thirteen countries contribute to 4E through work on four Annexes, by primarily examining and comparing approaches and achievements of policies for lighting, motor systems, and electronic products spanning most major economies.

The substantial body of knowledge, data and analysis for existing products and policies on energy consumption and efficiency in various countries and regions forms a sound basis for better national and international policies in the future.

Within the energy efficiency and the energy research areas at a European and international level, smart building, smart cities, and smart grids take greater attention and importance, offering as well potential for advancing the international cooperation through work at the IEA-4E. In this sense, after the decisions of the 4E Executive Committee in 2011 on a joint proposal of Austria and Switzerland, a Scoping study on Smart Metering Infrastructure was initiated in October 2011.

The rollout of smart meters, providing consumers with the information and services necessary to optimize their energy consumption and calculate their energy savings, is key to energy efficiency plans in Europe and other regions. Furthermore, the drivers for the introduction of smart metering systems range from reducing billing cost for utilities, over the implementation of peak load management and smart grids concepts, as well as fighting energy thefts unto simplifying and shortening the procedures for customers to change their energy supplier. Improvements to the energy performance of devices used by consumers, industry, and utilities – such as appliances and smart meters – should play a greater role in monitoring or optimizing their energy consumption, allowing for possible cost savings and reduction of technical losses. The high relevance of the topic is given on the one hand by the number of devices, e.g., European Directive indicating that 80% of households until 2020 shall have a smart meter; moreover smart metering is expected to be introduced not only for electricity but also for other commodities like gas and water. On the other hand, the time of operation (24 hours a day), and strong interdependencies between system design and requirements that are under discussion now and will have a very long term impact; highlight the actual relevance (e.g., real time measurement for grid operation? Quarterly hour measurements for time of use tariffs? data transfer steadily, once a day, once a month,…? Which communication technologies? Which display devices, etc.)

This is why this scoping study focuses on two themes where technologies, which can enable energy efficiency themselves, are seen as a factor in larger energy systems, and as such, are investigated for their potential and impacts.

The first topic of Smart Metering Consumption, lead by the Austrian experts at the ECODESIGN company GmbH, presents current work and understanding on the impact of implementing large scale roll out of smart metering and the own energy consumption required for the operation of this infrastructure. The lack of methodologies for assessing this consumption and only few standards of limited applicability indicate the need for further work on this subject. The benefits of smart metering, often quantified using cost-benefit instruments to inform stakeholders and governments responsible for major infrastructure investments, are lacking a solid assessment of the technical aspects of smart metering, especially for real operations in the field. The strongly advertised energy savings at the consumer´s side as a result of introducing smart metering might need to be reviewed in connection to the energy consumption associated with this enabling technology.

Many policy makers working on energy efficiency associated with end consumer products, are very familiar with household devices and their performance, but are less, if at all, confronted with technical and policy issues for equipment such as smart meters which provide an interaction interface with these end-users, but also an interface to a much larger system with other stakeholders.

The second theme, under the leadership of the Swiss experts at iHomeLab, investigates Non-Intrusive Appliance Load Monitoring NIALM. NIALM is the enabling technology used to get the energy consumption information at a single appliances level with minor to no alterations of the infrastructure. NIALM is also an enabler for feedback systems to provide real time, summarized and categorized data to the end users. Soft degradation, aging, and outdated appliances are identifiable with NIALM.

The connection to the end-user is highlighted again, as most of the private household and industrial building users have little to no understanding regarding the energy consumption and have limited instruments to assess and optimize it. Studies show that the (near) real time and detailed visualization of energy consumption figures offers an average potential of 5 to15% energy savings in modern homes and offices. Consumers need to see and understand the electricity being used by different appliances. They're keen to see whether a new appliance, or a change in habits, affects the amount of electricity used. The hourly metering values for office's and household's entire electricity use does not distinguish the effects or patterns of individual appliances, or register the effects of small, brief changes. Consumers have a clear wish to be able to understand the amount of energy used by different appliances and during different day times. This information could give the best results in increasing the energy efficiency through customer information, therefore, the examination and utilization of feedback-systems based on NIALM has been the main motivation to investigate this sub-theme in relation to the scoping study, and to explore potential areas of further work on NIALM.

To this end the authors provide this scoping study which identifies and examines “white spots” where knowledge and experience might need to be developed further for these two themes, based on the review of relevant international activities and the opinions of experts. Further activities that could be explored under the two themes are explained in the report.

Efficient Electrical End-Use Equipment
International Energy Agency

Executive Summary - Smart Metering Consumption

By Dr. Adriana Díaz and Dr. Wolfgang Wimmer – "ECODESIGN company" engineering & management consultancy GmbH, Vienna, Austria.

A number of countries and regions are deploying new metering systems; many others have set targets for implementation or are undertaking pilot trials. Advances in technology and international experiences make the metering panorama as a fast-changing one. The introduction of smart metering has being accelerated by legislation, as is the case of the European Union, particularly with the EU-Directive 2006/32/EC on energy end-use efficiency and energy services (Article 13), which explicitly mentions the use of advanced metering systems. Smart metering implementation is taking place with an increased emphasis on the role that the consumers play (demand-side) in contributing to energy efficiency when provided feedback instruments to make informed choices and change their behaviour.

The ECODESIGN company GmbH is carrying out since 2010 a study to assess the energy used by existing and planned metering systems in the context of Austria and Switzerland. This work served as the basis to investigate this subject on behalf of the IEA- 4E implementing agreement, to understand its current situation, directions, and possible areas of future work.
4E members have been asked to provide information to the authors, who have also conducted a review of international activities and progress in this field. On this basis, the following key issues have been identified in this scoping study, and are suggested areas of work to address Smart Metering Consumption:

Awareness	An awareness rising campaign is needed to understand the issue of Smart Metering Consumption for those "setting the rules" about Smart Metering Infrastructure.
Cooperation	IEA bodies could be brought together and should team up with other organizations such as ESMIG, DG INFSO, smart grid task force, SET plan initiative as well as standardization and regulation bodies. Initial interest has been shown but no clear commitment exists yet.
Methodology	A methodology is needed to measure and assess the energy consumption of Smart Metering Infrastructure. Particularly to enable the analyses of overall system efficiency and interdependency with system design parameters. On-going methodology developments, such as the one undertaken by the IEA-4E Standby Annex for networking products, provide an opportunity to explore a similar approach for Smart Metering.
Real measurements	Measurements of real field consumption of Smart Metering deployments are needed to identify the additional energy consumption due to the installation of smart meter infrastructures. Pilots and roll outs offer a valuable possibility to do so.
User feedback	In the framework of Smart Metering, optimized ways for providing feedback to users, which enables a net reduction in the energy consumption over time, have to be found.

Awareness

Own energy consumption of smart metering systems, although an obvious issue connected to the operation of this infrastructure, appears to be out of the scope of the work of most experts and regulators working in the energy, and even in the smart metering fields.Assessments explicitly looking at energy consumption of the smart metering infrastructure make assumptions based on industry expertise, rarely connected to real measurements in the field. Moreover, this consumption is often neglected based on the argumentation that potential energy savings at the end-user side would by far exceed the infrastructure own energy consumption. Smart metering will bring many more operational and societal benefits than own “costs”. At the same time, there is a lack of significant data about long term energy savings introduced through smart metering systems. Further work is recommended to raise awareness on this theme, especially for experts and decision makers in governments confronted with the deployment of an energy efficient smart metering infrastructure. This infrastructure will be set for decades, million devices will be deployed, and the associated consumption fixed when the technology and system architecture are chosen for these systems. Understanding these implications in terms of the consumption is an important issue.

Cooperation

The investigation of current activities in smart metering for the scoping study helped identify various organizations which could offer potentials for cooperation. These organizations are either working on Smart Metering or on related areas, such as the IEA and European Union. Their strength lies in the access to governments, industry players and experts. Venues for concrete collaboration need to be further explored.

Methodology

The lack of a specific methodology to assess the own energy consumption of smart meters and their infrastructure, in light of the complexity of various technologies and system requirements available (particularly taking into account smart grids concepts), is indeed a challenge. Additionally, in some countries there are still no roll outs available to conduct any real assessment on the energy consumption, and most of the analysis then is done on an economic basis looking at data from available experts and industry opinions, mostly related to capital and operational costs. This presents a clear opportunity for future work to advance the creation of a solid and systematic methodology for the assessment of the energy consumption of smart metering infrastructure. This methodological work can be informed, for example, by the existing methodology development of the IEA-4E Standby Power Annex for Network standby of products.

Standardization is another relevant topic, especially in connection with the development of a methodology to estimate the energy consumption of smart meters. Given the different technologies and system arrangements available and under consideration by smart meter operators, and technology developments, work in this area could be very valuable.

Real measurements

Future work in the subject of Smart Metering Consumption could focus on of globally surveying the technological trials (e.g., pilot projects) to get a better understanding of energy consumption of meters in real operational conditions. These pilots can also be surveyed for their possible specific work on addressing regulatory developments concretely connected to consumption of the infrastructure.

User feedback

Studies dealing with energy savings through feedback to consumers appear not having taken into account the energy requirements of the metering, display and communications equipment, which should be included in order to provide real net energy savings. As there is an increasing number of smart metering initiatives now being monitored, this could present opportunities to investigate energy consumptions of the installed feedback systems.

Efficient Electrical End-Use Equipment
International Energy Agency

Executive Summary - Usage and potential of Non-Intrusive Appliance Load Monitoring

By Stephan Tomek and Prof. Alexander Klapproth– iHomeLab Research Centre, Lucerne University of Applied Sciences, Lucerne, Switzerland.

Feedback to consumers with regards to their energy consumption has several facets. The information must be adjusted to the consumer's current situation and needs and does also depend on the personal learning curve. Consumers are very enthusiastic at the beginning with regards to energy displays and want instant feedback in order to quickly understand how and where the energy flows. However, consumers need to be motivated and specifically tied to the topic of energy efficiency in course of the project. NIALM can play an important role during this challenging phase and in the future of advanced energy efficiency projects.

The population growth leads to an increasing energy consumption in parallel to the constantly increasing energy demand per person. Governmental organizations are searching for solutions in order to cope with the drastic development of the energy consumption. NIALM can play a key role in the future of energy consumption and has the potential to raise public awareness about energy consumption.

The original idea for NIALM was developed by George Hart and his fellow researchers at the Massachusetts Institute of Technology back in the 1980s and is currently seeing a revival through recent technological advancements towards powerful low-cost and low-power measurement and processing hardware and its proliferation (e.g. in smart meters) as well as novel algorithms. The main motivation remained through the years, having a measurement node which identifies multiple loads is more cost efficient, then measuring each single appliance. Research has been fuelled by an overall increased interest in improving the electrical grid and increasing the energy efficiency in buildings and homes. This has motivated a renewed interest in NIALM technology from industry and academic researchers around the world. Universities put considerable research effort into data acquisition and device disaggregation to get a complete coverage of all available devices in a home or office building consuming power. Some projects were able to identify and disaggregate the various devices quite well; some projects struggled due to the complexity of the different operating states of the devices. None of the projects could correctly identify 100% of the appliances without measuring each single appliance independently. The biggest hit rate could be achieved through multi-layer data acquisition and multi algorithmic approaches. Unfortunately, this approach requires more computing power, more memory and thus is not energy efficient at all. To make it even worse, subsystems for pre-processing and post-processing need to be introduced too.

Providing ambient information like daytime, the weather or the presence of people can significantly increase the hit rate of the device detection and load disaggregation algorithms. It is equally important for the device identification to have a clear picture about the requirements. One key question to be answered at the beginning of a project is the purpose of the disaggregation: is the goal to improve the general load management, heavy loads needed to be identified. In the case of the identification of aging electrical appliances, an accurate and independent measurement needs to be done close to the appliance under surveillance.

Looking towards the market, there are few commercial products available today which can provide a load disaggregation to the end-user. Products, which help with automation of facilities like offices and homes, are available in a wide range. These products have the main goal to switch appliances remotely on or off. The next step in product development is to add power measurement. Having power measurement available in these products, the way to come up with a simple load disaggregation algorithm is not that long. From our perspective the big hype in commercial products is expected to hit the market within the next few years.

We strongly suggest the elaboration of an action plan in order to fuel commercial success, standardisation and product development. Moreover, to gain maximum value from NIALM with regards to energy efficiency, guidelines, standards, data sets, and certification aspects must be addressed and elaborated before manufacturers start to introduce their own proprietary standards. To develop features like device comparison with vendor databases, "Energy Footprints" need to be defined together with a standardized and certified measurement infrastructure. Making "Energy Footprints" publicly available means to host a database and provide support. To offer comparisons with neighbours or compare energy consumption on a national or international level categories for the load disaggregation do also have to be defined

The suggested areas of work recommended are as follows:

- Use the gained knowledge from the scoping study about existing networks and communities dealing with NIALM. Set up a circle which contributes to the NIALM topic. If necessary work out a proposal to build a new community with the goal to spread the basic knowledge and understanding of NIALM.

- Standardize the NIALM measurement approach – develop procedures and measures to distinctly identify and re-identify appliances with a high matching factor, independent of the environment. Agree on a set of pre-processed measurements to be used as the NIALM device footprint.

- Connectivity and Norming – boost the introduction of NIALM technology in modern in-home networks such as ZigBee by actively forming new versions of the standard. In-home networks are needed to connect metering points to the controller for data analysis and for visualization purposes.

- NIALM Database – Model definition and support of the implementation of a database for NIALM energy footprints. Development of procedures to enter and access data in a global way. Appliance data could be entered by manufactures or by end users for quicker adoption and shall be accessible to the whole community.

Thank you for your trust in the ECODESIGN company's and iHomeLab's expertise regarding the scoping study.

Scoping Study on Smart Metering Consumption

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1. Introduction – Motivation

In the context of climate change challenges and of the increasing demand for energy, the imperative to use energy efficiently is more than ever relevant. Strategies such as the introduction of intelligent measuring systems, called smart meters, are marching forwards.

A smart meter is an electronic device (without electromechanical components), enhanced by communication technology, which allows data transfer to a central node.

Together, the smart meter, the communication infrastructure and the centralized processing and storage of data form a smart metering infrastructure (KEMA, 2010).

Smart meters are considered as the first step to intelligent networks or smart grids - the infrastructure that enables the delivery of power from generation sources to end-uses to be monitored and managed in real time. In this way the benefits of enabling a system that provides information about energy are expected to accrue from the end-users, to operators and distributors as well as to providers of additional services (ESMA, 2008):

- For energy consumers smart meters are expected to bring a credible and reliable element the provided service or product (energy), e.g., through detailed billing, and are expected to facilitate choices for (responsible) energy consumption.
- For energy retailers and vendors smart metering may give flexibility to offer customers a wide mixture of tariffs options.
- Distribution system operators (DSOs) are expected to be supported in their real time management of a high quality network, in a way that benefits to the consumers are provided via (economical) incentives like time of use tariffs.
- Products and services suppliers are likely to have opportunities to develop new product and services adapted for the energy consumption patterns of the end-user.

According to the IEA Roadmap on Smart Grids, peak demand will increase between 2010 and 2050 in all regions. Smart grids deployment could reduce projected peak demand increases by 13% to 24% over this frame for the four regions analyzed in the roadmap (IEA, 2011). The smart grid will enable the development and integration decentralized, renewable energy sources (RES), maximizing the (regional) potentials of wind, solar, and photovoltaic plants. Smart grids will help addressing challenges of the electricity system infrastructure, such as dealing with peak demand within an ageing infrastructure.

At the political level there are visions and provisions in various regions for the deployment of smart meters in a medium to long term, in a way that many household and enterprises will be connected to smart metering infrastructure soon. As a first example the European Commission establishes in the 20-20-20 Directive, the reduction of Greenhouse gas emissions by 20% and the increase of renewable sources by the year 2020, setting as well a framework for energy efficiency through the Energy Efficiency directive which mandates the provision of accurate energy information to end consumers in the European Union. As a result, the United Kingdom is planning the installation of 47 million electricity (and gas) smart meters by 2020, exchanging the existing (Ferraris) meters.

The smart (electricity) metering hardware has to fulfill specific functions such as “data measurement”, “data storage”, and “data transfer”, and might comprise one or various components per household. These components are supplied with energy in a continuous basis for their operation. Therefore, the resulting energy consumption of the smart metering systems depends of several parameters, especially those related to the type of communication, but could also relate to the phases, and the implementation of additional functionalities related to the intended functionalities of the respective smart grid.

The possible implications for increased energy consumption due to the new infrastructure and its operation cannot be overemphasized and needs to be better understood, and until now, has received less attention than other topics. In Germany, Austria and Switzerland aspects of the interaction of users with smart meters are under more intensive investigation, e.g., Demand Response, home automation, and flexible pricing schemes, to name a few. An existing Bi-National project started in 2011 between Switzerland and Austria on “Smart Metering Consumption” provides the starting framework to expand the investigations at an international level. Key questions addressed in this ongoing project are:

- Which device and system characteristics are responsible for the energy consumption of the smart meters?
- What is the best available technology with regard to own energy consumption (of smart meters)?
- How is it possible to estimate scenarios of energy consumption due to smart meters for localities and regions?

The available smart meter technologies were mapped based on intensive information exchange with manufacturers and other stakeholders in the area of smart metering. Measurements were carried out for energy consumption of the smart meters under laboratory and field conditions, in existing smart metering pilot projects in defined regions in both countries.

As both countries are active members of the IEA implementing Agreement on Efficient end-use electrical equipment (4E), the work of the project was presented to this larger platform for further consideration, and the 4E members decided to undertake this scoping study on Smart Metering Infrastructure. This scoping study provides an initial footing to move forward on investigating specific aspects of the technology and/or policies as well as possible country engagements to be achieved in realizing the full potential of the smart metering infrastructure. A special focus of the study has been the inclusion of opinions of experts and 4E delegates, in relation to the state of the art and future developments of smart metering in their countries. The aim of the study is to provide recommendations for areas of work and further international collaboration.

The scoping study focused on smart meters for electricity. While smart metering concepts are likely to be also applicable to gas and other services, such extensions have not been taken into account in this study.

2. Smart Metering Consumption - key questions to be addressed

In general all devices being connected to the grid and consuming energy 24h a day deserve our attention regarding the energy consumption especially if they are operated in large numbers. A smart meter is such a product that is connected always to the grid, never switched off entirely and is planned to be rolled out in every household in Europe and other parts of the world. The potential risk of installing a significant energy consumption due to the additional smart meter consumption is there and the awareness about this consumption needs to the established in order not only to do the right things but also to do the things right.

A simple calculation shows the effect of permanent small consumption in large quantities of operated products. For a short calculation one could imagine a region/country with 12 million households every household should be equipped with a device that runs permanently 24h a day and for this example the energy consumption of this device shall be 10W. At the end of one year the annual energy production of a large river water power plant (approx. 1000 GWh) similar to the one running in the river Danube in Vienna is needed to power these devices. This theoretical example shows that awareness and caution is required when installing permanent energy consumers in every household.

The energy consumption of a smart meter is driven by certain functions of the meter itself and the aspects of its use in a wider context. The core functions can be seen as “metering” and “communicating” the measured values to a central data collection point – such as a data concentrator or head end.

