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SmartHouse/SmartGrid

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Smart Houses Interacting with Smart Grids to achieve next-generation energy efficiency and sustainability

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Related Readings that Document the Project

This final project report does not repeat all technical content developed within the whole research. Instead, it provides a focused overview of the main technical and scientific contributions, i.e. the developed technologies, the experiences from three field trials and the results of complementary simulation studies. The interested reader is referred to the other deliverables of the SmartHouse/SmartGrid project for an in-depth description of particular elements. In order to guide the reader through these deliverables, Table 1 provides an overview of all technical deliverables created during the project, along with a short description of its respective content.

All public deliverables are available at the SmartHouse/SmartGrid website under the publication section (http://www.smarthouse-smartgrid.eu/index.php?id=146).

Public deliverable
Restricted / confidential deliverable

No.	Deliverable name	Content	Last updated
D1.1	Requirements Analysis	Reports on the key stakeholders and their perspectives, on the key quality attributes and on the overall system requirements for the concepts developed within SmartHouse/SmartGrid. It defines nine business cases that serve as a reference for all further consideration in the trials and simulations.	Oct 2010
D1.2	Technology trends for SmartHouse/SmartGrid	Reports on the key technologies identified for the integration of smart houses and smart grids and their current state-of-the-art.	Oct 2010
D2.1	In-house architecture and interface description	Reports on in-house architectures and interface descriptions of all automated energy management devices used in the tree field trials. It includes descriptions and specifications of the Open Gateway for Energy Management Alliance OGEMA.	Dec 2009
D2.2	Coordination algorithm and architecture document	Provides a description of architectures and algorithms that will support the Smart House/Smart Grid concept; it gives an overview of the three technologies PowerMatcher, BEMI and MAGIC.	Dec 2009
D2.3	Implemented Interfaces with Technical Documentation	Provides a technical documentation of implemented interfaces for the architecture in the three field trials as defined in D2.1 and D2.2.	Oct 2010
D2.4	Enterprise Integration Document	Describes how the functionalities of smart houses (including smart metering) can be integrated into an energy retailer's business processes so as to take full advantage of the new flexibility for enhancing overall energy efficiency and competitive advantages.	Oct 2010

D2.5	Final Architecture for SmartHouse/SmartGrid	Describes the architecture that could facilitate future business cases in a smart grid, as developed within the SmartHouse/SmartGrid project. The experiences made in the project trials, as far as relevant in this context (and available at the publication date), are also described in relation to the architecture presented in this deliverable.	Mar 2011
D3.1	Common demonstrator design document	Describes the designs of each of the three field trials carried out in the SmartHouse/SmartGrid project.	Apr 2011
D3.2	Site specific demonstrator detailed design and implementation document	Specifies the detailed implementation of all field trials; in a common part, the commonalities and differences between the three distributed energy management tools used in the project are described, namely the PowerMatcher, the BEMI and the MAGIC systems.	Apr 2010
D3.3	A,B,C Field-test monitoring and control strategy evaluation document	Describes the field trial setup and analysis, results, lessons learned, and relates them to the measurable objectives for each trial individually.	Sep 2011
D3.4	General evaluation report including lessons-learned from all 3 field tests	This document sets all field trial results in relation to the overall SmartHouse/SmartGrid context and derives policy recommendations.	Sep 2011
D4.1	Case study for 1 million end-users	Discusses three country environments and customer groups, from which three scenarios are presented that serve as a basis for simulation studies that measure the mass-scale effect of SmartHouse/ SmartGrid technologies (business-as-usual scenario vs. EU EE/GHG and RE target scenario for 2020).	Oct 2010
D4.2	Report on simulation programme and results for mass application	Technical description of the software simulations and results that measure the mass-scale effect of SmartHouse/SmartGrid technologies. Presents and discusses simulation results for scenarios in the Netherlands, Greece and Germany.	Sep 2011
D4.3	Technical report on implementation on service infrastructure	Describes (i) an investment (NPV) analysis of different technologies developed within SmartHouse/SmartGrid that are applied to different business cases and (ii) the service infrastructure that an energy company that makes use of the SH/SG technology would need.	Sep 2011

Table 1: Overview of technical SmartHouse/SmartGrid deliverables

1. What SH/SG Was Aiming At

1.1. The Project's Initial Goals

The SmartHouse/SmartGrid project has affirmed the European goal of providing clean, secure and affordable energy, and set out to provide technical solutions that facilitate the integration of higher shares of such energy supplies, in this case decentralized renewable electricity sources. The project goal was to validate and test how ICT-enabled collaborative clusters of flexible smart houses can help to achieve the needed radically higher levels of sustainability and energy efficiency in Europe.

A brief problem statement for the project is summarized in the following:

> *The SmartHouse/SmartGrid project goal was to design, develop and validate new ICT-based, market-oriented and decentralized control concepts for the electricity system in Europe. These concepts will support the efficient integration of energy loads – such as private homes – and distributed generators – such as small renewable energy sources or CHP units – into a service-oriented electricity infrastructure.*

The intention of the project was to introduce a holistic concept for smart houses situated and intelligently managed within their broader environment. Smart houses should become capable communicating, interacting and negotiating with the energy utility on the one hand and with the single consumer devices and appliances on the other hand. Through this, the customer's flexibility in electricity usage (and generation in the case of a prosumer) can be exploited so as to raise the overall energy efficiency in the grid area.

The technologies developed within the project were supposed (i) to be based on available open industry standards from both the ICT and energy sectors and (ii) to employ communication and computing capabilities that are already in widespread use in mainstream home and working environments. This is important for keeping implementation costs low and for being able to test the technologies in the field during the project.

The technological challenges that the SmartHouse/SmartGrid project aimed to address were the following:

> *The envisioned SmartHouse/SmartGrid technologies are intelligent agent and e-market techniques for decentralized control and optimization at the network level. This comprises:*
>
> - *Intelligent customer-interactive in-house technology that provides energy management for smart houses using real-time information such as dynamic tariffs and metering data*
> - *Interface technology that technically aggregates and integrates smart houses into larger intelligent local networks interacting with the electricity grid*
> - *Agent-based distributed control technology that is able to monitor and optimally control large numbers of energy consuming and producing devices in a fully decentralized and bottom-up fashion*
> - *Electronic market and forecasting techniques that automatically optimizes the operation of clusters of smart houses on the basis of negotiated needs, priorities, and interests*

Each of the three SmartHouse/SmartGrid field trials was designed to deliver proof of concept of a specific aspect of the new technology:

- Scalability: The capability to handle the large-scale communication, negotiation and information exchange between many thousands of smart energy devices at the same time (carried out in the Netherlands).
- Usability: The capability to intelligently interact with the customer (such as home owners) and deliver optimal home energy management as a response (carried out in Germany).
- Applicability: The capability to control smart energy devices in a fully decentralized and bottom-up way such that optimum energy efficiency and security of supply at is achieved (carried out in Greece).

On the basis of the results and experiences from these field experiments, another project objective was to define a roadmap to mass application of the SmartHouse/SmartGrid technology.

1.2. Measurable Objectives

The SmartHouse/SmartGrid project has set itself some measurable objectives that help to quantify the (expected) impact of the developed technologies and their contribution to achieving Europe's objective to save 20% of energy consumption by 2020. These objectives are decomposed into four distinct categories which should be briefly summarized here again.

Measurable Objective A

"The developed ICT technical functionality works under real-life field conditions."

Detailed measures:

- *Scalability (A.1)*
- *Ease of use and responsiveness to end users (A.2)*
- *Real-time control flexibility and optimality (A.3)*

Measurable Objective B

"The developed ICT technology is affordable."

Detailed measures:

- *Affordability in terms of the knowledge & time resources required from end users (B.1)*
- *Affordability in terms of financial investment and operational costs (B.2)*

Measurable Objective C

"The developed technology has significant potential for mass application across Europe."

Detailed measures:

- *Low entry barriers regarding adoption and diffusion of the technology (C.1)*
- *Solid business case for energy utilities and energy service providers (C.2)*

Measurable Objective D

"The developed technology is able to achieve aggregate energy efficiency gains."

Detailed measures:

- *Efficiency gains through interactive feedback to users on optimal energy use (D.1)*
- *Gains as a result of optimized energy management of devices (D.2)*
- *Reduction of power grid losses (D.3)*
- *Raising the accommodation ceiling of local networks for local generation (D.4)*

In **measurable objective A**, it should be investigated whether the developed intelligent communication and negotiation architectures are able to handle large numbers energy devices simultaneously, whether they offer easy and adequate end-user interaction and whether they actually contribute to a more efficient operation in the electricity system, especially by integrating renewable generation intelligently. All these aspects are necessary technical prerequisites for the deployment of the developed concepts and technologies, so it is important to measure in how far the developed ICT concepts comply with these objectives.

In **measurable objective B**, it should be investigated in how far the developed technologies have a potential to be accepted both by investors and by end-users. For this, they have to be available at low investment and operational costs and skill level required by the end-user to use the technologies have to be low.

In **measurable objective C**, it should be investigated in how far the developed technologies have a potential large-scale adoption. Low entry barriers and positive business cases are important for mass adoption; these are investigated through this measurable objective.

The necessary gains in energy efficiency cannot be achieved by just looking at the level of individual units and only local intelligence in homes. Important energy efficiency gains will rather ensue from a combination of measures that takes the full energy demand-and-supply network into account. It is here, at the level of network intelligence, that ICT-enabled solutions will have their utmost added value, and are even unique in this because there is simply no other technical alternative in sight. The efficiency gains achieved through SmartHouse/SmartGrid technologies should be measured through the **measurable objective D**.

In the project, many of the given objectives were measured from the specific test plans of the three field trials that were carried out. Some measurements, especially the holistic system-wide questions like those listed in objective D, could not be done on the basis of the small-scale trials (which involve in the order of 10-100 households, respectively). Therefore, additional mass-scale scenario simulations were run in order to provide insights that help quantifying the further measurable objectives. Through this combination, an integrated view on the combined gains that can be achieved via the SmartHouse/SmartGrid concepts could be provided and will be summarized in this final report.