These main functions are performed with the smart meter respectively from its hard- and software. The design of the hardware representing the fulfilment of the functions can be differently and has also some influence on the energy consumption of the smart meter. Additional features contribute also to this consumption (see Figure 1).

Apart from looking only at the meters one needs to develop a system perspective since there are many stakeholders involved such as network operators, regulators, telecommunication providers, power utilities, energy service companies, to name a few. All of these stakeholders have their own specific requirements often related to energy consumption or even related to features that indirectly cause energy efforts at the metering point or elsewhere in the metering system. One example could be the required frequency and amount of data transferred to the head end.

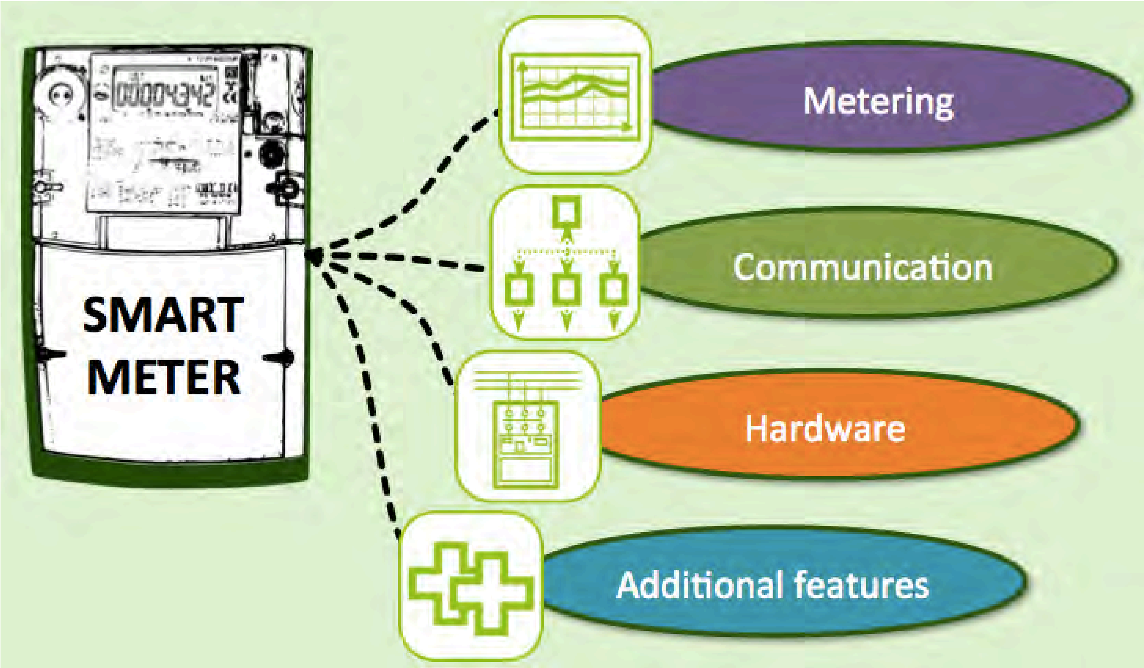

Figure 1 Aspects driving energy consumption of smart meters

Currently there is no internationally agreed methodology for assessing energy consumption of smart metering infrastructure, and little is understood at national level on how a possible methodology for comparisons could look like and what would be its value for further work on standardization and creation of policy frameworks. There is no coverage of smart metering power consumption in existing energy policies and even the metering equipment is not directly subject to policies at the moment.

Consequently there are the following questions that need to be answered when looking at the energy consumption of smart meters:

- The technical solution: What drives smart metering consumption?
- The side of regulation: How can smart metering consumption be assessed, compared, and eventually regulated or controlled?

Details to the drivers of energy consumption of smart meters but also to first attempts in regulation are described in chapter 4.

3. Overview of international Smart Metering Consumption initiatives

With a focus of energy consumption of the smart metering infrastructure, results from a questionnaire and contact with 4E delegates and experts, a review of the work of other organizations, and a literature review are included in this section.

3.1. Information from IEA-4E Delegates

All IEA-4E delegates were given the opportunity to provide their views about the subject of smart metering consumption via a questionnaire (available online at http://www.surveymonkey.com/s/Q27L7YP, and also provided in Word format).

The questionnaire was formulated with relatively general questions which did not explore technical aspects and their complexity in detail, but attempted to cover these in a general manner. The idea was that it would be possible for delegates to contribute with information for the purposes of this scoping study. In this sense, 10 questions were included: one about the person completing it, six focusing on the existing situation for smart metering in the corresponding country (multiple choice questions with space to comment), and the remaining three questions, for personal opinions on directions to consider for the future (providing opportunity for comments with a view from the country).

Answers were received from Australia, Austria, Japan, Switzerland, The Netherland and The United Kingdom (UK). For details on questionnaire and the list of respondents refer to Appendix 6.1.

No questionnaire answers were received from Canada, Denmark, France, Korea, South Africa, Sweden, and the USA at this time. Some country delegates indicated their interest on the subject and offered to provide additional information after trying to reach their contacts but this, unfortunately, did not happen to include their views in this study. Others indicated not being able to complete the questionnaire as no expertise inside their organizational unit was available on the subject of smart metering.

For countries like Sweden, and especially USA and Canada, where large roll out deployments of smart meters are on the way since a couple of years, it became extremely challenging and out of the feasible scope of this work, to separately investigate all of these initiatives.

For the interested reader, an overview of the progress of smart metering in various countries, including Sweden, USA and Canada, the European Smart Metering Alliance (ESMA) has been published at the end of 2009 the "Annual Report on the Progress in Smart Metering 2009". Appendix 2 of this ESMA report contains information on the status of smart metering in various countries (ESMA, 2009).

The "Smart Metering Landscape Report" of the project "SmartRegions – Promoting best practices of innovative smart metering services to European regions" (funded by Intelligent Energy Europe), analyzed all European countries and their smart metering progress along the dimensions of *legal and regulatory status* and the *progress in implementation*. According to these two dimensions the countries were arranged in five groups as dynamic movers, market drivers, ambiguous movers, waverers, and laggards (SmartRegions, 2011).

A summary of the questionnaire answers received from IEA-4E delegates and/or experts from Australia, Austria, Japan, Switzerland, The Netherland, and The United Kingdom (UK) are presented below.

The first question (**Q1**) was provided to get ***information for the delegate and/or expert answering the questionnaire*.**
From the six answers received only two were completed by the IEA-4E delegate of the country (Switzerland and Japan). The remaining four answers were completed by experts contacted by the country delegates or by the authors of this study.

The second question (**Q2**) dealt with the ***pre-conditions (e.g., legal framework) for rolling out Smart Metering in the country, as well as the planned strategies for roll-outs*.**
The answer received from The Netherlands indicates that apart from particular “national or regional” drivers, meeting the requirements of the ESD - Energy End Use efficiency and Energy services Directive (2006/32/EC) has been a strong driver for smart metering roll-outs. Article 13 of the ESD demands that member states ensure that final customers are provided with competitively priced individual meters that accurately reflect consumption and provide information on the actual time of use. Secondly, member states shall make sure that the energy bills are based on actual energy consumption, are clear and understandable, and are provided frequently enough to enable customers to regulate their own energy consumption. Each government might find a different interpretation for the smart meters and their (minimum) required functionalities, for example, for the frequency of energy metering and billing.
In Switzerland there is an ongoing impact assessment for smart meters, but no planned rollout yet. There is no legal framework at the moment.

In Japan, the Strategic Energy Plan of June 2010 includes provisions for promoting the development, installation of smart meters and relevant energy management systems (that can record detailed energy supply demand data and control a variety of equipment), seeking to introduce them for all users, in principle, as early as possible in the 2020s. In addition, in July 2011 the Energy and Environment Council of Japan has decided on the Immediate Supply-Demand Stabilization Measures, “striving to attain the initial target of installation of smart meters in all households in the 2020s ahead of schedule. The government aims to install smart meters for 80% of the aggregate demand within the next five years”. The concrete roll-out strategies are under consideration in the government committee on the smart meter systems.

Australia is establishing a consistent national framework including standards, a comprehensive consumer protection regime, and enabling legislation, within which businesses or consumers who could benefit from smart meters, would be able to install and use them. This framework will provide for different rollout models including where regional governments may mandate a rollout, consumers may request a meter, or businesses may roll them out commercially. The Ministerial Council on Energy - MCE decisions of the 13 December 2007 and 13 June 2008 set out the expected outcomes of smart metering, which include the following (NSMP, 2011):

- Reducing demand for peak power, with consequential infrastructure savings (e.g. network augmentation and generation)
- Driving efficiency and innovation in electricity business operations, including improving price signals for efficient investment and contracting

- Promoting the long term interests of electricity consumers with regard to the price, quality, security and reliability of electricity
- Promoting competition in electricity retail markets
- Enabling consumers (including residential, business, low- and high-volume users) to make informed choices and better manage their energy use and greenhouse gas emissions
- Manage distributional price impacts for vulnerable consumers
- Promoting energy efficiency and greenhouse benefits
- Providing a potential platform for other demand side response measures and avoiding discrimination against technologies, including alternative energy technologies.

Some of these drivers are also "national" drivers in other countries, with various levels of importance (not explicitly addressed in the questionnaire).
In the Netherlands a cost-benefit analysis was conducted in 2005 and revised in 2010. Referring to a situation of almost 100% acceptance of the smart meter as well as almost 100% standard readings, the 2010 cost-benefit-analysis concluded a positive business case of approx. 770 million Euros. The main beneficial items (in order of positive contribution) are energy savings, savings on call centre costs, a lower cost level as a result of the market mechanism (increased switching) and savings in meter reading costs. As mentioned before, an impact assessment study is being conducted in Switzerland.

The third question (**Q3**) referred to ***the existence of a regulatory body overseeing the roll out of smart meters in the countries.***
Responses indicate that there are countries where there is a responsible **governmental body** in charge, such as for The Netherlands and the United Kingdom.
For Austria the regulatory body overseeing smart metering developments and roll-outs is Energie-Control Austria (E-Control).
There is no single national roll-out in Australia and therefore no single regulatory agency overseeing it. The Commonwealth Government (Department of Resources Energy and Tourism) is developing the necessary policy, the Australian Energy Market Commission will develop regulation in line with this policy, the Australian Energy Market Operator will develop procedures to facilitate meter operation in the market, and the Australian Energy Regulator will oversee related cost recovery for regulated monopoly businesses.
The situation might be similar in other countries where roll-outs are regionally and autonomously developed (possibly CAN and USA, but no explicit answers were provided from these countries to Q3). For Japan no answer was provided on this question because details on the smart metering system are still under consideration.

Question four (**Q4**) had several multiple choice options to indicate ***what the mandatory functional and service requirements that smart meters must comply with are (This referring to national strategies, plans, or others factors setting requirements to the smart metering infrastructure).***
The choices selected by the five delegates/experts were:

Aspect	Australia	Austria	Switzerland[1]	The Netherlands	UK
Installation & maintenance requirements	✓	✓		✓	✓
Operational requirements	✓	✓		✓	✓
Energy consumption requirements (of meters)	✓		✓		✓
Display and storage requirements	✓	✓	✓		✓
Interoperability requirements	✓		✓	✓	✓
Prepayment & credit requirements	✓			✓	✓
Diagnostics & reliability requirements	✓	✓			
Data privacy & security requirements	✓	✓		✓	✓
Home Area Network requirements (HAN)	✓	✓			✓
Wide Area Network requirements (WAN)		✓		✓	✓
Requirements on auxiliary interfaces (e.g. for In-Home Display (IHD), home automation)	✓	✓		✓	✓
For your country, specific electricity requirements	✓	✓			
Other?					

The Swiss expert indicated that many of these requirements are yet not regulated in Switzerland and are ideas being evaluated in the impact assessment study.

For Japan no answer was provided on this question and the choices available.

Question five (**Q5**) asked about ***the existence of codes or standards for setting minimum performance or functional requirements for smart meters in the country.***
In the United Kingdom, Australia, and Austria these requirements and standards for smart metering are under preparation or revision.

The Industry Draft Technical Specification (IDTS) from the UK is the list of all requirements. The government is currently trying to reduce the requirements that it mandates and refer to existing regulations/standards, as part of its work in getting UK requirements approved by the European Commission. A series of “Detailed Design Specifications” (DDS) are being developed for the various system components. These are the electricity meter, gas meter, In-Home Displays (IHD),

[1] All the responses for Switzerland are referring to the ongoing, preparatory smart metering impact assessment and not to an existing roll out or pilot initiative as such.

Communication hub and, possibly, a data gateway (consumer access port). In addition UK industry is developing common interface specifications that meet the requirements.

A very basic set of specifications is defined by the regulatory body Energie-Control Austria (E-Control), called Directive about functionality of smart meters, with 10 general articles written mostly in the form or recommendations. The standardization process is going on, with Austria also contributing to the European standardization process.

For Australia the Smart Metering Infrastructure Minimum Functionality Specification document has been developed through rigorous consultation with industry (including international meter and infrastructure suppliers), and consumers and is to be verified through on-ground experience. The specifications will be enabled by references in regulation, which are currently in policy development.

Smart meters in the Netherlands comply with basic functionality and system architecture, defined in a regulated technical agreement, as well as in a smart meter industry standard (DSMR). All minimum functionalities for connecting the consumer to the energy distribution infrastructure are stipulated in a “Dutch Technical Agreement” in this area (NTA 8130).

In Switzerland there are yet no standards available. For Japan no answer was provided on this question because details on smart metering system are still under consideration.

Question six (**Q6**) referred to ***the existing pilot projects or roll out initiatives of smart meters in the country.***
The roll out of smart meters in The Netherlands will take place according to a two-stage approach. From 2012 until 2013 a small scale roll out will take place for experience purposes. The small scale roll out will take place in case of regular meter replacements (e.g. malfunctioning), new meters to be placed in newly built houses/ renovated houses, and new meters on request by customers. From 2014, the roll out will continue on a larger scale, aiming to have a smart meter fitted in at least 80% of households and small businesses by 2020, as mandated by the EU regulation (ESD).
The largest two projects in Austria on smart metering include the pilot exercise by Energie AG to test smart meters. Energie AG has installed around 80.000 meters by the end of 2011. These are using the Siemens AMIS system, which uses Power Line Communication (PLC).
The project Intelligent Energy Management System (IEM) of the power utility LINZ AG, started in 2007 as a pilot roll out for the installation of smart meters, with the aim of to facilitating information to end consumers about their energy use. Currently there are 57.000 smart meters installed, and plans considered the installation of a total of 150.000 by 2013. Despite of the fact that until 2020 80% of the end consumers shall be provided with smart meters (EDS), most of the network operators in Austria are still in the test stage of smart metering projects. Only the two Upper Austrian network operators Linz Strom GmbH (with 57.000 smart meters) and Energie AG (15.000 smart meters) have concluded their test phases and have integrated the smart meters in their normal operations.

There are important roll out initiatives in Australia, for example the Victorian State Government roll out to upgrade the State’s metering capabilities, with currently close to 1 million meters installed,

and aiming at a total of 2,1 million meters. Around 200.000 meters are supplying remotely-read energy usage data to the market.
The New South Wales - Ausgrid's smart meter infrastructure learning and evaluation (SMILE) trial is another initiative for testing technologies, data handling, and meter management systems. It comprises 3.500 fully functioning smart meters delivering data into the energy market. More than 700.000 interval meters manually read supporting time-of-use tariffs.
A variety of meter suppliers, communication, meter management as well as a variety of back-end systems are running in both initiatives.

The UK government sponsored the Energy Demand Research Project – EDRP. EDRP was launched in July 2007 and has been managed by the Office of the Gas and Electricity Markets - Ofgem on behalf of the Department of Energy & Climate Change - DECC. The EDRP was a major project to test consumer´s responses to different forms of information about their energy use. EDRP was not set up as a technology or roll-out trial. Four energy suppliers each conducted trials of the impacts of various interventions (individually or in combination) between 2007 and 2010. The interventions used were primarily directed at reducing domestic energy consumption, with a minority focused on shifting energy use from periods of peak demand. The project involved over 60.000 households, including 18.000 with smart meters. Measures were generally applied at household level but one supplier also tested action at community level (AECON Limited, 2011).
British Gas is currently working towards upgrading 2 million British Gas customers to smart meters by the end of 2012, with over 300.000 meters already installed across the UK. Both, electricity and gas meters are being upgraded (British Gas, 2012).
There aren´t yet roll out initiatives in Switzerland.
For Japan no answer was provided on this question.

Question seven (**Q7**) was *about **existing projects in the country focusing (among other aspects) on energy consumption of smart metering.***
In the answers from United Kingdom and Australia it was indicated that no specific project is **currently** looking at aspects of **own** energy consumption of the smart meters. In Austria and Switzerland the only existing project currently looking at this issue is conducted by the ECODESIGN company GmbH since 2010 on behalf of the Swiss Federal Office of Energy (SFOE) and the Austrian Federal Ministry of Transport, Innovation and Technology (BMVIT). Reports will be available late April 2012.

In Australia no project is specifically focusing on this aspect, but some information is being gathered. Experience so far suggests that the metering elements themselves mostly use between 1W and 0.1W but the communications component can use significantly more. It usually transmits in brief impulses so the average usage is still below the standard requirement of 2W for the meter as a whole, but this depends on the duty cycle.
For the small scale roll out planned in The Netherlands in 2013 and 2014, a monitoring program will evaluate the conservation effects of a series of smart meter based energy feedback experiments and pilots, *possibly also evaluating the energy needed for the operation of the smart metering pilots* (but this has not been explicitly indicated in the answer). These experiments and pilots are planned to

start in June 2011 under the coordination of the NL Agency. (Contacts will be available from June this year).
The remaining three questions were provided for delegates/experts to include their opinions.

Question eight (**Q8**) asked ***which aspects are the most relevant for addressing (and eventually regulating) smart metering own energy consumption?*** A multiple choice selection was presented which are included in the table below. All five respondents indicated technology used and communication requirements being, in their view, the most relevant aspects for addressing/regulating own energy consumption of smart meters.

The Australian and Dutch respondents selected also all the other choices, while the UK expert as well indicated Additional functions being relevant for regulating own meters consumption. This expert pointed out that it is likely that technology, communications, and additional functionalities could also be addressed under the European ECODESIGN Directive.
No answer was provided from Japan to this question.

Aspect	Australia	Austria	Switzerland	The Netherlands	UK
Technology used	✓	✓	✓	✓	✓
Communication requirements (e.g., extents, encryption, network topology)	✓	✓	✓	✓	✓
Data Management (e.g., data to be retrieved, to be stored, to derive from calculations)	✓			✓	
Billing requirements	✓		✓	✓	
Additional functions (e.g., Home monitoring, home automation)	✓			✓	✓

Question nine (**Q9**) asked delegates to ***describe shortly the initiative(s) in the country (with scope, extent and if available, key results) looking at own energy consumption of smart metering infrastructure (e.g., quantifying and/or regulating this consumption).***
According to the information of the experts providing answers to this questionnaire, there are no initiatives that focus on own energy consumption of the smart metering infrastructure in the Netherlands, the UK and Australia. In Australia the Smart Grid, Smart City project will include analysis of the own energy consumption (parasitic consumption) of each element of the infrastructure and data systems.

For Austria and Switzerland the project “Smart Metering Consumption” is the only initiative looking at this issue.
No answer was provided from Japan to this question.

The last question (**Q10**) asked ***the view of the experts on: which aspects (not mentioned in the questionnaire) shall be also considered when looking at own energy consumption of smart metering systems?*** A selection of choices was presented. The answers were as follows:

Aspect	Australia	Austria	Switzerland	The Netherlands	UK
Support for load control (electricity)	✓	✓	✓		
Support for other applications (Multi-Utility Control, home automation)	✓				✓
Support for micro- generation	✓	✓			
Facilitation of smart grids	✓	✓	✓	✓	
Other applications or possible future applications.	✓	✓			

Under other applications, the Austrian expert commented that smart meters will be only element in a future energy system, which will better link demand and supply based **on renewable energy sources** than the actual system. The smart meter should be energy efficient itself, but it should contribute to a bigger picture.

In the opinion of the UK expert once the system is set-up, energy consumption is largely determined, so number of meters and communication modules are key issues. However, good design can minimize the energy consumption of radio frequency communication (RF) systems and will be developed as regulatory pressure increases.

The Australian expert commented under other applications that all these aspects above, as well as **the provision for electric vehicles** should be considered when looking at own-energy consumption of smart meters. **These are all important capabilities to enable demand-side participation, and their "parasitic consumption" needs to be factored into future planning** (Mishael J, 2012).
No answer was provided by the Japanese expert on this question.

3.2. Information and interest from other IEA Initiatives

Study authors contacted the Operating Agent of the IEA Demand Side Management Programme – DSM Annex regarding this topic of energy consumption of the meters and associated infrastructure. The idea was to understand if this has been a subject addressed in any of the tasks of the DSM Annex so far, and to investigate possible collaboration areas with the DSM Annex.

From own review of DSM Annex activities Task XI, sub-task 1 on “Smaller Customer Energy Saving by *End Use Monitoring and Feedback* (EUMF)” was identified as somewhat related to smart metering and energy savings. The objective of the sub-task was to quantify work carried out in participating countries to provide energy end use feedback for smaller customers, how successful it has been, what further measures can be implemented and whether disaggregation and feedback have a viable role to play in current and future thinking for energy saving. It is also to quantify the degree of disaggregation and feedback needed to motivate end use behavior changes and whether the feedback needs to be automatically implemented with customers having override possibilities. Broad conclusions from this study can be summarized as:

- Domestic energy use has risen sharply over the past few decades. It is likely to continue to rise. Motivating customers to save energy can reduce that projected rise.
- EUMF can be used to motivate smaller customers to achieve a 10% saving in energy use.
- Different energy use, feedback and saving presentation methods have been assessed with the face to face customer interview being a preferred method.
- Different energy use disaggregation methods have been assessed with the face to face customer interview together with total metered data preferred.
- Field trials of EUMF show that customers can be motivated to save energy if they are presented with easy to absorb information and the required actions needed are easy to carry out. Customers are also likely to require continuous reminders to save energy (DSM Annex, 2005).

Another DSM task which could be relevant for smart metering and particularly for their own energy consumption is Task XVI “Competitive Energy Services (Energy Contracting, ESCo Services)”. Energy Contracting (ESCo) or Energy Service (ES), is a many times proven DSM instrument to implement energy efficiency measures for lighting, HVAC-technologies or even comprehensive refurbishment of buildings. An Energy Service Company takes over the technical and commercial implementation and operation risks and has to guarantee for the costs and results. ESCo services are also well suited to implement innovative energy technologies and renewable energy systems.
Experts from Austria, Belgium, Finland, India, Japan, Netherlands and Spain join forces to contribute to the market development of Energy Services by:

- Establishing an Energy Services Expert Platform
- Designing, elaborating and testing innovative energy services and financing models and to publish them in a series of manuals
- Developing and following up on country specific activities for implementing energy services in the market with a focus on selected market segments, and

- Offering expertise and initiating joint projects and services with other international organizations (DSM Task XVI, 2009).

Scoping study authors also contacted the Chair and Vice-Chair of the International Smart Grid Action Network - ISGAN, to explore their planned work. A possible interest in cooperation has been indicated. In principle ISGAN creates a mechanism for multilateral government-to-government collaboration to advance the development and deployment of smarter electric grid technologies, practices, and systems. ISGAN plans four “foundational projects, as:

- *Global Smart Grid Inventory:* to facilitate knowledge sharing and assistance,
- *Smart Grid case studies:* to develop comparable smart grid case studies,
- *Benefit/Cost Methodologies:* to improve benefit-cost analysis methodologies for smart grid and develop related tool kits, and
- *Synthesis of insights for high level decision-makers:* to develop a common vocabulary for discussing smart grid internationally and integrate the results of the above and related efforts into useful syntheses for decision makers.

ISGAN is also developing additional activities, including projects on transmission and distribution networks, renewable integration, and grid governance during the transition to a smart grid, as well as smart grid international research facility network and smart grid interoperability. Collaborations with the IEA-DSM Annex and the Electricity Networks Analysis, Research and Development - ENARD are foreseen.

The IEA secretariat has been contacted during this scoping study. The coordination unit responsible for the upcoming publication “Smart Meters and Smart Consumers”, showed interest in the subject of this scoping study.

3.3. Information and interest from other organizations

Various organizations have been contacted during the course of this study, as shown in Table 2. Notably; the European Smart Metering Industry Group - ESMIG provided a response specially tailored for this IEA scoping study (ESMIG, 2012). ESMIG provided the authors with a summary of **preliminary** results from an ongoing project on smart metering infrastructure and its own energy consumption. These preliminary results are being independently reviewed and will be available in a final report to ESMIG members later in 2012.

See **Appendix 6.2** for the complete summary. An extract of results from ESMIG´s study is included here:

*..."the information from ESMIG is based on real industry data, but is not yet ready for publication. This will happen once independent analysis has been carried out on the statistical work. Considering the current information, **the increased energy used for smart metering systems is mainly due to the addition of communications systems and energy displays**. These features are nevertheless, key to the delivery of daily accurate reads for European consumers and the potential delivery of energy savings for consumer. **The increased energy used is very small compared to the potential savings with only a 0.2-0.3% savings needed to balance the extra usage**"*.

The following summary in Table 1 was also provided in ESMIG´s contribution for the IEA scoping study.

Table 1 Summary of ESMIG preliminary results available for IEA scoping study

Calculations based on initial and unconfirmed data from ESMIG members	Existing energy used in operation [GWh/year]	Estimated energy for smart systems [GWh/year]	Change [GWh/year]
Electricity Meters	4200	4000 - 4500	-
Meter reading	60	-	-60
Communications Equipment – Modems and similar	-	4000 - 11000	4000 - 11000
Communications Equipment – data transfer and data centres	-	5 - 10	5-10
Display devices	-	1500 - 2000	1500 - 2000
Totals	4260	9500 - 17500	5240 - 13300
Electricity savings needed to neutralize increased energy use			**0.2 - 0.4%**

ESMIG also supported a study in 2011 branded as Empower Demand, on "The potential of smart meter enabled programs to increase energy and system benefits: a mass pilot comparison", written and published by the organization VaasaETT (VaasaETT, 2011).

This independent research demonstrates the actual effects of around 100 smart meter enabled pilots and roll-outs across the world, analyses what features and setup lead to the greatest effects, and summarizes lessons for utilities to maximize consumer benefits.This report concludes that significant reductions in the energy used by consumers, and the times of day they use the energy can be achieved by the appropriate smart metering installations. The display of almost real-time energy consumption data on in-home display devices (IHDs) led on average to an 8.7% reduction in energy consumption. Lower but still significant reductions of 5% to 6% on average were achieved through enhanced, more informative bills and access to usage data on websites. The different types of dynamic pricing mechanisms used in the pilots and roll-outs have all shown that energy loads up to 16% can be shifted ("peak clipping") for the benefit of consumers and utilities.

The report also highlights that the above-mentioned results of smart meter enabled programmes can be maintained over years. This demonstrates clearly that behavioral changes by consumers who make use of the potential provided by smart metering technologies can become permanent, securing the significant and long-lasting effects necessary to achieve the ambitious energy efficiency targets that European decision-makers are aiming for by 2020.

The benefits demonstrated by the 100 worldwide installations could, if delivered across Europe, contribute to the EU goal of a 20% reduction in energy use by 2020 if similar installations were set up across Europe. Smart meter data delivered through IHDs alone has been shown to be a quick, effective and high-performing tool for raising consumer awareness and education, leading to an average 8.5% energy reduction. The report has shown that the opportunities to use smart meter installations to allow demand pricing mechanisms, as part of the wider European objectives of smart electricity grids, deliver significant benefits. The Electricity Directive requiring 80% of European consumers to have smart metering systems by 2020 will allow many of these benefits to be achieved (ESMIG, 2011).

The European Commission DG Information Society - DG INFSO, Unit H4 on ICT for Sustainable Growth, through Mr. Rogelio Segovia has also been contacted for this study. His feedback indicated that INFSO has not yet conducted own studies on the consumption of smart meters but have published a methodology report for measuring the energy efficiency of the ICT sector. The current methodology results are:

- International Telecommunication Union- ITU/T International agreement on "Green ICT" methodology.
- GSMA Energy Efficiency Methodology incorporated in ITU's New Global Standard (GSMA represents the interests of mobile operators worldwide).
- The European Telecommunications Standards Institute approved Technical Standard on Life Cycle Assessment (LCA) of ICT equipment, networks and services: General methodology and common requirements (ETSI, 2011).

This expert mentioned that these methodologies have not been applied for the case of the smart meter devices.

In the UK, the British Electro-technical and Allied Manufacturers Association – BEAMA, provided answers to the questionnaire on behalf of the UK, and suggested this was an interesting topic not yet addressed by his organization.
Additional experts and organizations were contacted for the purposes of this scoping study via email and/or through web portals.
Table 2 presents the list of organizations contacted and their responses, in a compressed format.

Table 2 Organizations and experts contacted for the scoping study and their responses.

Organization/Expert contacted	Contact Information	Response received? Comments
IEA Secretariat	Mr. David Elzinga and Mr. Steve Heinen (answered). Energy Technology Policy Division. Authors of IEA "Smart Grids Roadmap", 2010. Steve.HEINEN@iea.org	Yes: IEA secretariat has not done any work on energy consumption of smart meters, but finds it a very relevant subject.
IEA Secretariat	Mr. Grayson Heffner – managing the IEA publication "Smart Meters and Smart Consumers" (upcoming).	Yes: Interested in the topic and a possible inclusion in own IEA publication. No own study. To follow-up.
IEA - DSM Annex	Operating Agent – Mr. Rob Kool. rob.kool@agentschapnl.nl.	Yes: Interested in the topic and a possible cooperation. No further details discussed and no specific commitment reached.
CEM initiative ISGAN - As of April 2011, ISGAN is formally an IEA Implementing Agreement.	Mr. Michele De Nigris, ISGAN chair. Michele.DeNigris@rse-web.it Mr. Russell Conklin – Vice Chair ISGAN. Policy Analyst US DOE. Russell.Conklin@hq.doe.gov. (no answer).	Yes: Interested in the topic and a possible cooperation. No further details discussed and no specific commitment reached.
Smart Electricity Systems, European Commission Joint Research Centre (JRC), Institute for Energy and Transport.	Dr. Ginaluca Fulli - Action Leader. Gianluca.FULLI@europa.eu	Yes: topic interesting, but no data available from JRC.
European Commission DG Information Society (DG INFSO), Unit H4 ICT for Sustainable Growth.	Mr. Rogelio Segovia – DG INFSO. Rogelio.Segovia@ec.europa.eu	Yes: no study on own consumption of smart meters. Provided reference to a methodology report for measuring the Energy Efficiency of the ICT sector.
European Commission DG Energy – Programme	Dr. Manuel Sánchez Jiménez – Programme Manager, DG ENER.	No.

Smart Grids Internal Market III: Retail markets.	Manuel.Sanchez-Jimenez@ec.europa.eu.	
European Smart Metering Industry Group - ESMIG (Brussels, Belgium)	Mrs. Zoi Mylona – Junior Policy Adviser. zoi.mylona@esmig.eu Dr. Howard Porter – Director, international Alliances. hporter@esmig.eu. Provided summary of ESMIG study and exchanged communications via email with scoping study authors.	Yes: provided a tailor-made summary for IEA purposes on own study on energy consumption of smart metering, not yet publicly available. **See Appendix 6.2**. Offered to review the results of the Austrian-Swiss study and give feedback, experts' opinion. Indicated that energy consumption of meters will continue to be subject of future ESMIG´s work.
ENEL Italy (Power utility) - Expert on smart metering System.	Mr. Flavio Cucchietti, expert ENEL, ICT Efficiency expert at ITU- Int. Telecommunication Unit. flavio.cucchietti@telecomitalia.it	No.
Research center - CENELEC	research@cencenelec.eu	No.
Open Meter Project - European Union.	info@openmeter.com	No.
Electric Power Research Institute – EPRI. (California, USA)	Online info request at: www.epri.com	No.
Association of Home Appliance Manufacturers (AHAM) – smart grids and appliances (USA).	info@aham.org	No.
Editorial team, Smartgridnews.com (USA)	editor@smartgridsnews.com	No
BIO Intelligence Service	Mr. Shailendra Mudgal- Executive Director. sm@biois.com	Yes: BIOIS has not worked on the smart metering aspects. Mr.

(Paris, France)		Mudgal thinks that this is an important topic.
Red Eléctrica de España - REE Spanish Electricity Network (Madrid, Spain).	Mr. Andrés Sainz Arroyo – DSM Department. asainz@ree.es	Yes: no specific data on consumption from REE but reference to their Demand Side Management (DSM) project “INDEL” on understanding residential energy consumption.
Iberdrola Spain – Distribution and DSM Department (Spain)	distribucion@iberdrola.es	Yes: no information (publicly) available on own consumption of smart meters.
China Productivity Center (New Taipei City, Taiwan R.O.C.)	Mr. Richard Chien-Chieh Hsu -R&D Innovation Department. 2475@cpc.org.tw.	Yes: no specific study available but general comments from local expert on smart metering issues.
University of Cambridge. Electricity Policy research Group. (Cambridge, UK)	Dr. Michael G. Pollitt - Author of report "Smart Metering and Electricity Demand: Technology, Economics and International Experience", 2009. m.pollitt@jbs.cam.ac.uk.	Yes: no data on own energy consumption of smart meters, provided contact to Dr. Darby, (below).
Lower Carbon Futures - Environmental Change Institute, University of Oxford (Oxford, UK).	Dr. Sarah Darby - Senior Researcher, Deputy Programme Leader. sarah.darby@eci.ox.ac.uk. Author of the study “The effectiveness of feedback on energy consumption”.(Darby, 2006).	Yes: no data on own energy consumption of smart meters but provided contact below to Mr. J. Parsons - BEAMA.
The British Electro-technical and Allied Manufacturers Association - BEAMA (London, UK).	Mr. John Parsons – Industry expert. JohnP@beama.org.uk.	Yes: no study on topic available but would look for more information. Provided answers to questionnaire for the UK, on behalf of DEE and DEFRA.
IIASA (Laxenburg, Austria).	Energy and Climate Change group.	Yes: No specific project on this field.
Electric and Electronics Industry Association of Austria FEEI (Vienna, Austria).	Dr. Klaus Bernhard – Director FEEI, Coordinator in the Smart Grid Austria Platform.	Yes: no specific data available. Responded part of the questionnaire with Austrian perspectives.

Energieinstitut an der Johannes Kepler Universität Linz (Linz, Austria).	Dr. Andrea Kollmann - Project manager. Kollmann@energieinstitut-linz.at	Yes: the institute is not dealing with technical aspects of smart meters.
Energy Agency of Graz (Graz, Austria).	Dr. Bleyl – DSM Annex task leader and Mr. Boris Papousek.	No.
Wien Energie (Austrian Power Utility) – Gas network and innovation standards. (Vienna, Austria).	Mr. Andreas Theurer. Expert on gas meters and with extensive knowledge on electricity meters.	Yes: topic is important. Provided valuable hints for technical references. Thinks the topic will gain even more importance in extensive roll-outs.

3.4. References of interest for Smart Metering Consumption

A summary of some relevant studies with direct and/or indirect references to energy consumption of smart meters and associated infrastructure is presented in this section, with a focus for Austria.

Title: **Smart Metering und sein Einsatz in Österreich**. (Smart Metering and its implementation in Austria). Master Thesis.

Authors, details: Michael Holzinger. Institut für Verfahrens - und Energietechnik der Universität für Bodenkultur. Vienna, January 2011.

Summary: This thesis investigated the use of smart metering in Austria, by describing and analyzing the effect of smart metering on the different actors (Power utilities, network operators, distributors and consumers) on electricity market and the costs and benefits of an installation of smart meters throughout Austria. Additionally this paper determines the contribution of smart meters to energy efficiency and also describes the current pilot projects with smart meters in Austria.

The results show, that the consumers will derive the biggest financial and non-financial benefits, while the network operators will have to pay the highest monetary costs. Because of this fact, the energy companies in Austria have mixed feelings about the adoption of smart meters. Therefore, it is important to clarify general conditions for the future. Also the energy companies guess, that the consumers will profit from the use of smart meters. How high the savings per household will be, because of smart meters, is very difficult to estimate, but current figures assume 1.0 % to 3.5 %. Altogether, the smart meters will lead to energy savings and a more efficient use of energy in Austria.

Relevance: Less relevance for the international scoping study but useful for the work of the Bi-National Austrian Swiss project on Smart Metering Consumption. It comprises a collection of data from previous studies for the Austrian context as well as opinions of national experts.

Title: **Studie zur Analyse der Kosten-Nutzen einer österreichweiten Einführung von Smart Metering.** (Cost-Benefit analysis of the introduction of Smart Metering in Austria).

Author, details: PricewaterhouseCoopers GmbH for E-Control, June 2010.

Summary: The goal of this study was to complete a cost benefit analysis for the implementation of smart metering, for gas and electricity, in Austria. The estimations are referred to the different stakeholders - consumers, energy providers, and network operators. The saving potentials for consumers and other market stakeholders were investigated, as well as the saving effects resulting from simplified processes and alternative price models (tariff models). For the cost benefit analysis, all direct and indirect costs and benefits were considered, for four proposed scenarios, based on the percent of metering deployment and timeline of implementation. The results show, for all scenarios, that benefits surpass the costs. The net effects in the cost benefit analysis are between 291 and 556 million Euros, depending on percent and time period of implementation of the smart meters. Of all, scenario 2 is the one with highest ne benefits (556 Million Euros). Scenario 2 is based on an implementation of smart meters up to 95% of all meters, with electricity meters being introduced between 2011 and 2015, and gas meters from 2011 to 2017 (Overall shortest implementation period of time).

Relevance: Very often mentioned reference in the context of Austria and smart metering. The technical data that have been used for the estimation of smart meter operational costs, specifically those costs due to their own energy consumption; are presented in this study as general figures, based on the report of smart metering impacts of the UK conducted by the UK Department of Energy and Climate Change - DECC (DECC, 2009). These energy consumption estimations of this DECC report are based on industry "experts´ opinions".