2. The Way How SH/SG Technologies Were Designed

The project lends from several smart grid concepts developed at different research institutes. These are, namely, the following three concepts:

- The PowerMatcher developed at the Energy Research Center of the Netherlands, ECN[3]
- The Bi-Directional Energy Management Interface BEMI developed at the Fraunhofer Institute for Wind Energy and Energy System Technology IWES
- The MAGIC system developed at the Institute of Communication and Computer Systems at the National Technical University of Athens

These three technologies were further developed within the project, and synergies between the approaches were identified. They all share one control paradigm which can be summarized as follows:

> *The concept of the project is to combine centralized and decentralized control approaches with the following philosophy: Let the end-customer decide as much as possible within his or her private grid. Therefore, offer the end-customer the online tools with appropriate boundary conditions and incentives to optimize his or her energy interface to the outside world according to actual (dynamic) prices and energy efficiency considerations that reflect the real-time needs of the public grid. To this end, provide centralized information but allow for decentralized decisions.*

The procedure for developing the SmartHouse/SmartGrid technologies followed a stringent approach. First, a set of business cases was defined that served as a reference for evaluating the usefulness of the technologies; these are described in Section 2.1. In parallel, the state-of-the-art of technologies relevant for the project was reviewed (see Section 2.2). Finally, the technologies were (further) developed and are briefly described here in Section 2.3.

2.1. Business Cases

The technological developments in the SmartHouse/SmartGrid project have been based on nine business cases that describe how smart grid approaches could be applied by single stakeholders in the electricity supply business. As shown in Figure 1, not all business cases are applicable to all stakeholders, but each stakeholder has more than one business case that he can apply. Table 2 summarizes the nine business cases. Detailed descriptions of them are given in deliverable D1.1.

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[3] The PowerMatcher team at ECN was recently taken over by TNO, the Netherlands Organization for Applied Scientific Research.

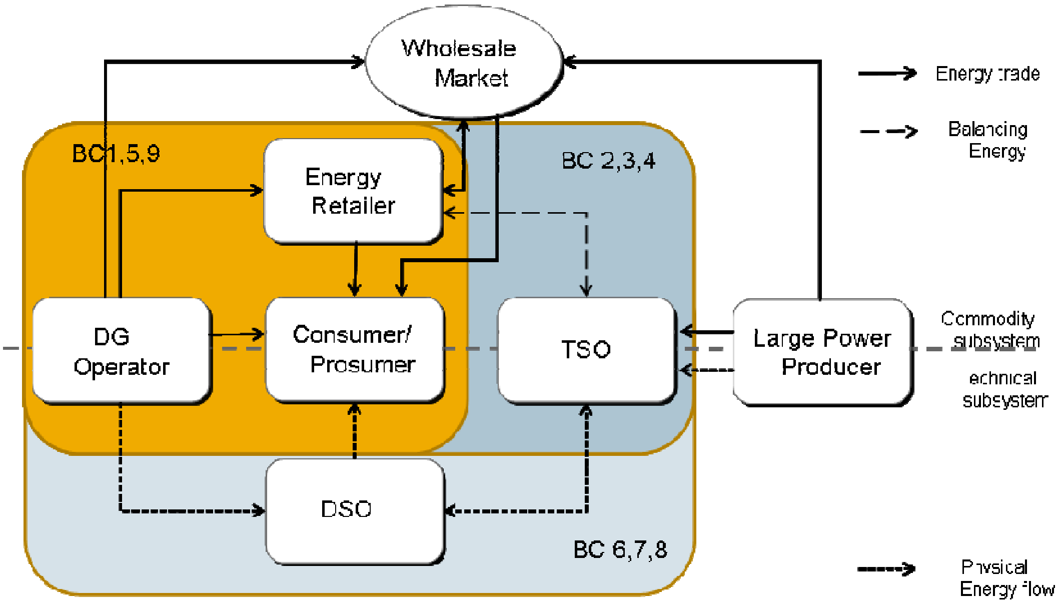

Figure 1: Mapping the business cases to the market participants

In the SmartHouse/SmartGrid project, nine business cases have been described. They formed the first step towards the architectural design of the ICT systems developed within the project. A short description of each case is provided in the following subsections 0 through 0. A more detailed description of each case is given in the project deliverable D1.1, which is publicly available at the project website.[4]

No	Name	Short description
1	Aggregation of houses as intelligently networked collaborations	When SmartHouses are able to communicate, interact and negotiate with both customers and energy devices in the local grid, the electricity system can be operated more efficiently, because consumption can be better adapted to the available energy supply, even when the proportion of variable renewable generation is high. A commercial aggregator could exercise the task of jointly coordinating the energy use of the smart houses or commercial consumers that have a contract with him (either via direct control of one or several participating devices or through providing incentives to the participating devices, so that they will behave in the desired way with a high probability, but not with certainty.
2	Real-Time imbalance reduction of a retail portfolio	This business case is rooted in the balancing mechanism as applied in Europe and defined by the ETSO Scheduling System.[5] It focuses on the balancing actions by a BRP during the balancing settlement period. The key-idea of this business case is the utilization of real-time flexibility of end-user customers to balance the BRP portfolio, instead of using traditional power plants. For each control zone, the BRP aggregates all its contracted flexible distributed generation and responsive loads in a *virtual power plant* (VPP). The BRP uses the VPP for its real-time balancing actions.

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[4] All public deliverables and further project related publications are accessible at http://www.smarthouse-smartgrid.eu/index.php?id=146

[5] For a description of this scheduling system, see D1.1 and D2.5.

3	Offering (secondary) reserve capacity to the TSO	This business case is rooted in the ancillary services as initiated by TSOs throughout the world. In this business case, the BRP should be able to offer its flexible demand and supply on the reserve market. In order to enable BRPs to offer flexible demand and supply on the reserve market, their bids have to fit into the above market structure. The key-idea of this business case is the utilization of real-time flexibility of end-users (prosumers) in balancing a control zone. For each control zone, market parties aggregate these flexible distributed generation and responsive loads in a *virtual power plant* (VPP). The TSO contracts in real-time part of these flexible loads for its real-time balancing actions.
4	Distribution system congestion management	This business case aims at deferral of grid reinforcements and enhancement of network utilization. The need clearly arises in areas with a large amount of distributed generation near one location. Non-coordinated control of (new) electric devices (e.g. heat pumps, electric cars) may lead to a sharp rise in needed capacity on lines and transformers. By coordination of these devices, they can be allocated timeslots for operation that are spread out over time. Furthermore, coordination can increase the simultaneousness of local supply and demand in case local generation is integrated. Congestion management as a service can used to better match own generation and consumption for prosumers; besides, distribution system operators (DSO) may be interested in improving the quality of supply in areas with restricted capacity in lines and transformers.
5	Variable tariff-based load and generation shifting	In well-functioning and liquid markets, the expectations of all market participants about the generation and consumption situation of the next day are well reflected in day-ahead power exchange prices. If these wholesale prices are passed over to the end-users, these have an incentive to shift loads from high-price times to times of lower prices. The key idea of the business case is, thus, to provide the customer with a variable price profile on the day before power delivery. At the customer’s premise, an energy management system should receive the price signal and determine the optimal timing for the energy consumption (or generation, for prosumers) of those appliances that can be shifted in time or that have a storage characteristic. The main value driver from the customers’ perspective is to receive a tariff and a technology which reduce their energy bills. The value driver from the retailer’s perspective is the opportunity to reduce his procurement.
6	Energy Usage Monitoring and Optimization Services for End-Consumers	Awareness of one’s energy use can stimulate behavioral changes towards energy savings. Personalized and well targeted advice on how to save energy can help further exploit the savings potential. This business case therefore suggests providing customers with detailed and comprehensible information about their own energy consumption. The additional value to the customer provided by the described information services can either be remunerated through additional fees or through enhanced customer loyalty. A combination of both is also conceivable.
7	Distribution Grid Cell Islanding in Case of Higher-System Instability	The key idea of this business case is to allow the operation of a grid cell in island mode in case of higher-system instability in a market environment. This business case considers that the islanding procedure is performed automatically. Technically, it involves monitoring and forecasting the available distributed generation and the loads and creating a load shedding schedule based on to the criticality of the consumption loads and on the customers’ willingness to pay for running the appliance during the island

		mode. During an event, decisions are taken how many and which loads have to be shed in order to maintain an island mode steadily. Grid cell islanding is of value to the DSO. Islanding helps him to quickly restore system stability within his grid area.
8	Black-Start Support from Smart Houses	The key idea of this business case is to support the black-start operation of the main grid. It considers that after a black-out, the local grid is also out of operation and the main goal is to start up quickly in island mode and then to reconnect with the upstream network in order to provide energy to the system. Black-start support is of value both to the DSO and the consumer. Flexible demand helps the DSO to restore system stability.
9	Integration of Forecasting Techniques and Tools for Convenient Participation in a Common Energy Market Platform	The volatility of the production level of distributed energy resources makes forecasting a necessary tool for market participation. The actor with the lowest forecasting error will have the most efficient market participation. This business case provides benefit for both the consumer and the aggregator. The aggregator has the ability to participate accurately in the wholesale market and gain by reducing the uncertainties. The consumer benefits from lower prices. However, it requires the participation of the consumers, since an accurate forecast requires online monitoring of the DER and not simply reading from the smart meter. The business case comprises of the data collection which is the most critical part that may lead to a correct forecast. The second part is the data evaluation and processing, e.g. for extracting a wind power prediction valid for a certain region.

Table 2: The nine SmartHouse/SmartGrid business cases

2.2. State-of-the-Art

The information representation and communication standards relevant and necessary to the integration of smart houses and smart grids can be grouped into three main categories, which have been reviewed at different points in the project:

- In-house technologies
- House-to-grid technologies
- House/grid-to-enterprise technologies

In-house technologies are used mostly for monitoring, control and management of devices within the smart house itself, as well as for extraction and usage of internal and external information for the smart house; these include mostly monitoring, but also control capabilities. Possible in-house communication technologies and their current development status have been reviewed in deliverable D1.2. The technological concepts for in-house technologies within the SmartHouse/SmartGrid project have been discussed in deliverable D2.1; a short summary of this work is given Section 2.3.2.

House-to-grid technologies are mostly used to interconnect houses, and to connect houses to grid operators and utilities, thus enabling an information exchange among them. They also include monitoring, but mostly take over control capabilities. Wide-area communication technologies that facilitate house-to-grid interaction are reviewed in deliverable D1.2. The actual technical realization chosen in the field trials is reported in the deliverables of work package 3 and, in summary, in Section 3 of this report.