Title: **Analyse der Kosten – Nutzen einer österreichweiten Smart Meter einführung.** (Cost-benefit analysis for a wide introduction of Smart Meters in Austria).

Author, details: Capgemini Consulting Österreich AG, for the Austrian Association of Electricity Companies (Verband Elektrizitätsunternehmen Österreichs - VEÖ). January, 2010.

Summary: The economic assessment of a national roll out of smart meters in Austria has been the focus of this study. The study includes a comparison with the current situation (status Quo) versus the introduction of smart meters. The focus lies strongly on the electricity market and the estimations were done with a perspective until the year 2028, so that two complete cycles of smart meters could be evaluated, considering a start of the roll-out as of January 2013. Three different scenarios were used for the study: Scenario 1 –"Business as usual (BAU)": with existing Ferraris meters continuing their operation (Baseline to compare other two scenarios). Scenario 2 – "EU Directive": 80 % of meters are replaced by electricity smart meters as of 2020. Scenario 3 – "100 % Rollout": until 2020 smart meters will be installed all across Austria (following by smart gas meters by 2024). By the end of 2009 there were 5.6 Million metering points in Austria (consumers and small and medium enterprises, with a yearly consumption of max. 100.000 kWh, or a connection of less than 50 kW. For the economic assessment, the method of Net Present Value (NPV) has been used. From the overall economic perspective, the results of the study indicate a negative NPV of the implementation, and therefore additional costs of 1.7 billion (for scenario 2) to 2.4 billion Euros (for scenario 3).

With respect to the operational costs, for scenario 2 there would be an increase of 67% of energy consumption compared to scenario 1, and for scenario 3, up to 77% increase of energy consumption (Energy consumption for the meters, data concentrators and communication devices)

Relevance: same as above, this reference is often mentioned in smart metering discussions in Austria, and presents results from a study commissioned by the industry players. No technical data has been reported directly, but is apparently used for the estimation of scenarios of energy consumption of meters as a basis for operational costs included in the analysis. These operational cost estimations are also, most likely, based on "experts´ opinions".

Referring again to ESMIG (ESMIG, 2012), the ongoing study on **Energy consumption of the smart metering infrastructure** mentioned before in Section 3.3 and included in Appendix 6.2 is of relevance to IEA-4E. The complete study will include more details – not yet provided in the summary to IEA-4E, on aspects of communications used and the amounts of data transmitted using the communication. The data used in the study were based on the actual energy use of existing meters, and on the actual or *predicted* energy use of the various elements of smart systems. The reason for some of this being based on *predicted* data, is that the roll-outs in Europe are thus far limited, and little if any on site measurements have been carried out. ESMIG indicated that their survey was intended to give an initial view on the situation, and is not yet complete. The results presented were average from the best and worst case scenarios:

- Smart meters: the energy used by smart meters will be within the same range to existing meters at 4000 – 4500 GWh/year;
- Communications equipment: modems 4000-10000GWh/year dependent on the level of functionalities and the precise technologies used;
- Communications equipment: data transfer and data centres 5-10 GWh/year;
- Display devises: 1500 - 2000GWh/year. *Very dependent on the type and design of displays as well as the assumed level of usage by the user.*

In conclusion:

- The replacement of all existing electricity meters with smart metering systems without displays will lead to a net increase of 4000 - 11000GWh/year.
- If display devices are also installed, there will be an additional increase of 1500 - 2000GWh/year energy used
- Total increased energy use for complete smart metering installations of 5500 - 13000 GWh/year.

On the variability due to functionality and communications methodologies, this information will really only become available once European member states have decided exactly what data should be transmitted, and how often. Whichever communications systems are used, the actual energy used will be dictated by these variables.

ESMIG indicated that it is unlikely that there will be an easy way to set maximum levels if different roll outs of smart metering in different countries require higher or lower levels of functionality and data transmission. This is an issue that ESMIG is due to have initial discussions with the European Commission in the near future. ESMIG is considering extending the project and showed interest in reviewing results from the Austrian - Swiss ongoing assessment of energy consumption of smart metering (ESMIG, 2012a).

Other studies were found assessing the impact of the introduction of smart meters for different countries, which have been used for analysis and decision making purposes, such as:

Study of KEMA, 2009 (for the Ministry of Economy and Technology of Germany): This study is titled "Energy savings through the introduction of Smart Metering". The 320 pages report states that the diversity of possible smart metering configurations, communication systems and feedback solutions are difficult to be all assessed. Nevertheless, specific cases were carefully analyzed and documented in this study, with the inclusion of data provided by experts from industry. A range of values on energy consumption of the smart meters and their infrastructure component (up to the provision of billing and feedback information in different ways) is presented, some of which were obtained from pilot projects. The data included also energy consumption for gas, water and heat meters, in addition to data for electricity meters. The conclusions of the study indicate that the potential for end-consumer energy savings due to the introduction of smart metering is on the order of 5% for electricity and 2.4% for gas.

Studies of cost-benefits of Smart Metering in the Netherlands: A comprehensive cost-benefit analysis was conducted in The Netherlands in 2005 by KEMA by order of SenterNovem (van Gerwen et al., 2005 for Agentschap NL). This first study resulted in a positive net present value of approx. 1.3 billion Euros. The study was revised in 2010 due to considerable changes in the political, economic and technical fields, and to investigate aspects such as energy efficiency, privacy and security, additional functional requirements, introduction of smart grids and other benefits to consumers. The revised cost benefit analysis also concluded a positive business case with a net present value of 770 million euros. The main benefit items were energy savings, savings on call centers costs, lower cost level, and savings on the costs of reading meters. The benefits of energy savings are the greatest. However, a certain level of uncertainty in determining the national average savings percentages remains unavoidable. These studies are based on information from other studies as well as data from different stakeholders from industry (network operators, suppliers, and meter manufacturers) (KEMA, 2010). The 2010 study presents a summary of cost-benefit analysis for other European countries: Germany, Sweden, Belgium, and the United Kingdom.

Cost-Benefit analysis for the United Kingdom (MacDonald, 2007; DECC, 2009): The roll out of smart meters in the UK will be a major infrastructural program, with about 50 million electricity and gas meters replaced. The cost of this roll out has been estimated at 8.1 billion pounds, with expectations of 11.7 billion pounds revenue of in the next 20 years. The result of the cost-benefit analysis has been positive, as the net revenue has been estimated at approx. 6 billion pounds. Data for the analysis has been obtained from consultation with industry experts.
The assumption used in the DECC Impact Assessment (IA) of 2009 for smart meters operational costs is based on previous Ofgem work, where it was assumed an.."*annual operation and maintenance cost of smart meters of 2.5% of the meter purchase cost. No further substantive evidence has been brought forward on this point"* (DECC, 2009).

Studies for selected Australian cases, **e.g., AMI Roll out and program in Victoria**: this roll out aimed at the deployment new electricity smart meters and associated communications infrastructure to all residential and small business premises across Victoria by the end of 2013 (AMI Roll-out) and, delivering new AMI enabled services to these customers (AMI program).

The Victorian Government, through the Department of Primary Industries, commissioned three assessments to update previous studies into the costs and benefits of the AMI Program.

These were:

- A review of the lifecycle costs of the AMI Rollout (referred as the 2010 Cost Report),
- A review of the lifecycle benefits available from the AMI Program based on the most up to date information available (referred to as the 2009 Benefits Report).
- A review of the benefits detailed in the 2009 Benefits Report (referred to as the 2010 Benefits Review), where the information provided in the 2009 Benefits Report was reassessed.

The summary report "*Benefits and costs of the Victorian Government's AMI Roll-out and AMI Program*" from August 2010 consolidates and presents the results of those three assessments of the costs and benefits of the AMI Rollout and the overall AMI Program mentioned above.

The present value of the total cost of the AMI Rollout, which will install smart meters together with supporting communications infrastructure, IT systems and processes, is estimated to be $1.621 billion11 (plus or minus $200 million) over the 2008 – 2028 timeframe. The total cost of the AMI Program, which incorporates functionalities and costs identified in the 2009 Benefits Report to enhance the range of services available to customers, is estimated to be $1.813 billion (plus or minus $249 million).

The benefits of the AMI Program have been estimated to be in the range $2.577 billion to $5.004 billion. Most of these benefits result from savings that will be experienced initially by the Victorian electricity distribution companies as improved operational efficiencies are realized through utilization of the AMI infrastructure itself. They do not depend on new legislation or regulations, discretionary actions on the part of retailers or consumers, or the provision of new services. These benefits are estimated to be $2.036 billion. The benefits of the AMI Rollout (as distinct from the AMI Program) have been estimated to range from $1.874 billion to $3.513 billion. The report concludes that…"The AMI Program is cost-effective no matter which mix of costs and benefits is used. In the extreme, if the low case benefits and highest costs are used, for either the AMI Rollout or AMI Program, a clear net benefit results" (Oakley Greenwood, 2010).

This report includes the assumption of a previous (2008) report to the Ministerial Council on Energy (MCE) that indicated..." IT systems opex is 15% of capex, which is consistent with the MCE analysis".

4. Identification of important aspects to address Smart Metering Consumption

With inputs from the review of international initiatives and the answers from experts and member countries, the **most relevant** aspects for formulating and focusing future work are identified. In this section an explanation of why these aspects are relevant is to be included as well. These aspects might include (with no specific order of importance) the following points below:

4.1. Identification of technical features relevant for Smart Metering Consumption

The technical features that play a role in power consumption of the smart metering infrastructure are identified and briefly described in this section, based on the smart meter itself (metering point) and the associated system where the meter is embedded as a key component. Further studies and collaboration work is likely to continue its focus on these technical aspects (according to the interest of stakeholders), and on the coming challenges and functionalities of the smart metering roll-outs.

Energy consumption at metering point

Following up from chapter 2 the energy consumption of a smart meter depends on the way it is metering, the form of communication, the hardware and firmware implementations and the additional features provided from the smart meter.

- **Metering**

The energy consumption due to the metering depends on the physical principle used for performing the measuring. To calculate the consumed power this is performed separately for voltage and current. For the later one, there are different principles used like shunt, hall sensor, Rogowski coil, etc. Another influence related to the metering is the sampling frequency, and permanent driven signal processing.

- **Communication**

For communicating the measured data to the data concentrator and/or the head end different technologies can be used, being responsible for different energy consumptions. Currently in use are GPRS communication, PLC - power line communication as the most common ones, but there are other concepts such as radio and ADSL communication.
The other aspect causing different energy consumption in the communication is related to the type of communication control, e.g., if it is a push or pull solution. When being pulled once a day the remaining time can be managed in a sleep mode, while in the other case a so called "keep alive" routines have to be permanently running.

- **Hardware**

The most important factor of the hardware influencing the energy consumption is certainly if the smart meter is meant to measure in a single or three phase grid. The power supply design, the level of integration in semiconductors, sensors, etc., also play important roles in consumption.

- **Additional features**

Other hardware components and their functionality determine the energy consumption, such as switchers and breakers, anti-fraud protection measures. Also Multi-Utility-Control (MUC: one per household), in-home displays, home automation features, and additional modules such as wireless solutions to broadcast the information inside the house can contribute to the energy consumption per metering point significantly. In special cases one could imagine a data transmission through in-house power line communication connecting to a WIFI access point to a tablet PC to inform the consumer about their energy consumption in the house. Those designs offer a relevant challenge to make sure the received information is resulting in a reduction of energy consumption that can compensate the consumption needed to power the information system itself.

System related energy consumption

Further energy consumption occurs due to the ICT infrastructure (apart from the smart meter itself). For communication purposes these are all active communicating nodes involved, in first line, the data concentrators when used. Also the energy consumption from storing data eventually has to be considered, depending on the amount of data to be stored.

The time of operation (24 hours a day), and strong interdependencies between system design and requirements that are currently under discussion which will have a very long term impact, this highlights the actual relevance of such discussions, e.g., real time measurement for grid operation? Quarterly hour measurements for time of use tariffs? Data transfer steadily, once a day, once a month? Which communication technologies?

MacDonald's assessment is that "consumption from such equipment (smart meters) *and the associated support systems* could easily reach 0.75 - 1% of the residential sector's energy consumption" (McDonald, 2007).

The estimate of energy consumption from ESMIG´s summary is a total increased energy use for complete (EU wide) smart metering installations of 5500 – 13000G Wh per year. This implies that 0.2 to 0.4 % of the expected energy savings are "eaten up" by the operation of the smart metering infrastructure (ESMIG, 2012). Refer again to Table 1 in Section 3.3.

4.2. Identification of key stakeholders, their interactions, and their role in influencing Smart Metering consumption

Because different stakeholders may affect technology features or establish specific policy requirements for the Smart Metering Infrastructure in various ways, part of the work has to cover the identification of stakeholders, their interactions, and their roles in the definition and performance (e.g., regarding power consumption) of Smart Metering Infrastructure.

If there is a regulatory body in the country overseeing the deployment of smart metering this organisation has a key role to set minimum requirements for functionalities. These requirements most likely are related to energy consumption of the Meters and the associated infrastructure. One example is shown in the UK where the roll out of smart meters includes an in-home display to provide feedback to the consumers resulting most likely into a larger energy consumption compared to other rollouts without the required displays. In the ESMIG summary for the IEA (ESMIG, 2012) the scenario for the calculation of the consumption of smart metering the aspect of the display consumption is named uncertain and very dependent on the type of display design as well as the assumed level of usage.
The grid operator determines the infrastructure and technology to roll out. The choices of what features the smart meters should provide determine not only the investment costs but also the energy consumption.

As an example how regulatory bodies and grid operators relate to the subject of smart meters: The Ontario Energy Board proposed basic smart metering functions and some minimal technical standards. Each energy company is free to develop its own smart metering framework. Targets are installation of 800.000 meters by the end of 2007 and covering all 4.3 million Ontario customers by the end of 2010 (KEMA, 2006).

4.3. Identification of existing Smart Meter standardisation activities and bodies

Through the questionnaire submitted to IEA-4E delegates it was partly possible to find out the state of requirements set in the countries for smart meters, and in particular, for own energy consumption of the smart meters. Answers to question Q4 indicate that in respondent countries there are specifications for minimum requirements of smart meters, with the exception of Switzerland and Japan, were these are under development. Regarding standards on energy consumption, as requested in Q5, respondents indicated that there are requirements to be fulfilled (in Australia and the UK). See Info-Box on maximum consumption for smart meters as declared in standards.

Maximum consumption for smart meters as declared in standards.

There is the international standard IEC62053-21 (2003) "Electricity metering equipment (a.c.) – Particular requirements – Part 21: Static meters for active energy (classes 1 and 2)" which includes, under Section 7.1.1, the limits for energy consumption of the meters (per phase) as **2W (10 VA).**

In Australia the energy consumption requirements of meters is covered in the Australian Standard AS62053.21-2005;7.1 for existing meters, and also specified in the section 6.3 a) ii of the Smart Metering Infrastructure Minimum Functionality Specification. It must be **less than 2W (10VA)** (from questionnaire answer of Mishael J, 2012).

In the Statement of Design Requirements of 2010, of the Smart Metering Implementation Programme of the UK, section 3 proposes a functional requirement to limit the average power consumption of any mandated equipment in the consumer premise to 2.6W total. This has been set in line with the values used in the updated impact assessment and is intended to ensure that the energy savings attributable to the installation of smart meters are not outweighed by the additional "smart" burden (Ofgem E-Serve, 2010).

From questionnaire answer of Mr. J. Parsons, 2012:…"the UK there is a **2.4 W maximum** average power demand allowed for the home system".

In Germany the "application rule" Electricity Metrology (metering Code) VDE-AR-N 4400:2011-09 – under Section 4.6 "Minimum requirements for measuring devices", point 2, indicates that in general it has to be made sure that any energy taken from the metering point is to be measured. Deviating from that, directly connected measurement devices are allowed to take energy from the unmeasured area only if the **maximum peak power is below 6W** (this means the maximum effective power consumption). This is mandatory beginning 01-07-2013 onwards.

At the European level the Mandate M/441 titled "Standardization mandate to CEN, CENELEC and ESTI in the field of measuring instruments for the development of an open architecture for utility meters involving communication protocols enabling interoperability" appears to be the most relevant ongoing standardization effort. Interoperability refers to the ability of a system to exchange data with other systems of different types and/or from different manufacturers.

The general objective of the M/441 EN 2009 mandate is to create European Standards that will enable interoperability of utility meters (water, gas, electricity, heat) which can then improve the means by which customer's awareness of actual consumption can be raised in order to allow timely adaptation to their demands. CEN, CENELEC and ETSI are requested to develop:

1. A European standard comprising a software and hardware open architecture for utility meters that supports secure bidirectional communications upstream and downstream through standardized interfaces and data exchange formats and allows advanced information and management and control systems for consumers and service suppliers. The architecture must be scalable to support from the simplest to the most complex

applications. Furthermore, the architecture must consider current relevant communication media and be adaptable for future communication media. The communication standards of the open architecture must allow the secure interfacing for data exchanges with the protected metrological block.

2. European standards containing harmonized solutions for additional functionalities within an interoperable framework using where needed the above-mentioned open architecture for communication protocols. These solutions must be standardized to achieve full interoperability. Solutions meant to be installed in living quarters should be silent, non-intrusive and safe.
3. The standards to be developed must be performance-based and permit innovation in the protocols that enable remote reading of utility meters and advanced information and management services for consumers and suppliers. In particular, the standards shall permit fully integrated instruments, modular and multi-part solutions. Standards developed under this mandate and M/374 should not conflict with each other and other standards and any overlaps should be indicated.

CEN, CENELEC and ETSI should take into account international, European and national standards that have already been developed or are under development (European Commission, 2009).
A Smart Meters Coordination Group (SM-CG) was set up to answer this mandate request.
Mandate M/441 has two phases. The first, requests the European Standards Organizations to develop a European standard comprising a software and hardware open architecture for utility meters, as indicated above under point 1. In this context, the SM-CG identified the main possible functional communication implementations relevant for smart metering systems and the standards relevant to meeting the requirements of mandate M/441, in particular to assist the active participation of consumers in the energy markets. The SM-CG produced a technical report, CEN-CLC-ETSI TR 50572:2011 "Functional reference architecture for communications in smart metering systems" which has been published in December 2011.

The second phase of Mandate M/441 requests the European Standards Organizations to develop European Standards containing harmonized solutions for additional meter functionalities within an interoperable framework, using where needed the open architecture developed under the first phase of Mandate M/441. To clarify standardization requirements and to ensure consistency in the smart meter dataflow, it is helpful to consider functionalities in details through Use Cases. The last meeting of the SM-CG took place on 6 December 2011 in Brussels (CEN, 2012).

On the subject of interoperability, it is worth mentioning the OPEN meter project. Started in 2009 and was projected to be finished in June 2011. The objective was to specify a comprehensive set of open and public standards for Advanced Metering Infrastructure (AMI), supporting electricity, gas, water and heat metering, based on the agreement of all the relevant stakeholders in this area, and taking into account the real conditions of the utility networks so as to allow for full implementation. The scope of the project was to address knowledge gaps for the adoption of open-standards for smart multi-metering equipments and all relevant aspects – regulatory environments, smart metering functions, communication media, protocols, and data formats – are considered within the project. The OPEN meter project was financed by the European Commission within the Seventh Framework Programme, Area 7/1: Smart Energy Networks / Interactive distribution energy networks, Topic 7/1/1: Open-Access Standard for Smart Multi- Metering Services. The OPEN meter project had six working packages.

- Working Package 1 - Functional requirements & regulatory issues.
- Working package 2- Identification of knowledge and technology gaps.
- Working package 3 - Pre-normative research activities.
- Working Package 4- Testing.
- Working Package 5 - Specification and proposal of standards.
- Working package 6 – Dissemination (OPEN meter project, 2009).

The OPEN meter project deliverables from Working package 5 (D5.1 – Specification of services, D5.2. Architecture specification, and D5.3 – Specifications of PLC technologies: PLC lower layers based on PRIME, G3 and Meters and More) form the basis for the contributions of the OPEN meter project to CENELEC standardization process. The high quality of the validation process performed in the OPEN meter project allowed CENELEC to take the OPEN meter proposals as “Draft Technical Specifications”. It is likely that the OPEN meter proposals become official “Technical Specifications” in February 2012 (OPEN meter project, 2011).
The situation of national standards in other countries/regions was not covered as part of this study as it was hoped that information would be available from country delegates.

5. Recommendations for addressing Smart Metering Consumption

The following key issues are based on the results of this scoping study and are recommended to address Smart Metering Consumption:

Awareness	An awareness rising campaign is needed to understand the issue of Smart Metering Consumption for those "setting the rules" about Smart Metering Infrastructure.
Cooperation	IEA bodies could be brought together and should team up with other organizations such as ESMIG, DG INFSO, smart grid task force, SET plan initiative as well as standardization and regulation bodies. Initial interest has been shown but no clear commitment exists yet.
Methodology	A methodology is needed to measure and assess the energy consumption of Smart Metering Infrastructure. Particularly to enable the analyses of overall system efficiency and interdependency with system design parameters. Ongoing methodology developments, such as the one undertaken by the IEA-4E Standby Annex for networking products, provide an opportunity to explore a similar approach for Smart Metering.
Real measurements	Measurements of real field consumption of smart metering deployments are needed to identify the additional energy consumption due to the installation of smart meter infrastructures. Pilots and roll outs offer a valuable possibility to do so.
User feedback	In the framework of smart metering, optimized ways for providing feedback to users, which enables a net reduction in the energy consumption over time, have to be found.

Awareness

- When contacting delegates from IEA-4E to ask questions about smart metering (in general) and their own consumption, few delegates had an overview of the subject and status for their country and could answer the questionnaire. Most delegates referred to experts outside 4E when looking for expertise in the subject of smart metering. In some cases, these experts seemed to have low awareness of this particular issue of own energy consumption of the smart meters and related equipment, and have not done work in this field. This suggests that further work might need to be commissioned to external experts, under the supervision of country delegates.
- Own energy consumption of smart metering systems, although an obvious issue connected to the operation of this infrastructure, appears to be out of the scope of the work of most experts and regulators working in the energy, and even in the smart metering fields. Assessments explicitly looking at energy consumption of the smart metering infrastructure make assumptions based on industry expertise, rarely connected to real measurements in

the field. Moreover, this consumption is often neglected based on the argumentation that potential energy savings at the end-user side would by far exceed the infrastructure own energy consumption. Smart metering will bring many more operational and societal benefits than own “costs”. At the same time there is a lack of significant data about long term energy savings introduced through smart metering systems. Further work is recommended to raise awareness, especially for experts and decision makers in governments confronted with the deployment of an energy efficient smart metering infrastructure. This infrastructure will be set for decades, million devices will be deployed, and the associated consumption fixed when the technology and system architecture are chosen. Understanding these implications in terms of the consumption is an important issue.

Cooperation

- At the European Union, ESMIG showed keen interest in reviewing the on-going work of the Swiss - Austrian study as well as possible future work coming from IEA. ESMIG pro-actively contributed to this scoping study with a summary and preliminary results on their current work. ESMIG indicated that they most likely will continue investigating the subject of energy consumption of smart metering infrastructure after this first project is concluded. Their strength lies in the access to industry players at the EU level, from which data could be obtained, from current roll-out as for pilot projects.
- Still at the European level, the DG INFSO seemed to have relevant work on methodologies for the ICT sector. It could be valuable exploring these methodologies in connection to the assessment of energy consumption of the metering infrastructure. In this case exchange and collaboration would be advisable. This might be a suitable organization to discuss the direction for standards. Additionally the smart grid task force and SET plan initiative could be involved in further work in this topic.
- The possibility to bring the topic to activities and collaborations within IEA could be further explored (e.g., ISGAN and DSM Annex)..

Methodology

- The lack of a specific methodology to assess the own energy consumption of smart meters and their infrastructure, also in light of the complexity of various technologies being available for the meters, communications, and head-end and system requirements (particularly taking into account smart grids concepts), is indeed a challenge, but also might present opportunities for future work. As previously indicated from some reference studies, the assessments of energy consumption of smart meters have mostly been done for specific (exemplary) cases of smart meter, communication and back-end configurations (e.g., in the KEMA, 2009 study). In this study the authors indicate that only the use stage of the complete life cycle of the infrastructure has been considered, namely, materials, production, distribution and end of life of the infrastructure (as established in the ISO 14040 series for Life Cycle Assessments) were not considered. Even for the assessment of the energy consumption for the operation (use) of such infrastructure, certain considerations were made to facilitate the assessment. As indicated before, the DG INFSO has developed a methodology for the assessment of ICT equipment, which has not been used for the case of smart meters.
- Standardization is a very relevant topic, especially in connection with the development of a methodology to estimate the energy consumption of the smart metering infrastructure. Given the different technologies and system arrangements available and under consideration by smart meter operators, and the on-going technology developments, work on this area could be very valuable.
- Standardization is one of the issues ERGEG is currently considering as a topic for further work, possibly in co-operation with other institutions.

Real measurements

- Future work in the subject of Smart Metering Consumption could focus on surveying the technological trials (e.g., pilot projects) globally to get a better understanding of energy consumption of meters in real operational conditions. These pilots can also be surveyed for their possible specific work on addressing regulatory developments concretely connected to consumption of the infrastructure. Likewise, these surveys could contemplate the estimation of real energy savings at the end-consumer side, enabled by smart metering.
- The issue of energy consumption of smart meters becomes a relevant theme for energy providers and network operators. Technical collaborations with these smart metering players might be the best way to move the topic and advance the knowledge further. These players would be the ones to involve in such a project, at a national level, which could be feeding a much larger initiative. Coordinating this through national energy agencies and Ministries would be advantageous, to motivate these players to participate, and to gain access to data for conducting research and further assessments.

User feedback

- Studies dealing with energy savings through feedback to consumers ranging in the order of 5% to 15% appear not having taken into account the energy requirements of the metering, display and communications equipment, which should be included in order to provide real net energy savings.
- There is an increasing number of smart meter systems that are now monitored to measure their effects on energy use, and other consumer and energy management impacts. This could present opportunities to investigate energy consumptions caused by the feedback systems installed.

6. Appendices

Appendix 6.1: Questionnaire on smart metering consumption and list of respondents.

Questionnaire for IEA-4E Scoping study on Smart Metering Consumption

The implications of possible increased energy consumption due to the implementation of Smart Metering Infrastructure need to be better understood. This is the motivation for starting this Scoping study. As part of the study we are conducting this questionnaire.
There are 10 questions. The first section is about Smart Metering in general (pages 1 and 2 with in total 7 questions), and the remaining 3 questions (on page 3) are about the energy consumption of the smart metering infrastructure itself.
Please feel free to comment in detail. This information will be used only for IEA purposes and the results will be presented in the next ExCo meeting (May 2012 in Sweden).

Thank you for your contribution!
ECODESIGN company GmbH, Vienna – Austria (diaz@ecodesign-company.com).

Q1. Please include your information[2]:
Name:
Last Name:
Country:
Organization:
Email contact:

Q2. What are the pre-conditions (e.g., legal framework) for rolling out Smart Metering in your country? What are planned strategies for this roll-out? Please comment below:

Q3. Which is the regulatory agency overseeing the roll-out and setting requirements on smart metering in your country? Please provide contacts if possible:

Q4. What are the mandatory functional and service requirements that smart meters must comply with? This refers to national strategies, plans, or others factors setting requirements to the smart metering infrastructure. Please select the most important ones and briefly comment below.

- ☐ Installation & maintenance requirements
- ☐ Operational requirements
- ☐ Energy consumption requirements (of meters)
- ☐ Display and storage requirements

[2] In the online questionnaire Question 1 needs to be answered to be able to proceed to remaining questions. See link to the online questionnaire at the end of this document.

- ☐ Interoperability requirements
- ☐ Prepayment & credit requirements
- ☐ Diagnostics & reliability requirements
- ☐ Data privacy & security requirements
- ☐ Home Area Network requirements (HAN)
- ☐ Wide Area Network requirements (WAN)
- ☐ Requirements on auxiliary interfaces (e.g. for In-Home Display (IHD), home automation)
- ☐ For your country, specific electricity requirements
- ☐ Other (please comment below):

Additional comments:

Q5. Do you use code(s) or standard(s) for setting minimum performance or functional requirements for smart meters in your country?

- ☐ Yes
- ☐ No
- ☐ Not yet but in preparation (comment below):

If "Yes", please specify which one(s):
If "in preparation" please also comment here:

Q6. Please describe below for the largest region(s) in your country where smart metering is already in active use, or for the largest pilot project(s), the following:

Name region 1 / pilot project 1:
Aim of roll-out/pilot project:
Number of metering points?:
Technology used?:
Other aspect:

____

Name region 2 / pilot project 2:
Aim of roll-out/pilot project:
Number of metering points?:
Technology used?:
Other aspect:

Q7. Are there any projects in your country focusing (among other aspects) on energy consumption of smart metering?

- ☐ Yes
- ☐ No

If "Yes", please describe briefly and provide contacts if possible:

Q8. In your view, which aspects are the most relevant for addressing (and eventually regulating) smart metering own energy consumption? Please select and comment below:

- ☐ Technology used
- ☐ Communication requirements (e.g., extents, encryption, network topology)
- ☐ Data Management (e.g., data to be retrieved, to be stored, to derive from calculations)
- ☐ Billing requirements
- ☐ Additional functions (e.g., Home monitoring, home automation)

Other aspects (or comments) please include below:

Q9. Please describe shortly the initiative(s) in your country (with scope, extent and if available, key results) looking at own energy consumption of smart metering infrastructure (e.g., quantifying and/or regulating this consumption). Please comment below:

Q10. Which aspects (not mentioned in this questionnaire) do you think shall be also considered when looking at own energy consumption of smart metering systems? Please select and comment below:

- ☐ Support for load control (electricity)
- ☐ Support for microgeneration
- ☐ Support for other applications (Multi-Utility Control, home automation)
- ☐ Facilitation of smart grids

Other applications or possible future applications (please comment):

Questionnaire was available at: http://www.surveymonkey.com/s/Q27L7YP
Questionnaire prepared by ECODESIGN company GmbH. www.ecodesign-company.com.

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Appendix 6.2: Summary of preliminary results of ESMIG study for the IEA-4E scoping study.

ESMIG input on the energy use of smart metering systems.

Date: 12.03.2012

Summary of information collated from members – NOT final and project NOT complete – information released for use in the IEA study on energy use of smart metering systems project only.

ESMIG input on the energy use of smart metering systems.

ESMIG is carrying out a study to assess the energy used by existing metering systems and the planned smart metering systems across Europe. Members have been asked to provide information to an independent statistician, who has collated it to give a set of average figures. Once all information has been collated, it will be subject to external verification. This project is not yet complete however, based on the data received thus far ESMIG is prepared to release for the use of the IEA study unconfirmed data. On this basis, the following information can be used;

Summary information

Based on the 270million households in the EU with electricity meters, roughly 4200 GWh energy is currently used by "dumb" meters – between 1 and 2 W per meter per year. In addition, the energy used by the manual reading has been calculated using a basic set of assumptions (a twice yearly manual read, 100m driven between reads), and is in comparison very low – 60Gwh). Therefore, the total estimated energy use for the currently installed electricity meters in Europe is about 4260GWh/year.

The basis of the data collected for smarter metering systems is:

- every meter in Europe is smart;
- each installation is connected to a remote communications systems, including the modem (or equivalent), all other communication equipment, and data transfer;
- 3 main communication methods were assessed – cellular, PLC and long wave radio systems – results have been average for this report;
- meter readings are carried out on a daily basis – compared to an average of twice yearly for typical existing systems;
- the energy used by stand alone energy display devices is covered, although this at the current time is only mandated for 10% of European homes.

ESMIG members have submitted information based on their estimates of the best and worst case scenarios for the different elements of smart metering taking into consideration a number of assumptions (daily reads, and assumed metering points for data concentrators etc.). The results presented below are average from the best and worst case scenarios received:

- smart meters – the energy used by smart meters will be within the same range to existing meters at 4000-4500GWh/year;
- communications equipment – modems 4000-10000GWh/year dependent on the level of functionalities and the precise technologies used;
- communications equipment – data transfer and data centres 5-10GWh/year;
- display devises – 1500-2000GWh/year, very dependent on the type and design of displays as well as the assumed level of usage by the user.

In conclusion:

- The replacement of all existing electricity meters with smart metering systems without displays will lead to a net increase of 4000-11000GWh/yr.
- If display devices are also installed, there will be an additional increase of 1500-2000GWh/yr energy used
- Total increased energy use for complete smart metering installations of 5500 – 13000GWh/yr.

ESMIG has also funded an independent assessment of the energy efficiency benefits of smart metering publicly available http://www.esmig.eu/newsstor/news-file-store/ED_download . The average saving for roll out with displays from the 100 situations surveyed is 8.5%, which in electricity savings is 255,000GWh per year. Therefore, the net benefit of smart metering systems would be a reduction of 242,000 to 249,500GWh per year.

The electricity savings required to recover the extra energy used by the smarter metering installations alone is 0.2-0.3%.

Summary

In summary, the information from ESMIG is based on real industry data, but is not yet ready for publication. This will happen once independent analysis has been carried out on the statistical work. Considering the current information, the increased energy used for smart metering systems is mainly due to the addition of communications systems and energy displays. These features are nevertheless, key to the delivery of daily accurate reads for European consumers and the potential delivery of energy savings for consumer. The increased energy used is very small compared to the potential savings with only a 0.2-0.3% savings needed to balance the extra usage.

Summary table

Calculations based on initial and unconfirmed data from ESMIG members	Existing energy used in operation GWh/year	Estimated energy for smart systems GWh/year	Change
Electricity Meters	4200	4000-4500	-
Meter reading	60	-	-60
Communications Equipment – Modems and similar	-	4000-11000	4000-11000
Communications Equipment – data transfer and data centres	-	5-10	5-10
Display devices	-	1500-2000	1500-2000
Totals	4260	9500-17500	5240-13300
Electricity savings needed to neutralise increased energy use			0.2-0.4%

7. **References**

- AECOM Limited, June 2011. “Energy Demand Research Project: Final Analysis”. Executive Summary. http://www.ofgem.gov.uk/sustainability/edrp/Documents1/Energy%20Demand%20Research%20Project%20Executive%20Summary.pdf. (Last accessed March 2012).
- British Gas, 2012. http://www.britishgas.co.uk/smarter-living/control-energy/smart-meters.html. (Last accessed March 2012).
- Capgemini (Capgemini Consulting Österreich AG), 2010. “Analyse der Kosten – Nutzen einer österreichweiten Smart Meter Einführung“. http://oesterreichsenergie.at/Smart_Meter_Wunsch_und_Wirklichkeit.html?file=tl_files/DOWNLOADS/Pdf.%20Netze/Capgemini%20Kosten_Nutzenanalyse%20Smart%20Metering.pdf. (Last accessed March 2012).
- CEN - European Committee for Standardization. Smart Metering, 2012. http://www.cen.eu/cen/Sectors/Sectors/Measurement/Smartmetering/Pages/default.aspx. (Last accessed March 2012).
- Darby S, 2006.”The effectiveness of feedback on energy consumption”. http://www.eci.ox.ac.uk/research/energy/downloads/smart-metering-report.pdf. (Last accessed March 2012).
- Demand-Side Management Programme (International Energy Agency) - DSM Annex, May 2005. Final Report “Task XI: Time of Use Pricing and Energy Use for Demand Management Delivery, Subtask 1 Smaller Customer Energy Saving by End Use Monitoring and Feedback. Richard Formby - Operating Agent. http://www.ieadsm.org/Files/Tasks/Task%20XI%20-%20Time%20of%20Use%20Pricing%20and%20Energy%20Use%20for%20Demand%20Management%20Delivery/Reports/Subtask1Report12May05.pdf. (Last accessed March 2012).
- Demand-Side Management Programme (International Energy Agency) - DSM Annex. 2009. Task XVI “Competitive Energy Services (Energy Contracting, ESCo Services)”. http://www.ieadsm.org/ViewTask.aspx?ID=16&Task=16&Sort=0. (Last accessed March 2012).
- Department of Energy and Climate Change. May 2009. “Impact assessment of a GB-wide smart meter roll out for the domestic sector”. http://www.decc.gov.uk/assets/decc/consultations/smart%20metering%20for%20electricity%20and%20gas/1_20090508152831_e_@@_smartmeteriadomestic.pdf. (Last accessed, March 2012).

  European Commission, 2009. “Mandate M/441 EN: Standardization mandate to CEN, CENELEC and ESTI in the field of measuring instruments for the development of an open architecture for utility meters involving communication protocols enabling interoperability”. Enterprise and Industry, Directorate General. Brussels.
- European Smart Metering Alliance - ESMA, 2008. “*Methodology for Estimating Energy Savings related with Smart Metering*”. http://www.esma-home.eu/UserFiles/file/downloads/Final_reports/ESMA_WP2D8_Report_on_Methodology_for_Estimating_Energy_Savings.pdf. (Last accessed March 2012).