House/grid-to-enterprise technologies are mainly used to couple the information generated within the smart house or the smart grid with enterprise services. As such, the nature of these technologies primarily targets monitoring, while it also supports the management of the infrastructure via decision support functionality that can be used to apply control strategies. SmartHouse/SmartGrid concepts for house/grid-to-enterprise communication have been described in deliverable D2.4 (and summarized here in Section 2.3.4(; the required underlying wide-area communication technologies are basically the same as for house-to-grid, as reviewed in deliverable D1.2.

A move towards more intelligent devices that can provide information in an interoperable way to 3rd parties as well as adjust their energy behavior in a flexible manner is a must. It is expected that in the next years, such appliances as well as industrial devices will be available on the market and that could communicate via Internet technologies e.g. web services. This will enable a new generation of smart applications to be developed. Existing standards (described in deliverable D1.2) such as DPWS, ZigBee, 6LoWPAN etc. would play a key role towards this direction. Special focus should be given to open approaches and Internet based technologies, as the smart grid is seen as part of a larger ecosystem strongly related to the Internet technologies and approaches.

Finally, great expectations are put on the market driven approaches as well as the possibility to open the access via standardized interfaces. Towards this end, work carried out in fora such as OASIS and in detail within the OASIS Energy Interoperation TC and OASIS Energy Market Information Exchange (eMIX) TC.

Deployment of Demand Response Schemes in Europe

In **Greece**, PPC currently evaluates several scenarios related to the development of a new service portfolio, by introducing new products in its supply division, aiming at introducing versatile tools for the demand side management, which is of the utmost importance for defending its supply market share. The products examined include new pricing schemes (i.e. fixed / indexed price or discounts schemes), enhanced features like multiple tariff, interruptible tariffs, prepaid schemes, green energy or loyalty programmes, web services for information and sale / after sale services, energy saving/efficiency services and automated energy management systems. The existing regulating environment imposes important hurdles for the implementation of many of these products, especially the ones related to tariffs. PPC is currently offering night time tariffs, with lower prices for residential customers during the night. Under negotiation are also several tailor-made tariff schemes with MV and HV customers, in order to allow smoothing of their demand curve by time-shifting loads from peak hours to valleys. In the summer, where Greece during the last few years is experiencing a shortage of power, there are incentives for MV and HV customers to allow power cuts, with the benefit of price discounts.

Typical time-varying tariffs in **Germany** are offered for customers who have night storage heaters, where the tariff during night hours is considerably lower than during daytime. Real-time pricing is deployed only in some small-scale field tests (cp. “Energiebutler” by MVV). Other small-scale examples are e.g. a demand side management program provided by a public services company in Saarbrücken, who shuts off contracted deep-freezers and refrigerators in supermarkets for 1-2 hours when load is high. These cooling devices cool down deeper in times of lower load. Another example is a chemical factory in Wilhelmshaven. Here, the utility can deliver up to 30 MW less power for a certain duration that has been agreed upon beforehand. Up to now, there are only singular demand side management programs in Germany, and few initiatives to deploy this rationale on a large scale. Besides these small scale activities and field trials, a larger series of field trials is currently in the preparation phase or has already started in the framework of six model regions within the E-Energy research scheme[6] co-funded by the national ministry for economics. The projects continue until the end of 2012 and much experience will be available by then.

In **the Netherlands**, small consumers can apply for a double tariff meter to be installed. During off-peak time (night, weekend), a much lower tariff is offered to the end-user, giving him the incentive to shift electricity use to these periods. The total potential for demand response in Dutch households has been estimated at 700–1,200 MW [SenterNovem 2004]; for the wholesale sector it is estimated at 1,730 MW, of which 1,200 MW is industrial and 425 MW in the horticulture sector [Deloitte 2004]. In the Netherlands, the horticulture sector has a large share of CHP installed. Fed by gas, they produce heat, light, CO_2 (for plant growth) and electricity. By installing large heat buffers and CO_2 tanks, a lot of flexibility is available for electricity

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[6] http://www.e-energy.de/

production. Although the capacity for each party is relatively small, as an aggregated group this flexibility is already utilized in today's wholesale market. Future residential demand response potential is expected to come from plug-in hybrid electric vehicles, electric heat pumps and air conditioning.

Standardization and Interoperability

Standards are a necessary part of the smart grid. The goal of such activities is to help with independence of single suppliers (commoditization), compatibility, interoperability, safety, repeatability, or quality. Worldwide, many standardisation initiatives try to create this prerequisite for the deployment of smart meter, smart grids and smart houses. The European Union recently issued the Mandate M490, which requests CEN, CENELEC, and ETSI to develop a framework to enable European standardisation organisations to perform continuous standard enhancement and development in the field of smart grids, while maintaining transverse consistency and promote continuous innovation. This activity has started after the SH/SG state-of-the-art review and was therefore not described in earlier deliverables; however, the activities are closely monitored by the consortium partners. Other activities that single consortium members are either engaged in or found worth having a closer look at contain the following:

- The standard **IEC 61850** was first introduced for substation communication, but is now preferred by IEC as the "seamless telecontrol communication architecture" for the future communication within the electrical energy supply [Schwarz 2002]. One of the most important features of this standard is the separation of the definition of data models (specifying what content is transmitted and what it means) and the underlying protocols defining how the data shall be transmitted. This concept allows for the extension of the standard to new applications by defining the appropriate data models quite easily. Data models as part of the IEC 61850 family have been approved for wind power plants (IEC 61400-25) and hydro power (IEC 61850-7-410). IEC 61850-7-420 for communication to distributed generation units will probably be available as approved standard within the first half year of 2009. This new chapter also defines basic data models for energy management including operational modes, set point curves and price profiles for electricity production and demand as well as ancillary services.
- The **IPSO Alliance**[7] was formed in August 2008 with the objective of continuously increasing the base to support and supplement the IP on every device like sensors and actuators for home automation and other applications. The smart grid, "smart cities", home and building automation, industrial applications, asset tracking, utility metering etc. are all taking of IP's rich history and adaptability. The IPSO alliance will perform interoperability tests, document the use of new IP-based technologies, conduct marketing activities and serve as an information repository for users seeking to understand the role of IP in networks of physical objects. Their goal is to promote IP as the premier solution for access and communication for smart objects.
- The **Open Gateway Energy Management Alliance (OGEMA)** provides an open software platform for energy management which links the customer's loads and generators to the control stations of the power supply system and includes a customer display for user-interaction. In this way end customers will be able to automatically observe the future variable price of electricity and shift energy consumption to times when the price is low. All developers and involved parties can turn their ideas for more efficient energy usage by automation into software for the gateway platform. Activities for developing the OGEMA specifications further are also run in the framework of the SmartHouse/SmartGrid project. The current status of the work is documented on the alliance website[8], and is also appended to this deliverable.
- The **Organization for Advancement of Structured Information Standards (OASIS)** is a non-profit consortium that has been developing open standards for e-business and web services since 1993. The OASIS Blue initiative focuses on smart energy. The Open Building Information Exchange (oBIX)

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[7] http://www.ipso-alliance.org/

[8] http://www.ogemalliance.org

committee focuses on the interface between the mechanical and electrical control systems (e.g. building management systems, HVAC systems), and enterprise systems. The OASIS Energy Interoperation committee focuses on the interaction between smart grids and their end nodes, for instance, smart building, industry, and more importantly homes. Furthermore, it aims to develop communication protocols to exchange important information such as dynamic price signals, reliability signal, emergency signals, market participation information (e.g. bids) and load predictability and generation information. Thus facilitate many of the envisioned enterprise level services such as emergency response, energy management and trading.

- The **Open Automated Demand Response Communication Standard (OpenADR)** began in 2002 following the California electricity crisis, and is an open standards-based communications data model designed to facilitate the sending and receiving of DR signals. It provides a suite of functions and capabilities used for automated exchange of DR information between utilities or network operators and their participants. The standard defines an interface and functions of a Demand Response Automation Server (DRAS) used to facilitate the automation of customer response. The DRAS is an infrastructure component in Automated Demand Response Programs that facilitates the communications among entities. The purpose of the DRAS is to automate the various communications channels necessary for Automated Demand Response programs and dynamic pricing. Such communications include varied price and reliability related messages and information that are sent from utilities / grid operators to the various parties that manage the consumption of electricity in order to curtail the consumption of electricity during peak periods.

2.3. SH/SG Technologies

2.3.1. The Overall Architecture

The SmartHouse/SmartGrid architecture has to account for the heterogeneity of concepts developed and tested within the project. One major overarching paradigm that has to be reflected is the distributed control paradigm. Following this, there needs to be some distributed decision making at the house level, which is facilitated through an appropriate in-house architecture (see Section 2.3.2), in combination with global coordination (Section 2.3.3). The latter, in turn, facilitates a business case of some involved enterprise (Section 2.3.4).

In the SmartHouse/SmartGrid projects, three different technologies for managing demand and supply in a way to realize the goals of an energy efficient, flexible and sustainable smart grid are developed. Table 3 summarizes the main characteristics of the three technologies PowerMatcher, BEMI and MAGIC.

PowerMatcher	BEMI	MAGIC
Basic concepts		
• Decentralized decision making about consumption and production • Decision-making based on centralized market equilibrium of all bids • Real-time mapping of demand and supply • Automated control of production and consumption units • Scalable architecture	• Decentralized decision making about consumption and production • Decision-making based on centralized tariff decision • Mapping demand to available supply • Automated control of consumption units • User-information for manual control of consumption behaviour	• Decentralized decision making about consumption and production • Decision-making based on centralized negotiation of requests • Mapping of demand and supply • Automated control of production and consumption units

PowerMatcher	BEMI	MAGIC
Methodology		
• Market-based concept for demand and supply management • General equilibrium theory • Market is distributed in a tree structure • Participants: devices, concentrators, objective agents, auctioneer • Device agents submit bids / demand and supply functions • Auctioneer determines prices • Round-based market place	• BEMI allows to decide decentrally based on tariff information • Decision consists of local information about devices and central information about variable prices • Pool-BEMI sends price profiles • "Avalanching" can be avoided by giving different price profiles to different customer gouprs • Day-ahead announcement of price profiles	• MAS-based using JADE (negotiation-based) • Grid announces SP/BP • MG tries to agree on "better" prices • Maximum of internal benefit • Based on symmetric assignment problem • Agents use reinforcement learning • Adapted Q-Learning • Three states (in|out|no exchange) • Number of involved agents differs with the action to take

Table 3: Overview of the SmartHouse/SmartGrid technologies

There are some important commonalities between the technologies developed within SmartHouse/SmartGrid. As already depicted in Table 3 in the row "basic concepts", it can be recognized that the common idea of the SmartHouse/SmartGrid implementation follows a unified approach: PowerMatcher, BEMI as well as MAGIC manage demand and supply on the basis of a centralized optimization tool that works with decentralized decision making. This is highly important for the acceptability of these technologies – each participant keeps full control over his devices, but has incentives to align the device operation with the global status of the overall system.