- European Smart Metering Alliance - ESMA, 2009. “Annual Report on the Progress in Smart Metering 2009”. Version 2.0 January 2010. http://www.esma-home.com/UserFiles/file/ESMA_WP5D18_Annual_Progress_Report_2009%281%29.pdf. (Last accessed April 2012).
- European Smart Metering Industry Group - ESMIG, 2011. Reference on website for the “Empower Demand Report”. http://www.esmig.eu/newsstor/news-file-store/ED_download. (Last accessed April 2012).
- European Smart Metering Industry Group - ESMIG, 2012. Summary for IEA-4E Scoping Study. Not available as public document.
- European Smart Metering Industry Group – ESMIG, 2012a. Personal communications via email, March 2012.
- European Telecommunications Standards Institute, November 2011. “*ETSI TS 103 199 V1.1.1 Environmental Engineering (EE); Life Cycle Assessment (LCA) of ICT equipment, networks and services; General methodology and common requirements*”. http://www.etsi.org/deliver/etsi_ts/103100_103199/103199/01.01.01_60/ts_103199v010101p.pdf. (Last accessed March 2012).
- KEMA report 40510016-TDC, August 2005. ”Domme meters woden slim? Kosten-baten analyse slimme meetinfrastructuur” (Are dumb meters getting smart? Cost-benefit analysis for a smart metering infrastructure). By R.J.F. van Gerwen, S.A. Jaarsma, F.T.C Koenis.
- KEMA 2006, “Smart Metering. July 2006, by Rob van Gerwen, Saskia Jaarsma and Rob Wilhite, KEMA, The Netherlands.
- KEMA Consulting GmbH, 2009. “Endbericht: Endenergieeinsparungen durch den Einsatz intelligenter Messverfahren (Smart Metering). Bonn, Germany.
- Holzinger, Michael, January 2011.“ Smart Metering und sein Einsatz in Österreich“. Master Thesis. Institut für Verfahrens - und Energietechnik der Universität für Bodenkultur, Vienna.
- International Energy Agency – IEA, 2011. “Technology Roadmap Smart Grids”, by Elzinga, D. and S. Heinen. http://www.iea.org/Papers/2011/SmartGrids_roadmap.pdf. (Last accessed March 2012.
- MacDonald, Mott, 2007. “Appraisal of Costs & Benefits of Smart Meter Roll Out Options, Final Report”. The Department of Business, Enterprise and Regulatory Reform (BERR). http://www.berr.gov.uk/files/file45997.pdf. (Last accessed March 2012).
- National Smart Metering Program - NSMP, 2011 (Australia). “NSMP Business Requirements - Work Stream Smart Metering Infrastructure. Minimum Functionality Specification”, Version 3.0 by Dr Martin Gill and Harry Koller.
- Oakley Greenwood, 2010. “Benefits and Costs of the Victorian AMI Program”. By Lance Hoch and Stuart James. http://www.oakleygreenwood.com.au/images/OGW-AMI-benefits-and-costs-report-.pdf. (Last accessed April 2012).
- Office of the Gas and Electricity Markets -Ofgem E-Serve, July 2010. “Smart Metering Implementation Programme: Statement of Design Requirements”. http://www.ofgem.gov.uk/Pages/MoreInformation.aspx?docid=40&refer=e-serve/sm/Documentation. (Last accessed March 2012).

- OPEN meter project, 2009. “Objectives”. http://openmeter.com. (Last accessed March 2012).
- OPEN meter project, 2011. “D 5.8 Second Report on Status of Standardization”. http://openmeter.com/files/deliverables/D5.8%20V1.0.pdf. (Last accessed March 2012).
- Pollitt, M., A. Brophy Haney, and T. Jamasb, 2009. “Smart Metering and Electricity Demand: Technology, Economics and International Experience". Electricity Policy Research Group, University of Cambridge, UK.
- PwC Österreich, June 2010.“Studie zur Analyse der Kosten-Nutzen einer österreichweiten Einführung von Smart Metering“.
- SmartRegions, February 2011. “European Smart Metering Landscape Report”. SmartRegions project Deliverable 2.1. http://www.smartregions.net. (Last accessed March 2012).
- VaasaETT Global Energy Think Tank, 2011. The potential of smart meter enabled programs to increase energy and systems efficiency: a mass pilot comparison (Short name: Empower Demand), by J. Stromback, C. Dromacque, and M.H. Yassin. http://www.esmig.eu/press/filestor/empower-demand-report.pdf. (Last accessed April 2012).

Efficient Electrical End-Use Equipment
International Energy Agency

HOCHSCHULE LUZERN

Scoping Study on Non-Intrusive Appliance Load Monitoring

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1. Introduction – Motivation

Most of the private household and industrial building users have only a small or no understanding regarding the energy consumption and have limited instruments to assess and optimize it. Consumers need to see and understand the electricity being used by different appliances. They're keen to see whether a new appliance, or a change in habits, affects the amount of electricity used. The hourly metering values for offices and households entire electricity use cannot distinguish the effects or patterns of individual appliances, or register the effects of small brief changes. Consumers have a clear wish to be able to understand the amount of energy used by different appliances and during different time periods. This information could give the best results in increasing the energy efficiency through user interaction.

Studies have shown that the real time and detailed visualization of energy consumption curves offers an average potential of 5 to15% energy savings in modern homes and offices. The information provided to the end-users must include categorization of appliance groups, like HVAC, lightening, white goods, computers, infrastructure and others. Having categories build will help the customer to understand his energy consumption and will help starting to develop his own energy efficiency strategy.

Non - Intrusive Appliance Load Monitoring (abbreviated as NIALM) is the enabling technology used to get the energy consumption information by single appliances with minor to no alterations of the infrastructure. Further, NIALM is an enabler for feedback systems to provide real time, summarized and categorized data to the end-users. With NIALM soft degradation, furthermore aging and out dated appliances are identifiable. With hints out of the appliance aging the customer can improve his self-developed energy efficiency strategy even more.

It has been recognized that the IEA endeavours to examine and utilize the potential of feedback systems based on NIALM in order to improve the energy efficiency. This is the main motivation behind this scoping study.

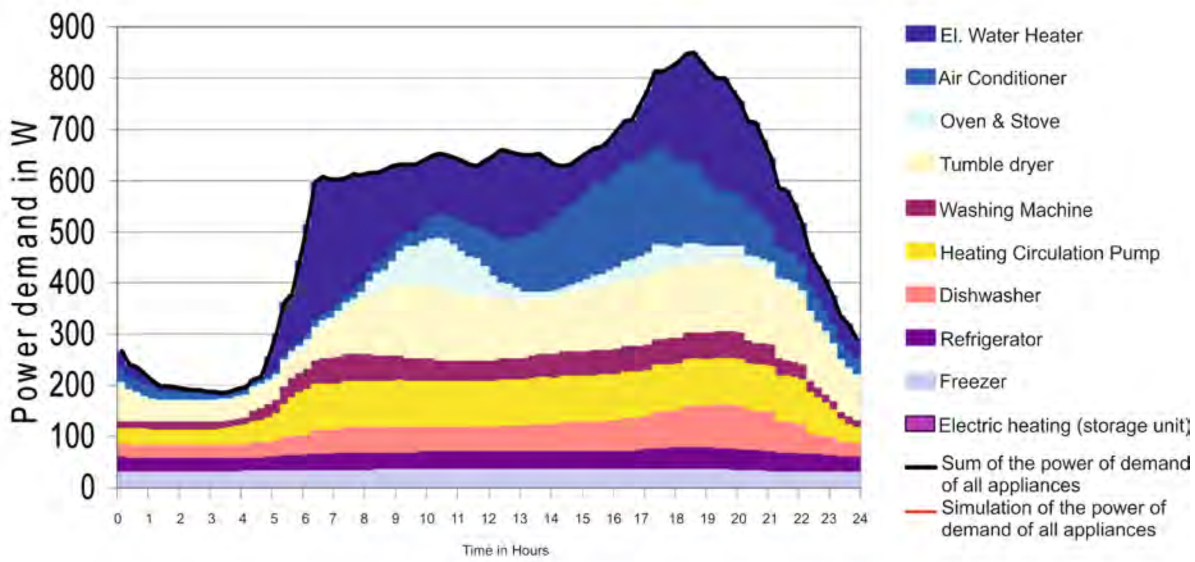
2. Non-intrusive Appliance Load Monitoring - Key questions to be answered

Targeting energy reduction in households and industrial buildings there are various ways to achieve this goal. Less energy efficient equipment can be exchanged with more efficient equipment. Products with a bad efficiency can be forbidden. Information's and trainings for efficient usage of energy can be offered to the public. Investments into products with better energy efficiency can be rewarded. Or other ways of reward and incentive systems can be introduced. All those ways require support of the government or regulatory bodies in order to set these rules into practice.

Providing the customer with details on its own energy consumption is another way to achieve one of the very important future targets: the increase of energy efficiency. Knowing the own energy consumption and knowing which devices have "eaten up" the most energy can change user habits. This information could give the best results in producing more aware and thus more efficient patterns of energy use. This is an area in which is a considerable potential for developing new products and services (ELAN,2010). The following section has the goal to explain the way how the disaggregation of electrical appliances for households and industrial buildings can be achieved.

Looking to the industry, the analysis of energy consumption in the production processes is the best demonstrated practice since years. The industry invests a lot in energy audits, in continuous energy optimization and sub-metering. The motivation is clear, the less energy is consumed - the less money is spent resulting in the increase of the company's revenue. Hence, more money becomes available for future energy efficiency projects. Beside the primary monetary advantages, the industry gets motivated by different governmental instruments and funds to aim at more energy efficiency. Apart from the energy consuming production processes, offices with less energy consumption have potential for improving the energy efficiency as well but are badly treated so far. Another benefit: Knowing where the energy flows during 24h/7days a week, gives an insight if office infrastructures are used well. Laser printers don't need to be switched on all the time, coffee machines as well. For office buildings the same rules can be applied like for households: The most equipment needs to be on, only when people are in. Who is in charge about the required information and able doing this?

The load curve shown in the following figure represents the energy consumption of an average European household over 24 hours. The penetration rates for all appliances – except for electric heating – were assumed to be 100%, meaning that each appliance is present and used in this home. The figure depicts great variance in the power demand consumed by appliances, with a clear peak demand of over 800 W during the evening, followed by a drastic reduction down to 200 W during night hours (SDASES, 2008).



Measurements like the one above need a clever technical solution to disaggregate the appliances with the goal of changing habits.

Customer interviews and our own experience brought us to the conclusion, that the process of energy optimization in the industry and in households following the same sequence. In our thesis, the process of analysing energy consumption is split into three phases:
a) the discovery phase
b) the correction phase
c) the observation phase

The goals of the three phases are different; also they have different requirements for the level of information details; for the data update frequency and for the accessibility of the information.

a) Discovery phase

The discovery phase is the initial phase when consumers aim to understand their own energy consumption. At this moment the consumption details have to be made available. The disaggregation of the load curve into single appliance is the necessary baseline to give the consumers a picture where the energy flows. NIALM plays an important role to disaggregate the appliances. The consumer is able to analyse the details and find out which appliances are on/off at what time-period (typical behavioural patterns). Making this exercise, the consumer starts to develop his own strategy, to influence his energy consumption. With NIALM the system can help the consumer to define the best energy optimization strategy based on the existing infrastructure and the appliances installed in the current home or office building. The strategy consists of load shifting activities, for instance, boilers heating up the water at daytimes when energy prices are low. Energy reduction actions, replacing out-dated incandescent light bulbs with state of the art LED technology or reducing the stand-by power by switching off the appliances completely when they are not required. The way how the energy data is brought to the customer level is another important aspect. During the discovery phase, the information must be accessible very easy and quick, for instance through smartphones or other existing devices. Beside the instantaneous power consumption also summarized values for different periods (i.e. day, week and month) are of interest for the consumer. Because of the changing requirements in the following phases it does not make sense to have a dedicated display just for the purpose of displaying energy data. Using existing devices like, picture frames, computers or TV screens to show instant energy data during the discovery phase is sustainable and does not require new devices.

b) Correction phase

The correction phase is the second phase, when consumers put the own strategy for energy optimization into practice. During this phase the consumption details must be made available. The disaggregation of the load curve into single appliance is essential to verify if the implemented strategy leads to the expected results or at least lead into the right direction. NIALM plays an important role to disaggregate the appliances. The consumer will frequently check his energy consumption to see if he meets his goals, set by himself. Meeting the goals makes him proud and eventually he starts to seek for more energy efficiency potentials. The correction phase takes normally 1 – 2 weeks' time. During this phase, the information must be accessible very easy (like in the discovery phase) for instance through smartphones or other existing devices. The instantaneous power consumption becomes less important, summarized values for day and week are of more interest to the consumer. He starts to compare on day and week level if he can see an improvement.

Using existing devices like, picture frames, computers or TV screens to show instant energy consumption during the correction phase is sustainable and requires no new devices.

c) Observation phase

The observation phase is the last and longest phase in an energy optimization process. However, entering the last phase in the energy optimization process does not mean that all of the work is done. The principle of the three phases is like a state diagram and it is possible at any time to restart with the discovery phase again. The three phases are linked in a way with each other where energy optimization is a repeating on-going issue. The disaggregation with NIALM during the observations phase collects long-term information. Part of the long-term information can be a summarized value of the up-time of appliances. For instance how many hours a month the air-conditioner is switched on. Other data to be collected is the aging of appliances. As an example: aging refrigerators starting to increase their power consumption and this will be detected by NIALM. During the observation phase consumers are especially interested in summarized values of week and month level. Consumer starts to compare one week with the other weeks or even on monthly level. The consumer is requesting information on demand; during this phase he doesn’t want to be informed all the time. With NIALM it is also possible to get notified when deviations to the normal power consumption are occurring like the aging of appliances. Computers or TV screens can act as information displays, notification by e-mail is also a possible way to bring the information to the consumers level.

Conclusion

Consumer’s feedback for energy consumption must have different faces. Depending on the current need and the current phase the information should be different. Consumers are very enthusiastic at the beginning and need instant and fast feedback to understand how and where energy flows. This enthusiasm is decreasing through the time consumers spend with always the same look and feel of the energy information system. The information must be easy accessible in various ways to serve understandable the need of having instant updates at the beginning and a notification for appliance deviations on the long run. A dedicated display calls for additional energy consumption; it can catch the interest of the consumer only at the beginning of the energy optimization process. Using existing devices or computers is a sustainable way to provide information.

NIALM plays an important role during all the phases of the energy optimization process. From disaggregation of load curves to the observation of single appliances or to summarized up-times of devices to calculate the payback time for more efficient solutions.

3. Overview of international activities on the topic of NIALM

NIALM method has been developed in the 1980s at the Massachusetts Institute of Technology (MIT). Since that time various universities and organizations like MIT, Carnegie Mellon University of Pittsburgh USA, Fraunhofer Center of Sustainable Energy Systems USA, Hochschule Furtwangen Germany and Université libre de Bruxelles worked on the topic. This list is not complete and there are other institutes doing research in this area.

During the last 20 years, there was a lot of progress in NIALM research activities.

One driver of the progress is the availability of more computing power. Computer prices dropped and the chips became smaller at the same time. Today we reached a situation where huge computer power is available in each single small device. The computing power is required to analyse the electrical characteristics of the devices in details. Second driver is the change in mindset. After serious accident in the Energy sector like melt down in Tschernobyl and Fukushima. But also Blackouts like Northeast Blackout in 2003changed the energy awareness of people. When energy prices start to climb because of supply shortages people ask themselves how the own energy consumption can be lowered. Research has been fuelled by an overall increased interest in improving the electrical grid and increasing the energy efficiency in buildings and homes. This has motivated a renewed interest in NIALM technology from industry and academic researchers around the world.

The Following pages will give an overview of the different methods, algorithms and concepts on NIALM. With the questionnaire sent to the 4E delegates we received valid information about international activities. Thanks to the delegates, that shared their knowledge with us! The complete analysed questionnaire is available in appendix A.

Methods for data acquisition

The data acquisition for the processing of device identification builds the core aspect in the process of NIALM.

Current Waveform (CW)

The current waveform provides quite complete set of information to describe load behaviour of a device. If the signal recording is done with a high sampling rate, the available device data characteristics can be understood well. Having a high enough sampling rate gives the option of further signal processing like fast Fourier transformation (FFT). This method is easy to implement and the required components are available on the mass market.

Active and Reactive Power (PQ)

The oldest and most frequently used signature to distinguish and monitor electrical devices consists of the active power P and the reactive power Q. This was the initial method when NIALM was developed 1980 at the MIT from George W. Hart. With a two-dimensional load profile it is possible to distinguish simple devices from each other. These parameters are often used in state machines.

Harmonic current (HAR)

With a fast Fourier transformation (FFT) of the current signal, the current harmonics are calculated. The FFT provides as result the magnitude of the current and the phase to the base current. Laboratory results have shown that most electrical appliances can be distinguished with the pattern of the first eleven current harmonics (only the odd ones).

Instantaneous Admittance Waveform (IAW)

IAW is defined as the quotient between the instantaneous current and voltage waveform as in $IAW(t) = \frac{i(t)}{v(v)}$.
The result of this calculation is the instantaneous admittance. The reason for choosing instantaneous admittance instead of impedance is because most household appliances are connected in parallel and, therefore, the equivalent admittance meets the feature-additive criterion.

Instantaneous Power Waveform (IPW)

IPW is defined as the product of instantaneous current and voltage waveform as

$$IPW = i(t) * v(t).$$

This value is also known as the instantaneous power.

Eigenvalues (EIG)

Dynamic loads are more difficult to detect then single state or multiple state devices. The current waveform of dynamic loads, such as a vacuum cleaner, could vary from cycle to cycle. In order to capture these dynamics, the current waveforms are rearranged into a matrix form to perform an eigenvalue analysis of the time series. Singular value decomposition (SVD) is used to extract the principle component of the current envelope waveform.

Switching Transient Waveform (STW)

All aforementioned features are derived from steady state condition. Furthermore also switching transients are a good signature to measure the load behaviour. One way could be to calculate the instantaneous power for every half cycle and use the resulting waveform as an STW. It is also possible to use directly the individual samples of the waveform. The STW requires a high sampling rate, this leads to a high memory and computing power demand.

Algorithms

The past processing of the captured data in algorithms will distinguish individual appliances from each other. Below are briefly described some models and techniques, which are used in NIALM algorithms.

Least-Square

Least-square is inter alia used to obtain a curve of individual data points. Least square means that the overall solution minimizes the sum of the squares of the errors made in the results of every single equation. For example, this technique can be used to win the current waveform from the individual sample values. In a transient signature, this curve can be compared with a curve in a database to find the appliance with maximum-likelihood estimation (see maximum-likelihood estimation).

Support Vector Machines (SVM)

Support Vector Machines can be used in Neural-Network for signature recognition. In general SVM is a concept in statistics and computer sciences for a set of related supervised learning methods that analyse data and recognize patterns, used for classification.

Integer Programming

A further technique used in NIALM algorithms is based on integer programming. Integer programming is a mathematical feasibility or optimization program in which some or all of the variables are restricted to be integers. This can be the basis of a method to estimate the state of an appliance.

Fuzzy-Logic

Fuzzy logic is a further method which is used in NIALM algorithms for pattern recognition.

Artificial Neural Networks (ANN)

Another opportunity for signature recognition is Neural-Network-based algorithms. These algorithms are complex, but offer a great potential with many opportunities.

Genetic Algorithm (GA)

Genetic algorithms are one of the stochastic search techniques. These attempt on the basis of one or more feasible solutions (points in the solution space) to approach step by step the optimal solution. More precisely GA's belongs to the heuristic optimization processes.

Decision Mechanism

Most Common Occurrence (MCO)

This decision mechanism chooses the most commonly occurred device within the database. For the computational mechanism, this is the least demanding expenditure because only the total number of votes within the database must be counted. Note that the chance of having a tie is relatively higher because the decision index is always an integer. For instance, two devices can have the same amount of votes.

Last Unified Residue (LUR)

A further decision mechanism is the last unified residue. In this method the mechanism selects the best appliance which has the last unified residue. A LUR is a comparison between an unknown signatures and a signature of the database.

Maximum-likelihood estimation (MLE)

In statistics, maximum-likelihood estimation is a method of estimating the parameters of a statistical model. In a NIALM System this calculation is used to determine the most likelihood appliance of a database. This technique can be applied very well to the pattern recognition.

Factorial Hidden Markov Model (FHMM)

The hidden Markov Model is a statistical model in which the system being modelled is assumed to be a Markov process with unobserved (hidden) states. This model is a method to make a disaggregation. In practise, each device in a home is described via a Hidden Markov Model (HMM) and each device has a hidden state at each time.

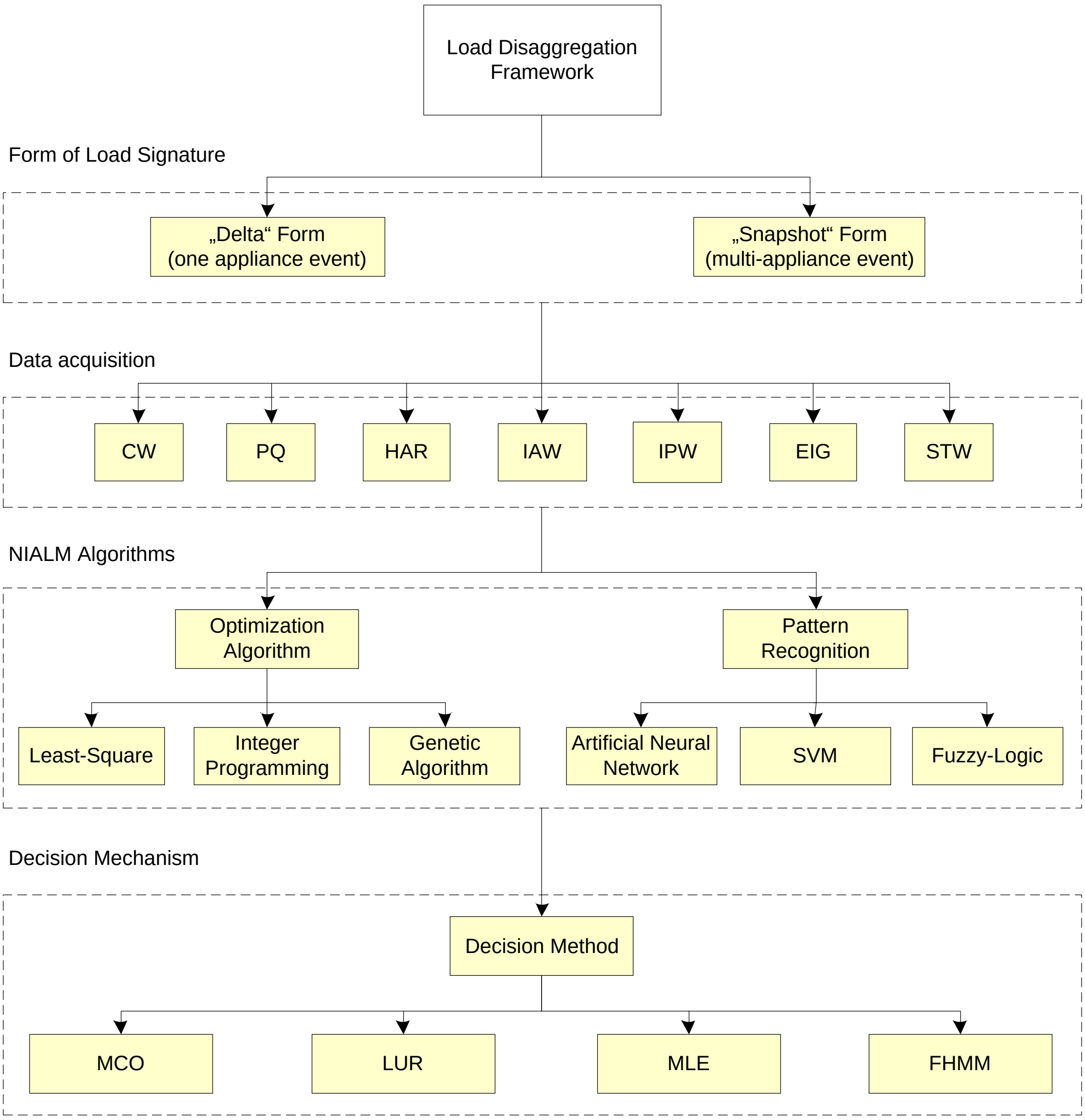


Figure 1: Overview of a load disaggregation framework

Field trials and IEA activities

The goal of the most papers was to show a way to get 100% identification and precision in the detection of the electrical appliances. Commercial aspects were not considered in most of the studies.

Enhancing Electricity Audits in Residential Buildings with Nonintrusive Load Monitoring (JoIE,2010)

The Paper "Enhancing Electricity Audits in Residential Buildings with Nonintrusive Load Monitoring" put a spot on the commercial ideas with NIALM. The projects explains a clear need, and a good value proposition, for providing building owners, professional energy auditors, and other interested parties, including home owners, with simpler tools that would produce more accurate estimates of the energy consumption of the individual electrical loads in a building at a reasonable cost. (JoIE,2010).

Experiment: As a proof of concept, and in order to obtain preliminary data that would help us evaluate the feasibility of using NIALM to support electricity audits in a residential building, we decided to focus our attention on the refrigerator. The NIALM prototype system was installed in an apartment building, and plug-level power meters were used to accurately track the individual consumption of this appliance. The experiment consisted of monitoring this load for a week, using the two methodologies (NIALM and plug-level meters), and then comparing the estimated energy consumption as computed by each. The measurements taken by the plug-level meters would be considered as the "ground truth."The NIALM system was first trained on the refrigerator, by providing it with two start-up and two turn-off signatures, and then on 17 other two-state appliances present in the home to differentiate. The end goal was to predict the energy consumption of the refrigerator with the NIALM system.

Results: We evaluated the data obtained during a period of 5.5 days,4 calculating energy measurements on both the predictions of the NIALM and the measurements taken by the plug-level meter. The resulting difference in energy estimates for the 5.5 days of the experiment was 14.8%,with the NIALM system underestimating the actual consumption by 2.29 kWh.5 The plug-level meter measured 15.48 kWh, whereas the NIALM algorithms predicted 13.19 kWh.

Conclusion: The results presented above, although limited to a single appliance, show promise for the feasibility of utilizing NIALM for supporting the goal of residential electricity audits. Even if not for the energy calculations, estimates of when the refrigerator cycles take place (when the events occur) can be helpful. Perhaps the most significant source of error for this experiment was the refrigerator's defrost cycle. This type of event was not identified during the training process. Thus, the NILM algorithms detected an event when this occurred, but could not classify it as belonging to the refrigerator.

IEA: Demand Side Management Program: Task XI: Time of Use Pricing and Energy Use for Demand Management Delivery : Subtask 1 Smaller Customer Energy Saving by End Use Monitoring and Feedback (DSM, 2005)

As an IEA activity, the Demand Side Management Program, Task XI: Time of Use Pricing and Energy Use for Demand Management Delivery, Subtask 1Smaller Customer Energy Saving by End Use Monitoring and Feedback investigated the aim of NIALM.

Objective: The objective of the study is to quantify what work has been carried out in participating countries on the topics of providing energy end use feedback for smaller customers. The task is to determine how successful it has been, what further measures can be implemented and whether disaggregation and feedback have a viable role to play in current thinking for energy saving. It is also to quantify the degree of disaggregation and feedback needed to motivate end use behaviour changes and whether the feedback needs to be automatically implemented with customers having override possibilities.

Approach: The study has analysed work carried out and results of trials involving real customers in order to quantify customer responses to end use energy saving motivators. It has also assessed the impacts on customer responses and energy saving of different levels of end use demand disaggregation and the way the information is presented. Disaggregating energy end use into its constituent parts is difficult to carry out at low cost. Many techniques and methods have been analysed to assess their suitability as energy saving motivators. Methods for applying End Use Monitor and Feedback (EUMF) as a cost effective and continuous methodology for motivating end use energy savings have been quantified using different levels of end use data disaggregation and presentation.

Results: Feeding back disaggregated energy end use information to smaller customers using a range of methodologies has been shown to motivate energy savings of the order of 10%. A survey in one country showed that 70% of smaller customers were prepared to make changes to save energy if they were advised how to do it and it involved little inconvenience. Monetary savings resulting from the application of EUMF to direct electric heating customers have been estimated to be worth 100 Euro per year per customer. Direct measurement of specific customer, end uses of energy on a continuous basis is probably too expensive for wide scale application to smaller customers. Estimates of the costs of face to face and Internet interviews with customers to collect data and feedback end use information and advice show this to be an attractive option. EUMF motivator messages have also been shown to encourage customers to replace energy inefficient end uses with efficient ones.

IEA: Demand Side Management Program: Task XXIII: Role of the Demand Side in Delivering Effective Smart Grids: identifying tools to minimise the risk and maximise the rewards associated with the Smart Grid from the consumer's point of view.. (DSM,2012)

The current pace of change within the electricity supply industry, both in the UK and worldwide, is unprecedented. The wide ranging measures being implemented to reduce the emissions of greenhouse gas emissions, particularly the wide scale deployment of time variable renewable generation, presents a number of challenges in relation to the balance of supply and demand. No longer is it considered viable for electricity to be provided 'on demand' in response to the requirements of end-users. Rather, a coordinated approach is required whereby energy production and demand are integrated to ensure the use of renewables can be optimised whilst also minimising the use of fossil fired generation and network infrastructure investment. Such an approach is the essence of the Smart Grid concept. Whilst there is considerable focus on the technological aspects of delivering Smart Grids, little is understood of the extent to which consumers are willing to embrace new technologies and initiatives that enable their use of energy to be actively managed. There is a real risk that if customers do not adopt new approaches to the way that they consume electricity, Smart Grids may not be able to achieve their full potential.

Therefore, a new project, led by EA Technology, will focus on investigating the role of consumers in delivering effective Smart Grids.

Besides other objectives we highlight the following two, which may be of interest for the work on NIALM.

1) Identify tools to minimise the risks and maximise the rewards associated with the Smart Grid from the point of view of the consumer, whilst still satisfying the needs of other stakeholders;

2) Map the technological opportunities to achieve services (how smart does the grid need to be)

We got in contact with the responsible Linda Hull (Operating Agent) and explained our intention to pick up load disaggregation with NIALM, it was positively recognized but not further commented. According to Lindathe task XXIII has not yet been started, but it will be ready in May 2012.

Commercially available products

Looking towards the market, there are few commercial products available today which can provide a load disaggregation to the end-user. One product is called Watteco EnPowerMe Software (Watteco), another one is called Enetics (Enetics) both products have not been assessed during this scoping study.

Products, which help to automate facilities like offices and homes are available in a wide range. These products have the main goal to switch appliances remotely on or off. Companies which offering such remote switches are extending the functionality of their products piece by piece. For instance products penetrating the market, which offer power measurement besides the switching function. Having power measurement available in these products, the way to come up with a simple load disaggregation algorithm is not that long. From our prospective it is a question of a few years until first commercial products are available, which offering full advantage of NIALM.

Networks and communities

There is no community established to consolidate the work done on NIALM during the last years. Building up a community is a growing need to discuss the standardization of datasets and performance metrics for commercial products, as well as possible areas of collaboration among different research groups.

Mario Bergés from Carnegie Mellon University organizes the first International Workshop on Non-Intrusive Load Monitoring 7th May 2012.

The mission of this workshop is to create a forum that can unite all the researchers that are working on the topic of energy disaggregation. There are currently no specialized conferences or workshops dedicated to this topic, and the contributions (which have been increasing in the past 5 years) come from researchers in a wide variety of fields and from different backgrounds.

The main objective of this event is to review the main types of approaches that have been explored to date to solve the problem of electricity disaggregation, and to then discuss possible paths forward knowing what has been tried and what has yet to be experimented. We also intend to have a group discussion about possible solutions to the growing need for standardized datasets and performance metrics that can allow the field to move forward, as well as possible areas of collaboration among different research groups.

Conclusion

The goal of most of the published projects was to introduce and verify a method for data acquisition and for the device disaggregation. Some projects could identify and disaggregate the various household devices quite well, some projects struggled in the complexity of the different states of the devices. In Europe and in the US the average household consist of about 25 devices. Some devices have multiple states, like cookers or microwaves or TVs. This fact makes it complicated for the system to identify the devices exactly. Variable states devices like drill machines are even more complex to identify. Compared with office buildings, the amount of different appliances is less then households and therefore the identification should be easier. All of the previous introduced methods for data acquisition and the described disaggregation algorithms have their strength and weaknesses. None of the approaches used in different projects could identify 100% of the appliances correct. The highest hit rate could be achieved with multiple layer data acquisition and multi algorithmic approaches. Such ways of device detection requires more computing power and more memory; they are not energy efficient any more. In addition subsystems for pre-processing and post-processing need to be introduced.

Considering further information like day time, weather or people attendance can significantly increase the hit rate of the device detection and / or the disaggregation.

Another aspect which has an influence to the device recognition is the distance to the appliance. Measurements done at the entry point of the building provides less details and it is more difficult to identify small loads. Having decentralized measurements points, smaller consumers like cell phone charges can be well identified by the system.

Asking for the right measurement method and the right dataset of an appliance it's important to define the goal of the device identification first.

If load profiles must be analysed and disaggregated in order to understand the dominating load in buildings then the centralized approach might be the right one. If devices must be analysed more detailed and the device aging or damage should be detected, the decentralized approach will provide more accurate results.

The goal of the most papers was to develop a way to get 100% precise recognition of the appliance and a complete disaggregation of the load curve. Public aspects were not considered in most of the studies. The two field trial projects (JoIE,2010) (DSM,2005) concluded device disaggregation gives the required level of end-user information. The cost of the tools is rather high but the disaggregation technique opens a field with various opportunities.

With the proceeding of international work shop on Non-Intrusive Load Monitoring the baseline for a community to consolidate the past and future research activities on NIALM is set. The community has the goal to bring research, government and industry to the same page. For the future work on NIALM in the IEA 4E IA it is vital to collaborate with this young and growing community.

4. Identification of important aspects to NIALM

Guidelines, standards, data sets and certification aspects must be addressed and elaborated before manufacturers start to introduce their own proprietary standards. To develop features like device comparison with vendor databases, "Energy Footprints" need to be defined together with a standardized and certified measurement infrastructure. Making "Energy Footprints" publicly available means to host a database and provide support. To offer comparisons with neighbours or compare energy consumption on a national or international level categories for the load disaggregation do also have to be defined. Making products and components interoperable we have to think about communication standards.

With NIALM we going to bring light into the dark, the technology is available but we are not yet there. The following chapter explains different energy efficiency concepts to be achieved with NIALM and will show the necessity of standardization and norming to make the technology a win for all stakeholders. Sometimes a questionnaire is referred, this questionnaire is available in appendix A.

Achieving a higher energy efficiency

NIALM can become the baseline for a higher level of appliance energy consumption details. Without the disaggregation of appliances the end-user remains lost and without any facilitation to develop his own energy reduction strategy. The disaggregation of appliances is the key element for user specific information and future services. The idea is explained in the following section.

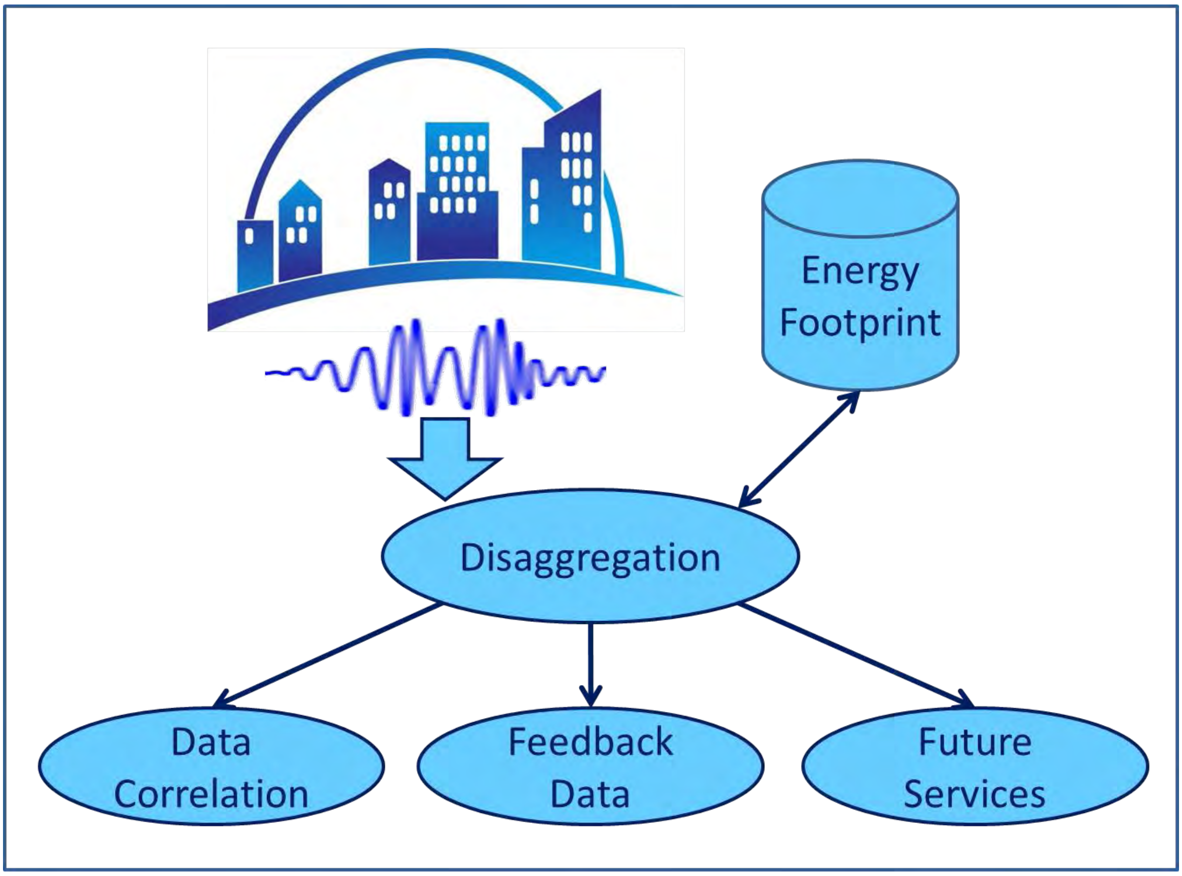


Figure 2: Overview of energy efficiency concept with NIALM

We split the usage of the disaggregated electrical data for energy efficiency into three parts. The first part is the data correlation. The disaggregated data will be aggregated into new specific data sets for further processing and usage. An example is the categorization of appliance groups, like HVAC, lighting, white goods, computers, infrastructure and others. The categorization gives the end-users a precise picture about the energy flow. Another example is the reverse engineering of load curves from the time based state change analysis of the appliances. End-users understand if certain appliances need to switched on or off at night or day.