Each of the three technologies is based on the concept to map the consumption demand to the producible or produced energy. On the one hand, the consumed energy amount needs to be adjusted in an appropriate way. This adjustment of the energy amount to be consumed is possible by deploying several features like automatically switching on and off consuming devices or manually influencing the consumer's behavior. These features are part of all the three architectures especially the automated switching of the controllable devices in the households. The control of the shiftable production of energy is in a similar way possible by means of automated on and off switching features for e.g. CHP producers.

Each of the concepts includes a central negotiation or calculation mechanism that tries to map the producible energy to the consumable energy for all sources (smart houses and production sites) within the enclosed smart grid. External production sites producing and providing a certain amount of energy can be included in the negotiation process as a fixed and non-controllable amount of energy. Therefore, the architecture of all three set-ups contains some central coordination mechanism.

The way how the three coordination mechanisms are designed is similar from a high-level perspective, but different in the details. Each tool either collects information or forecasts the desired amounts of energy to be consumed or produced from all participating smart houses and production sites. Each tool is able to understand besides the desired energy amounts some indicators that state under which conditions the energy will be consumed or produced. One condition is used for all of the three tools: It is a piece of information about the desired price, if energy is shiftable. After having collected all offers and requests the tool analyses together how the equilibrium can be reached under the sent conditions.

One major difference between the negotiation procedures is the time interval for the repetition of the negotiations and therefore for the consideration of unforeseeable changes. The PowerMatcher and also the

MAGIC system can work in (near) real-time. The advantage is that for unforeseeable demand or production requests a short reaction time can be expected to map the complementary production or demand requests. The BEMI technology, in contrast, works on a time scale of a day, where day–ahead considerations of production and consumption patterns are done in order to define the price levels that act as decision guiding signals.

Finally, the field trials will demonstrate if a lower repetition of equilibrium calculations is sufficient. The near real-time negotiation causes a high degree of scalability and performance requirements. The PowerMatcher tool does the real-time negotiation using a multi-level approach realized by the use of agents clustering several smart houses or concentrator levels stepwise. For a lower number of smart houses, the concept of real-time could scale easily, but for a higher number of smart houses the concept has to be proved.

Decentralized decisions about consumption and production are made by all of the three field trials. This fact is the main common part of the three architectures. The control of switching on or off of a certain producing or consuming device is always done within the smart house itself. Even when for the smart house a central control is established, the decision remains within the house. Of course the decision is guided by a centralized determined and provided signal (e.g. virtual price signal or a real-time tariff / price structure or direct control signals).

Due do the difference between the technologies, SmartHouse/SmartGrid does not have a common architecture in the classical notion, but an amalgamation of heterogeneous approaches that are "glued" together with SOA. This is compatible with the future smart grid vision as we do not expect that a single architecture will prevail; rather several heterogeneous approaches will be applied but all of them will exchange information at higher level via common standardized approaches such as those enabled by web services (WS-* standards).

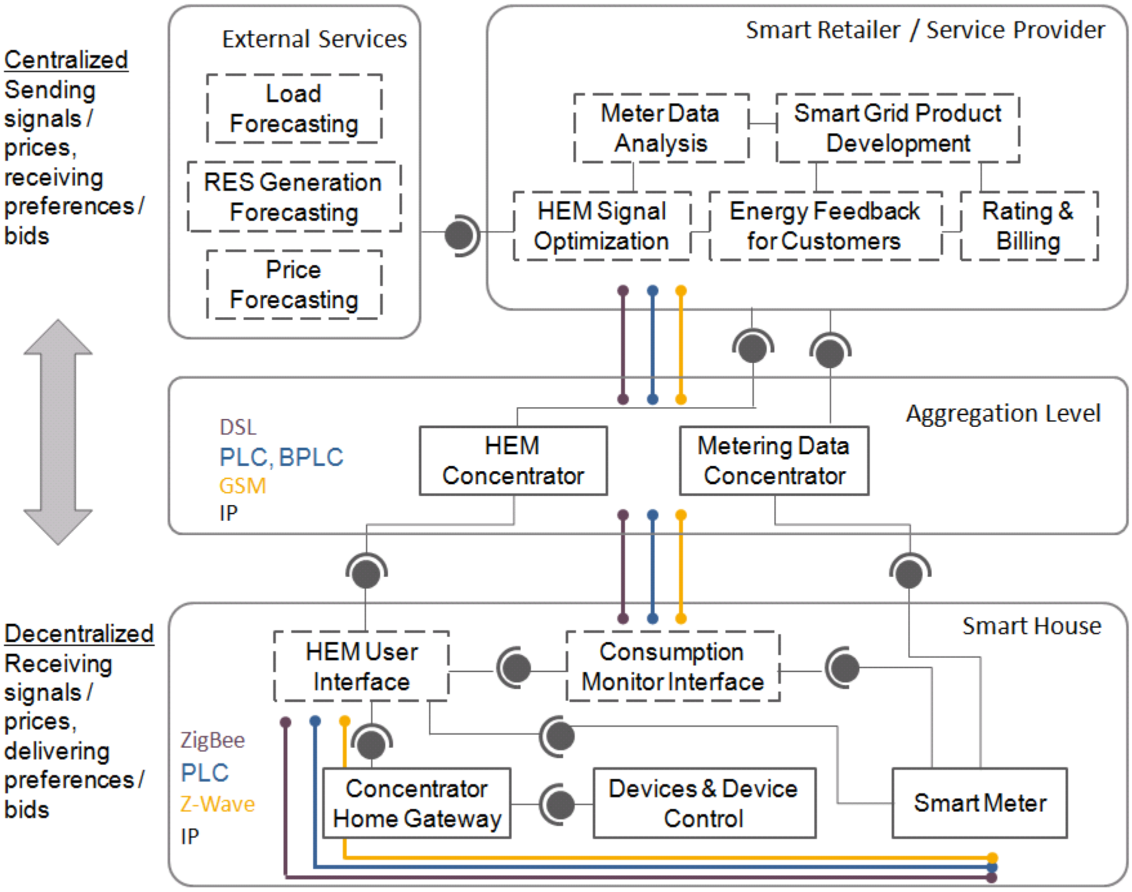

Figure 2: Architecture of loose coupling via services

2.3.2. In-House Architecture

In general, the in-house architecture consists of:

- Intelligent nodes/agents that perform communication and control operations over these communication systems. In some cases, these nodes just perform basic control functions such as temperature surveillance or switching commands from the home automation systems, in other cases (such as the PowerMatcher concept), each node is a real intelligent agent.
- A dedicated communication gateway to the outside world, which exists in most cases. In concepts such as BEMI, the communication gateway is at the same time the in-house manager, in other concepts it is just a communication gateway without higher control capabilities than other agents in the house.
- Several devices operated by the customer and measurement nodes. In general, the meter can be considered a measurement node though having a special role for most business cases.
- A user interface

An in-house architecture should provide an environment for applications in the area of energy management and energy efficiency at the customer's place. It should allow for access to devices and other hardware functionalities that are connected to the system via standardized data models or device service models; in the future, automated registration of new devices based on standardized data models and device services would be further desirable developments. Further (future) tasks of in-house technologies are to make data provided from outside the communication gateway that might be relevant to various applications (such as the price of electricity) accessible based on standardized data models, to define standardized software services of the communication gateway middleware ("framework") for using these data models and device services and to provide standardized software services for functionality that will be needed for many applications: the user web interface, persistent storage of certain types of data and logging.

From these goals, several architectural elements (Applications, Resources, Communication drivers and API Services) of the framework can be identified (see Figure 3). It comprises of several components:

- **Application** – a piece of software that is able to run in the environment of the in-house framework. In contrast to a communication system driver, it is not used to enable the physical connection to hardware.
- **Resource** – a representation of states, parameters or other data generated outside the system; a resource can either represent a physical device, a communication system and its parameters/state or data transmitted to the system from a control station, such as a price profile.
- **Resource Type** – a model definition for *resources*. In order to enable automated device identification and plug&play, standardized resource types have to be used on all framework implementations. However, it shall be possible to add new *resource types* to a framework when standardized types are available. In an object oriented perspective, this is the class description of which the *resources* are instances.
- **Communication System** – which is able to connect the data representation of a *resource* with the actual physical device it represents or with the external data source (e.g. the control station delivering the price profile). In this way, the information of the physical connection of each resource is made transparent to the rest of the framework as it is processed solely by the *communication system*. Each connection links one data element of a resource to an address of a communication system.
- **APIService** – the framework needs to offer several functionalities to the *applications* and *communication systems*. These services can be grouped into the administration of *resources*, the administration of *applications*, the system time they are using and the way they are executed, services for persistent storage of preferences data of *applications* and of data structures that are commonly needed by applications in the area of energy management and efficiency, access to a user interface and services for logging and evaluation of text log messages as well as of measurement data series. The *APIService* is the entity of all modules of services of the framework. Further services available to *applications* and *communication systems*

can be provided by *applications*, but the services of the *APIService* can be expected on every framework implementation, thus being a base set for interoperability.