The second area of data usage is called feedback systems. Feedback systems have been mentioned in reports and publications very often as the most important end-user communication to motivate for more energy efficiency. One possibility to keep the end-user motivated is to entertain him, keep him interested to the topic and provide different types of the visualization of the energy consumption. We will not explore the various aspects and approaches for feedback systems in this report. Just as an outcome out of our questionnaire we show the main points identified: Energy efficiency tips are important for all the participants. Instant feedback as well as daily, monthly or seasonal comparison with past values is very important too. Social comparison is the least important criteria selected in the questionnaire. The comparison with different users is depended on the cultural background of people and in some countries it can lead to very good results in energy reduction. The complete analysed questionnaire is specified in appendix A.

In the third part we are touching the wide field of future services based on the NIALM device disaggregation. Comparing the appliances with vendor's specification is the one idea. This can lead to the exchange of goods or claims. Both aspects increase the transparency for the customer. Knowing the appliances installed in offices and household proposals for products with better energy efficiency can be done. The other idea of future services can be advices from independent energy efficiency consultants. Once you share your load profile with a consultant he can make you a proposal to increase your energy efficiency. Observation of appliance ageing would open new opportunities too. Bringing NIALM to the size of power outlet sockets can increase safety: Dangerous equipment, like drilling machines cannot be used without the attendance of adults or if the Iron is switched on for couple of hours a notification can be given to the end-user.

NIALM can help to push regulatory decisions. If outdated light bulbs must be replaced with energy efficient light solutions by order, NIALM will help to identify such undesired products. Sure this sound a bit exciting but it is a valid opportunity. Other ideas are black lists. Inefficient products will be listed in black lists and made public available. This can help to inform and motivate end-users to exchange goods with more efficient ones.

The open questions and white spots must be identified and addressed to make all this happen with NIALM.

Standardisation, Metrics, Database, Communication

One of the most important goals of a future NIALM community is to build a standard about "Energy Footprints". The standard is required to define how an electrical appliance can be described. During research activities many appliance measurements have been done but most of them cannot be compared with the work from other projects. What is the best data set? The big number of data

acquisition methods leads to various possible data set definitions. What is known for the moment, there is no definition available which can fulfil all the requirements for a wide usage of NIALM. The community need to spend effort to write down the definitions for adequate data sets of "Energy Footprints".
The defined data sets require a corresponding metrics. With the metrics it is possible to pinpoint to the correct appliance, which is stored in a global accessible database, even if there are different supply conditions on the mains side. The impedance of the grid and the supply voltage may vary from installation to installation. Supply voltages and grid frequencies are different from region to region. The metric is required to make a normalization of the measured "Energy Footprints" for the usage in global databases.
NIALM systems should offer the possibility of accessing a global database where "Energy Footprints" are stored or can be uploaded. With access to these footprints appliances in household and offices will be identified faster. The tracking of the appliance for the energy consumption and for the aging can begin immediately. If appliances are unknown in the NIALM system, end-users can upload the footprints by them self's to make life easier for other users. Best case would be if companies start to store the footprints of their own products in the database. The database will increase transparency to the customer but it will give also opportunities for service which have the goal to improve the energy efficiency and propose better products to the customer. NIALM will boost competition on the consumption side of appliances. NIALM system will make its own measurement and will find out quickly if there is a deviation to the vendor's specification. Today there's no global database with such footprints. The database definition must be done.
To reinforce the topic, the introduction of NIALM definitions into communication standards is vital. If the compatibility between NIALM components from different producers can be achieved, the objective has been fully met. Bringing the data set to the level of device communication the industry will get encouraged to enter the topic of a standardized NIALM concept. Norming bodies and Alliances like the IEEE or ZigBee Org are good hosting places for the distribution of the standard.
NIALM can be seen as a gold mine in the industry. To avoid proprietary systems, guidelines and reference designs should be made available fast to the industry to shorten the time to market. If available, companies will pick up first drafts of NIALM and use it for their system modularity. The compatibility between systems and components of NIALM is a key element to make it a win for the end-user.

NIALM is a quite complex topic and requires joint forces from research, industry and governments.

Stakeholders

NIALM has the objective to bring maximum value to all of the stakeholders. Who are the stakeholders regarding to the successful rollout of a NIALM system?

End-user

The end-user has been mentioned many times during this report and it is clear that he belongs to the core of stakeholders. He is motivated by monetary reasons; with NIALM he can save money. The NIALM system must bring a quick pay back. The system has to be affordable compared with the value it brings. For instances: If users can increase people safety with NIALM systems, more added value is

brought to the end-user. The more services NIALM offers the more user groups get interested which see benefit in the usage of NIALM.
The systems have to be easy in installation and operation. If the system is too complex to handle during the installation phase because of a cumbersome appliance learning procedure the risk to fail is high. The same risk remains if the expected information about the energy flow cannot be made available to the end-user.

NIALM system developers

Certain companies will see NIALM as a gold mine. They will harry up and push R&D to come up with products very quick to serve the market. The incite is to get a big share of the NIALM market. Motivation of companies to follow the standard can be done by a jump start. Building up complex knowledge requires costly time and leads to a delay entering the market. Jump-starting companies will shorten the time. Doing this standardization drafts about NIALM must be made available at a very early stage or companies must get the opportunity to participate in the standardization work.
History has shown many times, that companies tend to develop their own standards due to missing standards or because of market protection reasons. Both reasons lead to missing compatibility of components and data. The market will not profit from that. The end-user will recognize this as a hurdle and hesitate buying a NIALM system.

Producer of electrical goods

This group of stakeholders can see NIALM as a threat because of the increasing transparency. Goods are normally tested from certification bodies once they get released. During the product lifecycle changes of electrical parts are very common. The electrical power consumption can differ through such product changes and lead to mismatches in the device identification. Who the handle this situation?
Other producers see NIALM as an opportunity. Companies which are spending already effort on the power consumption of their goods receive a platform were products can be compared with each other. It's a fight on equal terms. The energy consumption of appliances becomes a sales argument with increasing importance.
Producers must get a simple way to store "Energy Footprints" in the data base. If regional data sets are required simple correlation methods are required. The database in combination with services has to being added value to the producers of electrical goods.

Service providers

Providers of new service models can take a maximum benefit out of NIALM. The field of business ideas is very wide. These companies see NIALM as gold mine too. Service providers will follow the implemented standards of the NIALM system developers. Neither the system developers are not taking use of the standardization work nor will the service providers use them.
The risk is, that service providers will act as multiplier of proprietary solutions coming from the implementation of NIALM system developers.

Universities

Universities are the inventors of NIALM. A huge amount of "man years" were invested counting all the hours spent on NIALM research. Many papers were published which may help companies to increase their knowledge on NIALM. The universities and research centres cannot be released from their responsibility now. The academic community has to bring the gathered knowledge into the standardization and norming of NIALM. Furthermore the knowledge transfer form universities to the industry should be addressed as well.

The joint work of universities in a NIALM community has to come up with results towards standardization and norming in a short time. Representatives from the industry shall have the opportunity to enter the discussion in an early stage to make them partners of useful and wide accepted standard.

Norming bodies and Alliances

As non-profit organizations norming bodies and alliances do not follow a monetary motivation to support NIALM. Short through put times in the standardization and norming work are wish full and desirable for the industry.

Governments

Most Governments following the “International Climate Convention” and have clear objectives defined for the next decades in the area of: reduction of CO2 emissions; limiting the increase in electricity consumption and increasing the contribution of renewable energy in the energy production. The objectives are very challenging for governments. The motivation for governments to support the introduction of NIALM is the opportunity profiting from the potential of energy efficiency increase being found at end-users, in household and offices.

Utilities

Depending on how the topic of NIALM develops, energy providers have no or only a small added value of NIALM. NIALM has its primary aim in the consumer information and secondly in additional services. Utilities can play a role in offering specific services linked with NIALM.

Energy Labels

Energy labels, like EnergyStar or TopTen EU can develop an increasing interest in the usage of “Energy Footprints”. The Energy Labels are helpful for the end-users during the decision process buying the best affordable product considering the initial and operation costs. Offering the observation of appliances during lifecycle is a new business model for these companies. Until now, only the best products in class are listed on the web side of the energy label companies. If the end-user can compare the actual inventory of all electrical appliances with the best in class ranking of the energy labels he would receive more inputs about the state of the art of his equipment and maybe he exchange equipment. Getting a comparable overview of facilities will stop end-users from buying a new devices and putting the old one down to the cellar as a second source, like refrigerators. Moreover, with a standardization of Energy Footprints for all types of goods, appliances can enter the ranking overview faster. TopTen makes its own measurements about a product before its getting listed. With a standardized process, producer of electrical equipment can make the measurements by them self’s. As soon as end-users searching the database for a matching product the prove of the measurement and correct data is done. If appliances are unknown in the NIALM system, end-users can upload the footprints by them self’s to make life easier for other users. The database will increase transparency to the customer, it offers the opportunities for future service to improve the energy efficiency and propose better products to the customer. NIALM can boost competition between energy efficient appliances.

5. Recommendations for further action

Main task to be performed

• Use the gained knowledge from the scoping study about existing networks and communities dealing with NIALM. Set up a circle which contributes to the NIALM topic. If necessary work out a proposal to build a new community with the goal to spread the basic knowledge and understanding of NIALM.

• Standardise the NIALM measurement approach – develop procedures and measures to distinctly identify and re-identify appliances with a high matching factor independent of the environment. Agree on a set of pre-processed measurements to be used as the NIALM device footprint.

• Connectivity and Norming – boost the introduction of NIALM technology in modern in-home networks such as ZigBee by actively forming new versions of the standard. In-home networks are needed to connect metering points to the controller for data analysis and for visualization purposes.

• NIALM Database – Model definition and support of the implementation of a database for NIALM energy footprints. Development of procedures to enter and access data in a global way. Appliance data could be entered by manufactures or by end-users for quicker adoption and shall be accessible to the whole community.

6. Appendices

A) Questionnaire provided to the 4E delegates with the goal to receive the knowledge of the 4E.

The questionnaire has been sent to the 4E delegates on 26th January 2012.

With a focus on NIALM for appliance recognition, results from the questionnaires are included in this section.
The 22 official IEA-4E country delegates and their support delegates were given the opportunity to provide their views about the subject of NIALM for appliance recognition via a questionnaire (available online at http://www.surveymonkey.com/s/CZ3DZR6). The questionnaire included 9 questions: one about the person completing it, three focusing on the existing situation for NIALM for appliance recognition in the corresponding country (multiple choice questions with space to comment), and the remaining five questions, for personal opinions on directions to consider for the future (multiple choice questions providing opportunity for comments with a view from the country).
Answers were received from Austria, The Netherlands, South Africa, Sweden and Switzerland. A summary of answers received is presented below.

The first question (**Q1**) was provided to get ***information for the delegate and/or expert answering the questionnaire.*** (Alphabetic order)

- Peter Bennich, Sweden
- Roland Brüniger, Switzerland
- Theo Covary, South Africa
- Konstantin Kulterer, Austria
- Hans-Paul Siderius, Netherlands

Japan informed that it is not possible to provide information.

The second question (**Q2**) referred to the **existence of universities or research institutes working on the topic NIALM.**

Organization	Details	Comments
Sweden		
Interactive Institute	http://www.tii.se (Original) http://www.tii.se/projects/beaware Further information on the project BeAware can be found here: http://www.energyawareness.eu/beaware/	Interactive Institute is a partner of the BeAware-Project which deals with feedback systems.
Chalmers University of Technology	http://www.chalmers.se/ee/EN/personnel/bertling-lina	No information on NIALM found
Switzerland		
US-Fraunhofer Institute	Kurt Roth	Publications from

		Fraunhofer Institute have been reviewed.
Lawrence Berkley National Laboratory	Richard Brown	Works on wireless power metering.
University of Brussels	Frederic Klopfert and Quentin Jossen	Publications from Brussels have been reviewed.
Austria		
Energieinstitut, Johannes Kepler Universität, Linz	http://www.energyefficiency.at/	Some projects dealing with energy efficiency, but not explicitly on NIALM
ICT TU-Wien	https://www.ict.tuwien.ac.at/home (http://publik.tuwien.ac.at/files/PubDat_200382.pdf)	The publication, Hidden Markov model based procedure for identifying household electric loads has been reviewed.
Ars Electronica Future Lab	http://www.aec.at/futurelab/	No information found.
Netherlands		
	No specific details, reported activities years back in USA, Finland and Japan	
South Africa		
	No information provided	

The third question (**Q3**) referred to ***people knowing about NIALM, products using the technology, pilot installations or field trials.***

Organization	Details	Comments
Sweden		
Cap Gemini	http://www.se.capgemini.com/insights-and-resources/bypublication/smart_metering_the_foundation_for_smart_grid	Link doesn't work
Vattenfall	http://www.vattenfall.se	No information on NIALM found
Switzerland		
	No information provided	
Austria		
Miele Deutschland Bosch Siemens Hausgeräte	Mario Bergés from Carnegie Mellon University worked together with Bosch on the topic.	It is very difficult to receive information about research

		activities from companies.
Smart City Linz	http://smartcitylinz.at/?page_id=15	This is a project on energy efficiency in general, not on NIALM in special.
TU Graz	http://www.ifz.tugraz.at/Projekte/Energie-und-Klima/Abgeschlossene-Projekte/Smart-A	This project has load aggregation in scope. Information about NIALM was not found.
Netherlands		
	No information provided	
South Africa		
	No information provided	

Question four (**Q4**) asked about **organizations or norming bodies dealing with NIALM.**

Organization	Details	Comments
Sweden		
Swedish board for accreditation and conformity assessment	http://swedac.se/sv/	Verification pending
Switzerland		
	No information provided	
Austria		
	No information provided	
Netherlands		
	No information provided	
South Africa		
	No information provided	

Question five (**Q5**) asked about ***the categories of most interest into which the appliances could be classified.***

Aspect	AT	CH	NL	SE	ZA
Hot water (Boiler)	√	√		√	√
Cooking / Fridge / Refrigerator	√	√	√		√
Washing / Dishwasher	√	√	√	√	
Heating / Cooling / HVAC	√			√	√
Lighting / Illumination	√	√		√	
Standby	√	√		√	
Entertainment	√				√
Building Automation	√			√	
Other	BA relevant				

	for office buildings				

"Hot Water", "Cooking / Fridge / Refrigerator" and "Washing / Dishwasher" are the categories of most interest (80%) to classify the appliances into.
For 60% "Heating / Cooling / HVAC", "Lighting / Illumination" and "Standby" are important as categories for appliances.
"Entertainment" and "Building Automation" are of less importance (40%).
Austria also has selected all other choices, whereof "Building Automation" was selected in dependence of office buildings.

Question six (**Q6**) asked for ***the aim of a feedback system beside power consumption*.**

Aspect	AT	CH	NL	SE	ZA
Energy efficiency tips shall help to change habits, based on the current behaviour	(2)	(1)	(2)	(1)	(1)
Social comparison with neighbours or equivalent settings	(2)	(2)	(2)	(3)	(2)
Daily / monthly / seasonal comparison with past values	(3)	(3)	(1)	(1)	(1)
Feedback regarding appliances running outside the specification		(3)	(2)	(1)	(2)
Proposals for alternative products with less energy consumption	(1)	(1)	(3)	(2)	(1)

(1): very Important; (2): important; (3): nice; (4): not important

All choices are of some interest, at least nice. There is no choice rated not important.Energy efficiency tips, proposals for alternatives and comparison with past values are the three most important features for a feedback system besides showing actual power consumption.Energy efficiency tips are important or very important for all countries.Proposals for alternative products with less energy consumption are nice for The Netherland, important or very important in other countries.The daily, monthly or seasonal comparison with past date is very important in The Netherlands, Sweden and South Africa but nice in Austria and Switzerland.Feedback regarding appliances running outside specification is very important in Sweden, important in The Netherland and South Africa and nice in Switzerland. No answer was provided by Austria.Social comparison is the least important criteria. Except for Sweden all countries find the social comparison important.

Question seven (**Q7**) asked for***future services that might be of interestand could be realized based on an installed NIALM-system.***

Aspect	AT	CH	NL	SE	ZA
observation of appliance ageing, like HVAC systems, fridges, washing machines, dishwashers		√		√	
observation of current regulations (banning of incandescent light bulbs)					
compare single appliances with the vendor specification in global databases		√		√	√
Share your load profile and appliance activities with energy efficiency consultants	√			√	√
Other			None of above	Alternative 2 was formulated unclearly	Use results in the implement ation of the South African S&L programm e

Comparing the appliances with vendor's specification and sharing the load profile with energy efficiency consultants are the two most important services.Observation of appliance ageing is important for Switzerland and Sweden.The Netherland don't want share any information of the NIALM-system, especially for the purpose of observing current regulations. They are strictly against observation of NIALM data.Sweden stated that option "observation of current regulation" was formulated unclearly. Also The Netherland asked, what exactly was meant by this option.South Africa wants to use the NIALM-system for the implementation of the South African S&L programme which is due to be implemented in 2013.

Question eight (**Q8**) asked for ***possible hosts of global appliance databases?***

Aspect	AT	CH	NL	SE	ZA
IEA					√
NPOs like: Energy Star or Top Ten Europe		√			
Norming bodies (IEEE etc.)					√
Manufacturers					
Other	CLASP, CECED		See comment	See comment	

Only Switzerland and South Africa did select at least one option.Austria proposed two other organizations.

Sweden and The Netherland are concerned at least with the proposed organizations. Both provided additional comments.Comment from Sweden: Could be regional databases maintained by governmental bodies. At present there is a proposal that the EU Commission should run a product database, via its Joint research centre. Very important for the regulatory work. - Avoid private founded organizations, too uncertain long term management.Comment from The Netherland: The first question is whether such a database is desirable and necessary.

Question nine (**Q9**) asked for ***further ideas or fields of interest to be explored in more detail.*** Only The Netherland provided an answer: In principle NIALM should work without any further data or interference.

7. References

1. Electricity use in the home, twenty ways to save - ELAN, 2010
www.elanprogram.nu/underlag/electricity_use%20_in_the_home.pdf

2. Journal of Industrial Ecology – JoIE 2010
"Enhancing Electrical Audits in Residential Building with Nonintrusive Load Monitoring"
http://onlinelibrary.wiley.com/doi/10.1111/j.1530-9290.2010.00280.x/abstract

3. IEA: Demand Side Management Program, Task XI: Time of Use Pricing and Energy Use for Demand Management Delivery, Subtask 1 Smaller Customer Energy Saving by End Use Monitoring and Feedback -DSM, 2005
http://www.ieadsm.org/Files/Tasks/Task%20XI%20-%20Time%20of%20Use%20Pricing%20and%20Energy%20Use%20for%20Demand%20Management%20Delivery/Reports/Subtask1Report12May05.pdf

4. IEA: Demand Side Management Program, Task XXIII: Role of the Demand Side in Delivering Effective Smart Grids: -DSM, 2012
http://www.ieadsm.org/ViewTask.aspx?ID=16&Task=23&Sort=0

5. Smart Domestic Appliances in Sustainable Energy Systems - SDASES, 2008
Project Newsletter No. 3 November 2008
http://www.smart-a.org/Newsletter_3_Smart-A_FINAL.pdf

6. Watteco EnPowerMe Software - Watteco
http://www.watteco.com/index.php/component/content/article/138.html

7. Enetics – Enetics
http://www.enetics.com/prodmainSPEED.html