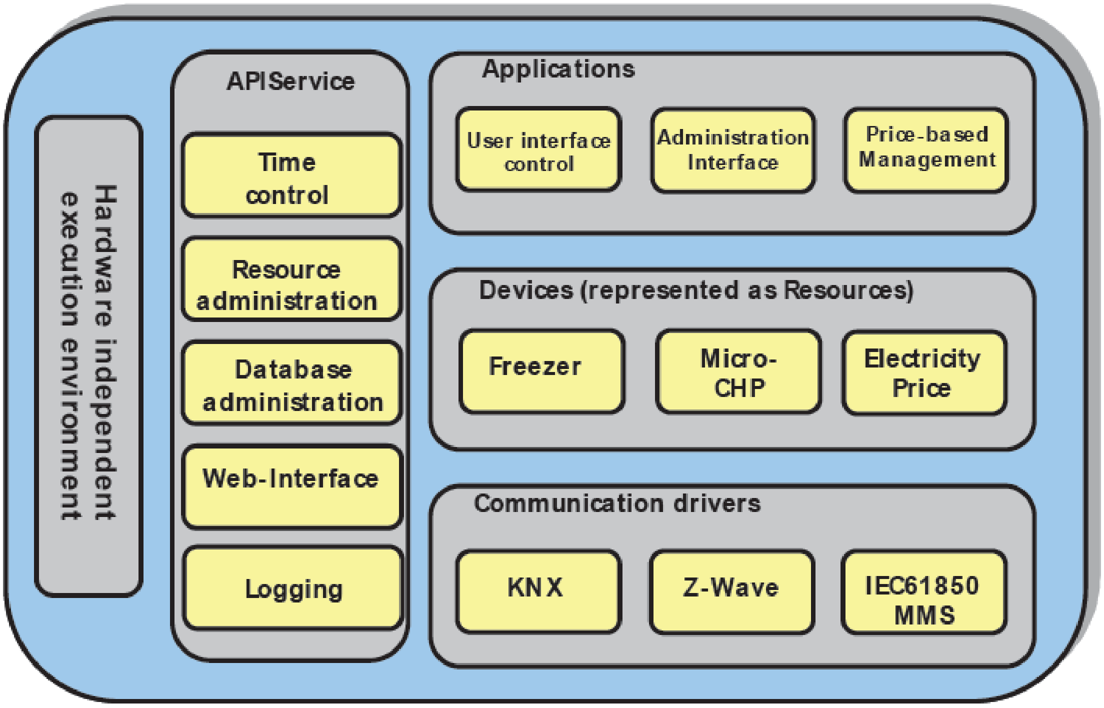

Figure 3: Communication gateway middleware – schematic overview

In order to define and develop a standard for the in-house services, Fraunhofer IWES has started the Open Gateway for Energy Management Alliance (OGEMA)[9] in September 2009. The scope of this alliance is to provide an open software framework for energy management in the building sector, including private buildings and households. This framework is to be run on a central building gateway which serves as the interface between the smart house and the smart grid, allowing for integration of parallel running applications from different manufacturers in the area of energy management and energy efficiency. The development of a reference implementation for this framework is also goal of OGEMA and will continued also after the end of the SmartHouse/SmartGrid project.

2.3.3. Coordination Algorithms

As for the coordination approaches in SmartHouse/SmartGrid, three different complementary approaches have been followed:

The **PowerMatcher**: In this concept, a large number of agents are competitively negotiating and trading on an electronic market with the purpose to optimally achieve their local control action goals. In the market-based optimization, the optimal solution is found by running an electronic equilibrium market and communicating the resulting market price back to the local control agents. The PowerMatcher concept has been described in detail in deliverable D2.2 and in other deliverables. More information on the PowerMatcher is provided under http://www.powermatcher.org/. Another valuable source is the article by [Kok et al. 2009]. The PowerMatcher technology has already been proven in several field trials in real-life circumstances and with different commercial and/or technical control goals (e.g. in the CRISP[10] and Integral[11]).

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[9] http://www.ogemalliance.org

[10] http://www.crisp.ecn.nl/

[11] http://integral-eu.com/

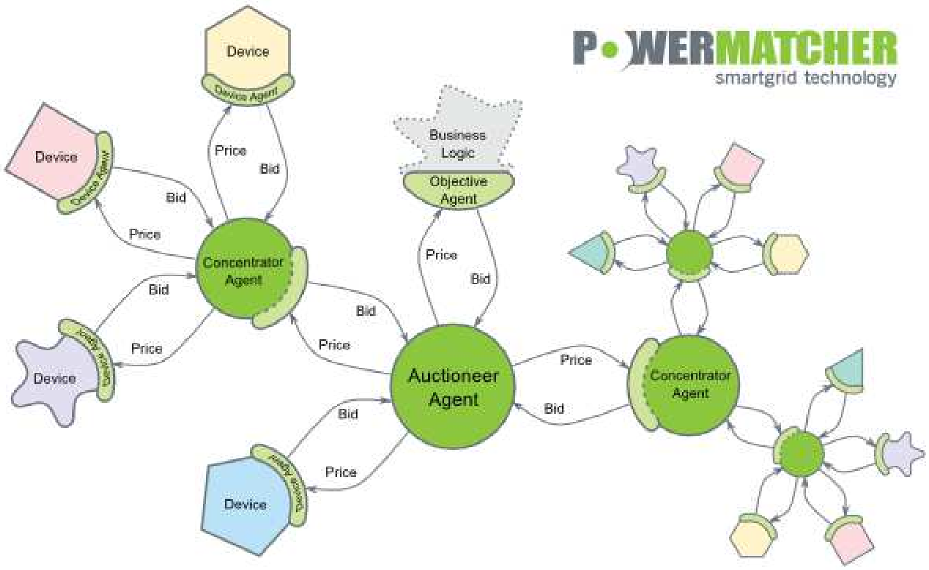

Figure 4: Schema of the PowerMatcher technology

The **Bidirectional Energy Management Interface BEMI** uses an energy management approach that is organized in a decentralized way and avoids a central control of the individual loads and DER. In this approach, every decentralized market participant operates a bi-directional energy management interface which optimizes the local power consumption and generation automatically, depending on local as well as central information like e.g. variable tariffs. The BEMI concept has been described in detail in deliverable D2.2 and in other deliverables. A good overview of the technology is also provided in [Nestle/Ringelstein 2009].

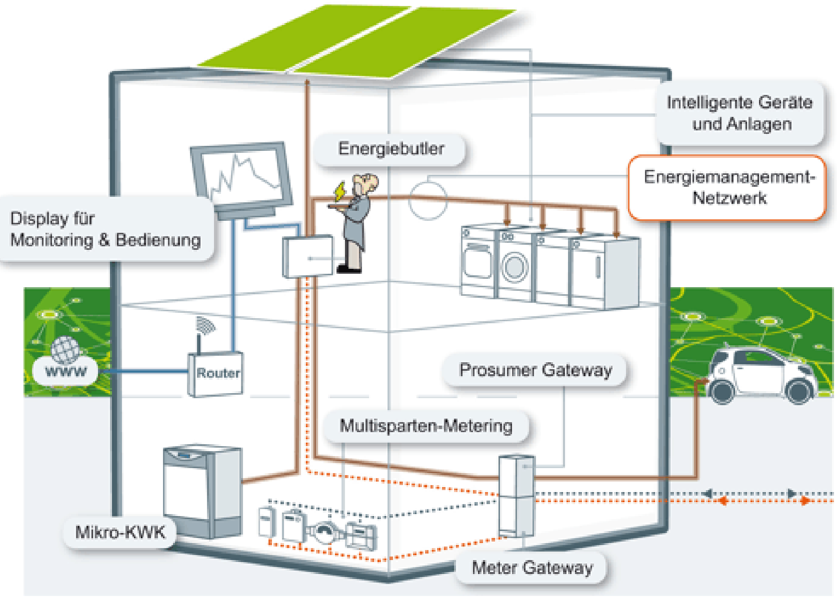

Figure 5: Schema of the BEMI technology

The **MAGIC** system provides a different approach that enables the coordination of the actors. The system provides an architecture that supports complex interactions between the agents based on an advanced agent communication language. The system is implemented upon the JADE[12] platform and also provides part of the system organization, since the concept of coordination between the agents imports significant complexity

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[12] JADE stands for Java Agent Development Framework, http://jade.tilab.com/

to the system. The MAGIC concept has been described in detail in deliverable D2.2 and in other deliverables. More technical details are described in [Dimeas/Hatziargyriou 2005].

Figure 6: Schema of the MAGIC technology

Summarized shortly, one could say that the PowerMatcher and the BEMI approaches are primarily designed for "normal" operation, whereas the strength of the MAGIC approach is in the reaction to critical and emergency system states. However, the agent negotiation algorithms from MAGIC could also be used in normal situations for cost minimization, and the PowerMatcher could also contribute to managing critical grid situations, because it balances local demand and supply in real-time. The BEMI coordination focuses on day-ahead planning, which primarily helps to optimize trading positions for an energy supplier, but as the BEMI gateway can already communicate with all connected household appliances, it can also be enhanced with further functionality for facilitating more business cases in the smart grid. Further developments of all three technologies will draw from the experiences gained with each of the coordination approaches.

2.3.4. Enterprise Integration

The general technical infrastructure needed for all three SH/SG technologies developed, i.e. PowerMatcher, BEMI and MAGIC, is one (or more) control units within the house and one central optimization unit at the enterprise level. The in-house control units are usually distributed over lightweight control at the device (i.e. one device agent at the lowest level of the architecture or one controllable switch) and one home gateway that concentrates the information within the house and that may optimize the device operation for the whole household. For PowerMatcher, the gateway can be interpreted as the concentrator that aggregates the bids and submits a summarized demand function; for BEMI, the gateway does the optimization and actively switches the connected devices; for MAGIC the gateway can be interpreted as the highest level of the multi-agent system which includes all the services necessary for achieving the system's goal.

The enterprise level system communicates with the home gateway in order to transmit information about the current system status. This can be done in form of a real-time (PowerMatcher) or day-ahead (BEMI) price or a notification about a grid event (MAGIC). This combination of decentralized and centralized collaboration is visualized in Figure 7.

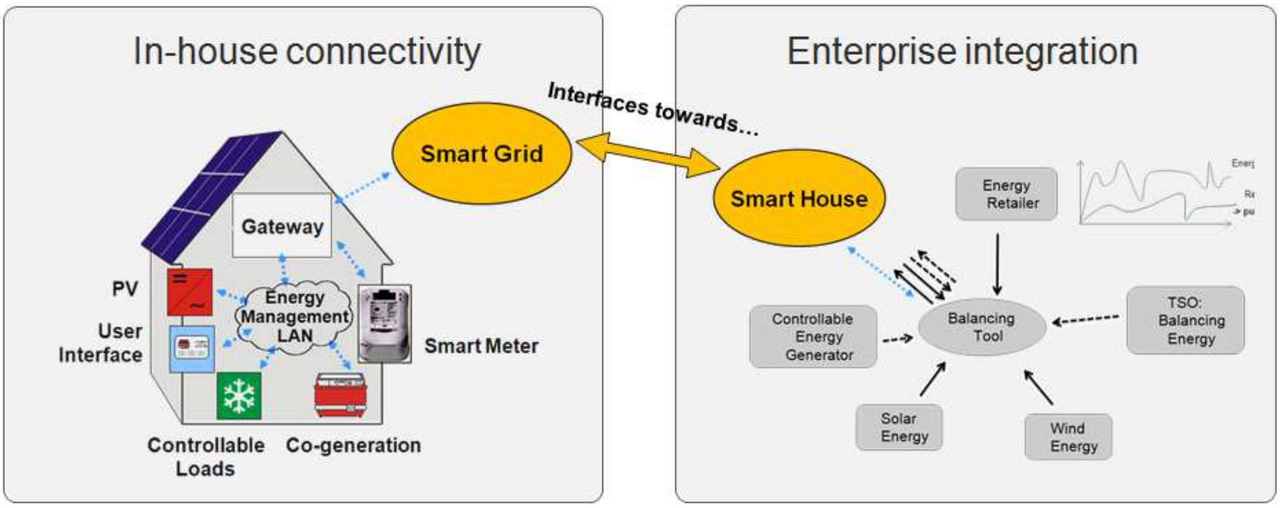

Figure 7: Connection between the in-house architecture and its integration within enterprise processes

It has to be mentioned that usually only one of the business cases described in Section 2.1 can be implemented at a time by the enterprise. Usually, the aggregated flexibility in energy consumption and generation by a cluster of households can either be used for minimizing procurement costs of the energy supplier or for participating in the balancing market or for balancing the portfolio of a BRP or for other business cases that build upon the given flexibility. For example, once an enterprise has bundled the households' flexibility and sold it for balancing purposes, these households are bound to delivering balancing energy in case it is needed, and do no longer have the full flexibility any more to pick the cheapest time slots for running their appliances. Therefore, the proper choice of the business case that should be supported has to be the first step.[13]

Moreover, the business cases that can be implemented by any enterprise depend on the market role that this enterprise has in the energy market. As summarized in Figure 8, each enterprise (and also each further player in the overall system) has a different involvement in the smart grid.

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[13] In order to facilitate this step, investment analyses for possible business cases that can be implemented with the three SmartHouse/SmartGrid technologies have been carried out as part of the project and will be provided in deliverable D4.3. A short version of the analysis is also available in a conference paper [Jötten et al. 2011].

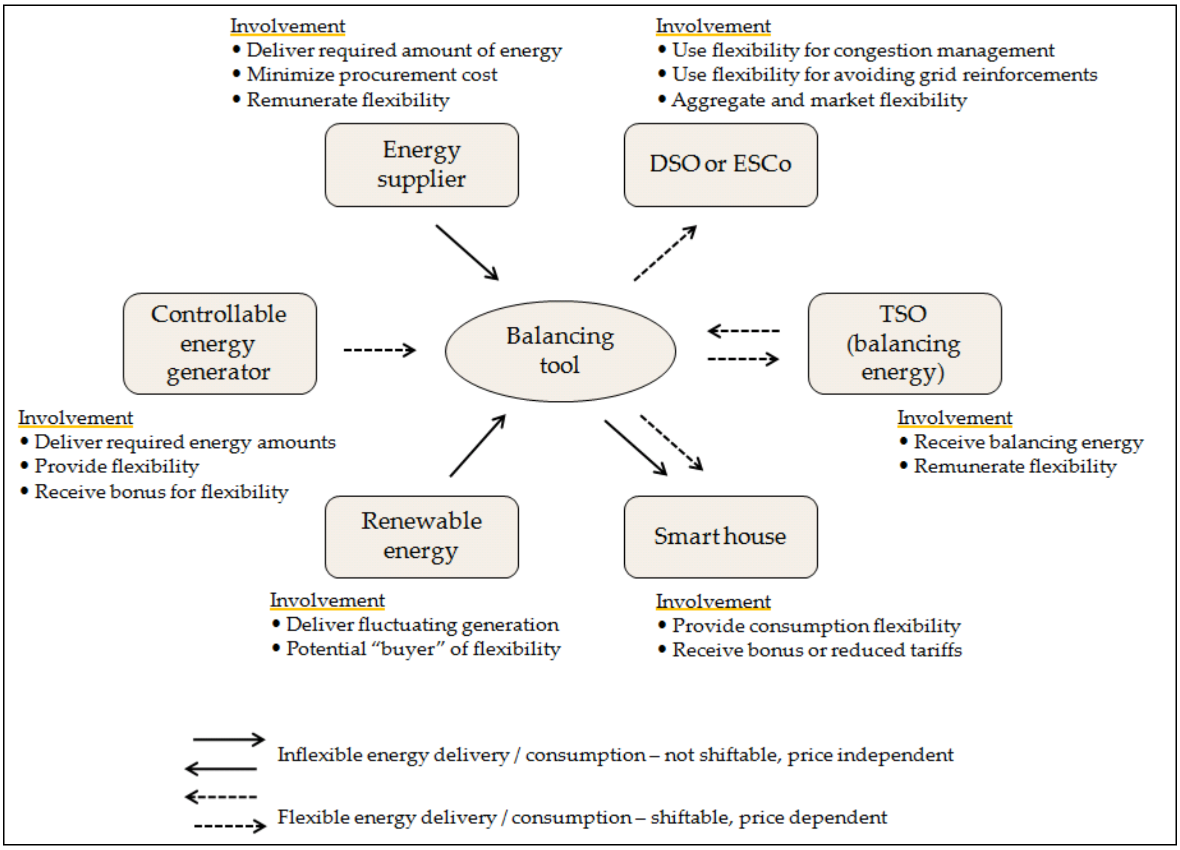

Figure 8: Enterprise integration via a balancing tool

The functionalities that each of the enterprises require and the tasks each of them carries out are different. These have are summarized in the following for an energy retailer, a DSO and a commercial aggregator.

- Energy retailer – The energy retailer plays a central role for successfully establishing a smart grid, because he is responsible for the delivery of energy to the contracted delivery points. He has to choose one balancing tool (PowerMatcher, BEMI or MAGIC, in this case) that helps him to balance all available electricity resources with the electricity demand. Other functions he has to carry out are:
  - **Metered data analysis –** The retailer needs to get all detailed metered data (profiles) about the energy delivered or generated at a certain point of delivery. Therefore, he would need efficient tools for collect, storing and processing the metering data. Retailers can then perform interval-based profitability analytics and create individual incentives for special customer groups.
  - **Accurate forecasting and balancing –** The energy retailer utilizes tools that help him to balance his portfolio, based on forecasting techniques and his own historical data. If derivations from these forecasts occur, the balancing tool operated by the retailer can help him to use the demand flexibility to balance them out.
  - **Definition of energy products or tariffs** – SH/SG approaches lead to more complex products in terms of price intervals or price rules that can be defined according to the availability of detailed metered data. In order to keep tariffs simple, retailers could also use time of use tariffs.
  - **Energy usage monitoring and feedback** – The data collected from a smart meter should be automatically analyzed and put into a customer portal or report (coming with the monthly bill) for the consumer. The customer feedback should also provide transparency about the operation decisions that an automated home energy management system, such as the PowerMatcher, BEMI or MAGIC system, has taken. The user should be able to see at what times his flexible loads have actually run and what cost savings could be realized by this optimized operation.
  - **Billing –** Billing functionalities like ToU billing, profile-based or real-time pricing billing, best billing (billing calculation based on different price schemes with a comparison afterwards to choose and bill

the cheapest option to the customer, as implemented, e.g., in field trial B), or fixed fee billing are possible options to be used in the SH/SG context. It is decisive that the bill transparently reflects the customer's reaction to any incentives provided for load shifting, so that the customer develops trust in the technology and the incentives can produce the desired behaviour.

- **DSO** – The distribution companies play an important role in the development and establishment of smart grids. Their main contribution to the smart grid is the distribution grid itself. In liberalized markets, DSOs do not participate in the business of the energy supply, but concentrate on the development and maintenance of the distribution grid. A smart grid needs to deal technically with higher loads during times when a lot of energy is generated (and consumed). In case of a large-scale adoption of electric vehicles, this task will become more demanding, as peak consumption might rise sharply, if no simultaneous measures for avoiding peak loads and spreading shoulder loads are taken. This would imply a more expensive grid infrastructure and an investment into the grid construction. Hence, the DSOs interest is to avoid an extensive usage of the grid in peak times. Load shifting of energy usage and generation to an equalized degree of grid utilization is the best choice to use the grid most efficiently. Roughly spoken, the capacity of the grid is the indicator that defines the maximum energy load during peak times that can be managed by the grid. For this reason, the DSO could base the prices for grid usage on the capacity that is needed in peak times. In a smart grid with a high share of distributed generation, another new phenomenon can occur at the distribution level. Traditionally, the distribution grid has been designed to transport electricity from the higher voltage level over low voltage lines to the end-consumer. As the many smaller decentralized units feed in their electricity on the medium and even low voltage level (e.g. photovoltaic panels, small combined heat and power plants), the load flow can also change its direction. So there will be times at which load is flowing from the lower to the higher voltage level. Here again, the DSO can either extend his infrastructure so as to meet these new technical requirements, or he can use the optimization capabilities within a smart grid in order to encourage a local use of the locally generated energy, thus avoiding load flow reversals.
    - **Define the grid-usage tariff or bonus scheme –** If the DSO uses the smart houses' flexibility, he can either incentivise the desired behaviour through variable grid usage fees or special bonuses. The former method is quite uncommon in Europe – today, grid usage tariffs are usually based on the consumption that is transferred through the grid, regardless of any scarcity situations.
    - **Installation of smart meters –** If we assume that metering will still be performed by the distribution companies (which is still the case in most European countries), DSOs will remain the owner of the meters and are the party that has to invest into the smart metering hardware.

- **Aggregator** – A commercial aggregator can contract a set of smart houses who stay with their current retailer but who offer to shift certain loads when needed for system stability or efficiency. The flexibility of all contracted households can then be used for offering reserve capacity on the balancing procurement markets. For example, this aggregator could realize the business case to offer (secondary) reserve capacity to a TSO (cp. Section 0) via the balancing power markets. In this case, the aggregator has to define the bonus scheme that makes smart houses participate in the balancing, take care of correctly remunerating the flexibility that was actually provided by the smart houses, and participate in the balancing power market for generating the necessary income to make the business economically viable.

3. Testing the SH/SG Technologies in the Field

All three developed technologies have been tested in the field in different settings. The trial setups, results and lessons learned are summarized in the following.

3.1. Mass Scalability: Trial A

3.1.1. Trial Setup and Objectives

Field trial A demonstrated the mass scale perspective of automated aggregated control of end-user systems for energy efficiency, combined with testing the information exchange with enterprise systems using data traffic at mass-application strengths. The scale of mass-application is set at one million households.

One sub-goal of the trial was to demonstrate that the performance of automated control of one million households is adequate with respect to the business case on *Real-time Portfolio Imbalance Reduction*. This business case (see Section 2.1 and D1.1 for details) gives a balance responsible party (BRP) the ability to control the flexible demand and supply of household appliances in order to improve its overall demand and supply balance within a settlement period. Since this settlement period varies in Europe from 15 to 30 minutes, the control actions at the BRP enterprise level should preferably be in the order of five minutes or less. In this way, a BRP will have at least three moments during a settlement period to exert its control.

Another sub-goal was to demonstrate the ability to handle variable tariff based metering data from the smart meter through the smart grid infrastructure to the enterprise system for billing and rating. The business cases above are based on real-time tariffs, which implies that prices can change at any moment in time. Billing will be based on integrated volumes and prices over fixed periods, and we assume that this will be periods of 15 minutes. Therefore, the meter interface should be able to handle both the real-time changing tariffs on the usage side and the integration into periodic volumes and prices at the meter reading side.

Field trial A is built around the PowerMatcher technology. The PowerMatcher is designed to be scalable and applicable on a large scale. Field trial A will give proof of this in two ways:

- Performance of control: In order to control a cluster of households for a business case the control signals should reach the households and the devices fast enough to support the business case.
- Performance of metering and billing: Variable pricing leads to large amounts of detailed measuring data which has to be processed by the enterprise system.

A main challenge for the field trial A is to reach the number of one million households. It is impossible due to the large numbers involved to include one million real households in the trial. Therefore, a large part of the trial will be based on simulated entities. For the same reason it is not feasible to simulate every single household as a separate entity. The main criterion in the setup of the trial therefore was to simulate the behavior of one million households. The setup of the trial is given in Figure 9; it shows hierarchical structure of the PowerMatcher technology with two levels of concentrators between the enterprise system and the smart house gateways. The metering data will be communicated through the same layered structure.

In Figure 9, several components can be differentiated. On the left side are the real world components in the test (encircled in red). Concentrator 1.1 is dedicated to the control of real smart houses that are part of PowerMatching City, an existing test field in Hoogkerk in the north of the Netherlands, that has been established in the Integral project (http://integral-eu.com/). Concentrator 1.2 is connected to 100 real smart meters; this part is dedicated to delivering metering data and does not implement the PowerMatcher control. Concentrator 2.1 connects concentrators 1.1 to 1.100 to the enterprise system located in Karlsruhe, Germany.

On the right side are the virtual components in the system, running on a virtual PC environment (encircled in blue). The branches underneath concentrators 1.3 … 1.100 and 2.1 to 2.100 are replaced by data providers providing bids and metering data from respectively 100 and 10,000 mimicked households each. This leads to the data traffic of a total of 100*100*100 = 1,000,000 households, both control information and metering data.

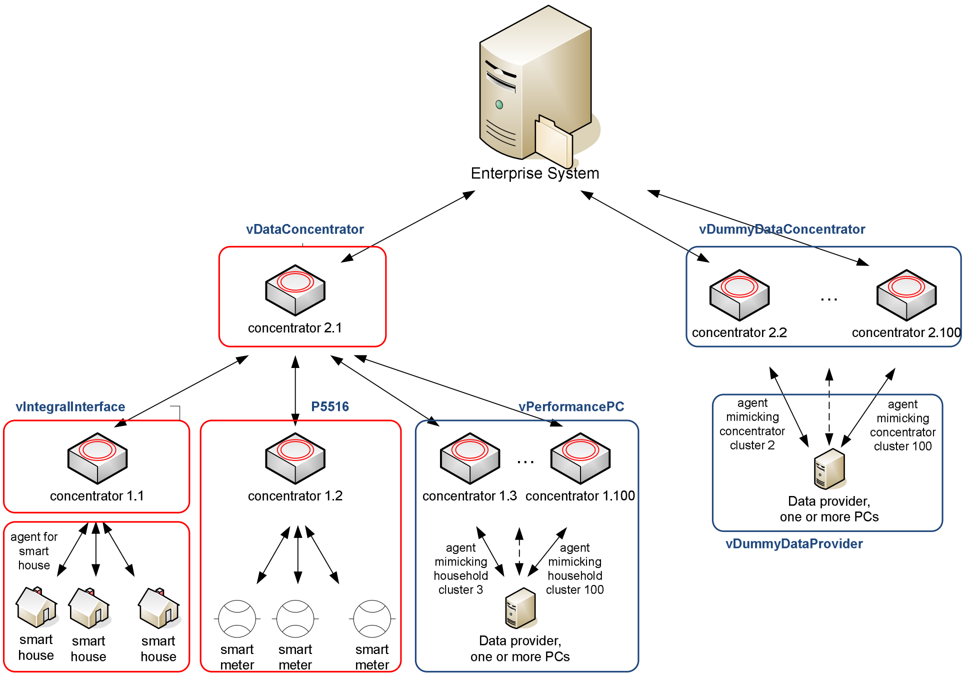

Figure 9: Overview of components in field trial A

The metering infrastructure set up to evaluate scalability of the enterprise system follows the Software as a service (SaaS) approach, i.e. applications are hosted on (distributed) Internet servers and access to the value-added servers are provided. An overview of the SH/SG trials is depicted in Figure 10. A commonality among all trials is the enterprise integration and the services provided at that layer. The Internet-based metering platform features several components that implement the necessary services, such as MeterReading service to report real-time measurements, and is hosted in an Internet server. The only way to communicate among the platform and the different metering data-collections points is via web services over the public Internet. As such, a concentrator, a smart meter or any other metering data entity can contact the necessary web service and submit the collected data. A metering service was realized as a web service used to submit the acquired metering data to the platform. This web service is developed as the stateless Enterprise Java Bean (EJB), where the EJB server-side component encapsulates the business logic.

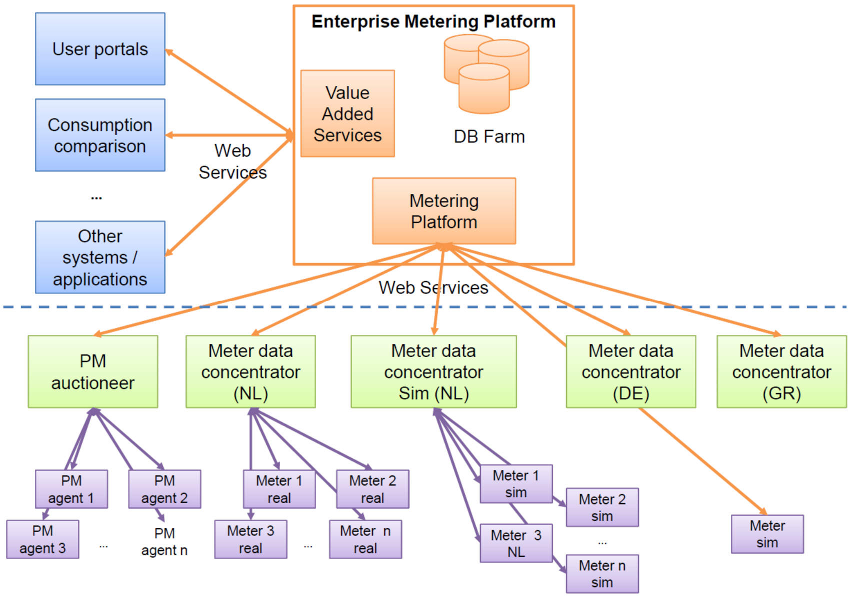

Figure 10: Smart metering trial overview

3.1.2. Measurements and Results

A simulation was set up running 1 million virtual households on the SH/SG side of the setup and was connected to the PowerMatching city field test of the Integral project to measure latency of the communication of the control signal coming from the enterprise and reaching the lower level device agents in the smart houses, both real and simulated. In order to connect to the PowerMatching City field test, some adjustments had to be made which added artificial delays to the latency. To accommodate for software discrepancies two objective agents and several web services were used to enforce the SH/SG price on the PowerMatching City cluster (Figure 11). Bids and prices signals were recorded with the corresponding time at each level of the simulation to measure the latency.

The results of the latency test can be depicted in Table 4 below. Influence from an objective agent on the SH/SG side of the simulation reached that of a real device on the Integral side in under five minutes (on average four minutes) thus meeting the desired target. However, there was a large amount of artificial latency which influenced this result and could allow for one minute for reaching the agents. This artificial latency was caused by the polling and measurement tactics enforced on the PowerMatching City cluster. Further, an additional auctioneer, web services and objective agents were required to complete this test. Figure 11 visualizes the impact of artificial latency.

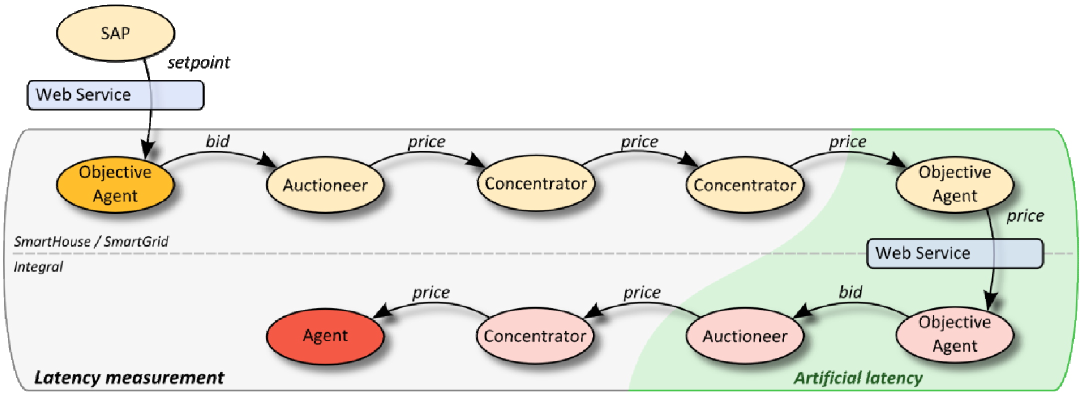

Figure 11: Latency test

	Node	Measured performance	Net performance	Artificial latency
Virtual network	Enterprise	0 sec	-	-
	Concentrator level 2	70 sec	10 sec	(30 + 30) sec
Real network	Concentrator level 3	142 sec	22 sec	(30+30) sec
	Home gateway	205 sec	25 sec	(60) sec
	Device	240 sec	30 sec	(30) sec

Table 4: Latency test results for controllability

On the metering side, it was discovered that a large portion of time is spent on internal processing of meter reading submission requests inside the application server itself. For example, the total request/response time for a one socket connection, for a single meter reading submission, was approximately four times longer than the time required to insert the metering data into the database. This difference was the first sign that the application server load should be balanced over multiple nodes. As such, further performance enhancements should be focused on reducing the request processing time. For instance, using a meter data concentrator to collect meter readings and submit them in bulk to the main server. This way, the request processing time per meter reading can be reduced, yielding higher efficiency. However, even more aggressive performance-related strategies might provide better results, such as usage of in-memory databases or strategic (on-demand or periodic) committing to the database.

The experiments consisted of a client pushing a high amount of requests with generated metering data; as such, the communication throughput is limited by the TCP receive window (receive buffer) on the server side. The server side reaches its buffer limits (TCP window size) followed by the TCP window scaling (RFC 1323), that is, to increase the TCP receive buffer size above its current value. The client will continue to generate data, but it will be kept in the output buffer until the server updates its window size to an equal or greater value of the message size to be sent. These steps will be repeated until all data is transmitted.

According to current smart grid industry practices, each meter under a concentrator is sending its current reading every 15 minutes. In one of the experiments carried out in the SH/SG project, each concentrator had receiving rate of meter readings at 60 meter readings/second. With this level of granularity, a total of 54,000 meters would be connected to the concentrator. The results show that, for the tested (off-the-shelf hardware and software) configuration, the Metering Data System (MDS) performance peaks around at 66 concentrators. These results showed that at meter reading submission intervals of 15 minutes, roughly 3.5 million meters can be incorporated within this configuration (as depicted in Table 5). Further experiments have been carried out and are reported in deliverable D3.3 and in [Karnouskos et al. 2011].

Interval	Max. meters / concentrator	Max. meters / MDS
1 min	30,000	240,000
5 min	150,000	1,200,000
15 min	450,000	3,600,000

Table 5: Maximum number of meters per concentrator and MDS

3.1.3. Key Findings and Lessons Learned of Trial A

Even ignoring the artificial latency in the PowerMatcher communication which impacted the latency between an objective agent and device agent is well within the settlement period for the BRP. Therefore, it was proven that there is potential to balance control via demand side management at a household level. Furthermore, there is also potential for balancing ancillary services for the TSO using this same method.

As we have stated, the Smarthouse/SmartGrid project started with the assumption that there will be no common architecture penetrating all layers of the envisioned smart grid. Our trials have proven that this is a viable approach and the intermediate communication and data exchange layers are appropriately wrapped. To this end we reinforce here from our trial experience that we need standardisation towards the capabilities of the smart meters, smart services and energy management systems, towards energy related services and towards data models depicting the energy data acquired. The European industry with support from the regulatory framework should strive towards standardising the basic behaviour to be integrated in the services while in parallel leaving room from extensibility and future functionality.

On the metering side, it turned out that there was no tool available for asset management of the smart meters used in the trial. Internal clocks where not synchronized, however this was not a problem because a timestamp was given by the acquisition software when data was written to the database. As the measurement data are accumulated values it was not a big problem when values were missing or duplicated. It was noticed that once in a while the meshed RF network delivered duplicated data: same origin, value and timestamp. The application should be robust enough to handle this. While duplicate meter readings arriving from the meters was a non-malicious error, it highlighted a situation that may arise. Data will need to be checked not only for compliance to specific formats, but also “logical” checks should be in place. Resubmission of measurements intentionally or by mistake may result to security as well as enterprise application misbehavior if not tackled effectively. While the focus of the project was not on security, in a real world deployment it would be of paramount importance as it should be expected that malicious users could try to tamper with the system. In this instance, it would be quite possible to “inject” erroneous metering data in an attempt to destabilize the system, lower its performance, or even reduce the monthly bill. As such, going forward, it would be important to devise formal processes for handling events such as these.

3.2. Win-Win Situations: Trial B

3.2.1. Trial Setup and Objectives

The main objective of the Trial B is to test the automated response of household devices and the customers' behavior on variable electricity prices within a real utility environment. Part of the solution proposed by the field trial B is to integrate a demand-side energy management system as an active part of the grid by offering incentives to use electric devices at specified times. This energy management system should be flexible, so that it can be extended by control functions for electricity generators, e.g. micro CHP in combination with thermal storage devices to allow electricity generation when needed while also supplying heat/warm water when requested. Therefore, decentralised energy management in households as tool for balancing between local consumption and local supply of electricity was investigated in one hundred households.

The participants in the field test were predominantly male (approx. 80%) with average age of 49 years. The majority of the participants live in single family homes which they own. On average, 2.8 people live in a single household and more than two thirds of the participants live together with a partner in one household. Furthermore, the participants are characterised by an above average education and income. A cluster of participants was located in Mannheim's ecologically oriented suburbs of Wallstadt and Feudenheim with a larger number of customers acting as consumers and (PV-based) electricity generators, i.e. *prosumers*.

The core of the energy management system used is a newly developed device called "Energiebutler". Together with a broad band power line (BPL) modem and peripheral additional modules (e.g. smart meter, data storage/data aggregator, switchboxes) the Energiebutler serves to optimize selected households appliances based on a tariff profile received day-ahead via a broadband power line used for communication with the DSO. Automatically switched devices were dish washers, washing machines, fridges and freezers, or dryers (with max. two devices switched per customer). In addition, other devices could be started or stopped by the customer any time according to price incentives by a simple click on the web interface. Consumer interaction with the Energiebutler and the communication between all elements of the smart house is presented at the Figure 12

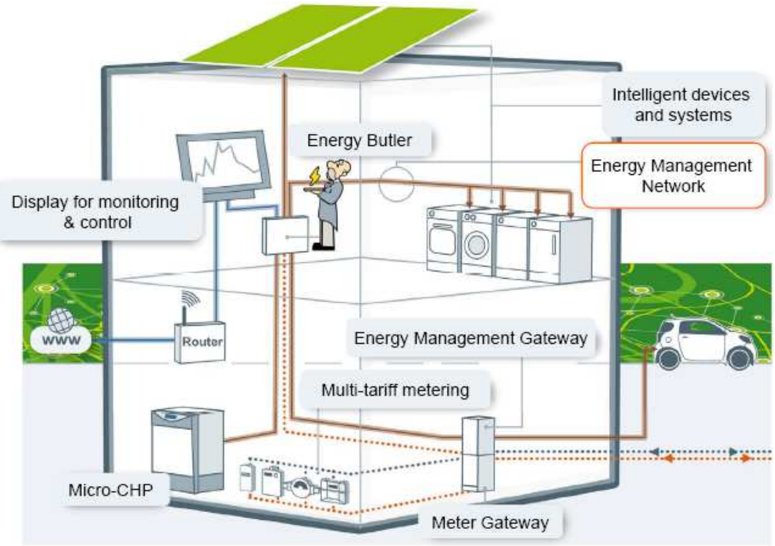

Figure 12: The Smart house as envisioned by MVV Energie

The energy management system to be tested in the field trial is using two main units together with supporting additional equipment:

(1) a smart meter to measure the electricity consumption digitally, and

(2) the Energiebutler together with switchboxes to start/stop connected household devices and primary equipment

The energy management system not only comprises these units within a single household, but also a supporting technical infrastructure involving a lot of rather complex processes and equipment. This results in the effect that many failures only become apparent once the system is installed at the target sites despite any previous lab tests of the single units. In order to keep high customer satisfaction and considering interaction between various stakeholders – between the customer and MVV, between MVV and the equipment developer, hardware manufacturer and other third parties involved – a failure management system was introduced. The field trial installations were conducted in several phases, starting with a small group of households in the first phase and with further replication to a large number of the customers in the subsequent phase. The two main phases were:

- Elaboration and installation of the smart meters according to suitability and price and their testing afterwards
- Testing and checking the functioning of the newly developed hardware and software for the Energiebutler energy management system, including education, training and care of customers and installation teams as well as implementation of a new billing procedure

Due to design and time/budget restrictions, the field trial finally was more focusing on the tests of the components and the optimisation of the processes of the whole data chain and the customer care.

Four preferred tariff profiles were chosen for weekdays and working days with two different profiles for each of them. Each tariff profile used for the field trial had only two price levels: low and high tariff with a minimum period of one hour for the price to be constant after a level change. The tariff profiles were static which means that the same sequence (high and low tariff) applied for every working day and every weekend day and holiday, respectively.

The installation phases took place from March 2010 until May 2011. Internal tests of the newly developed Energiebutler showed many technical problems and failures in the combination of new hardware and software causing delays. In response to the delays and in order to ensure the debugging with optimal acceptance and as much as possible gathering of data, the field trial was divided into three different phases, which is elaborated in more detail in the next section.

3.2.2. Measurements and Results

In first tests of the energy management system, a previously developed prototype turned out to be not expandable to run new software that would reflect the requirements of the business case studies elaborated in work package 1; the main shortcoming was in too little memory and processor capacity. Therefore, a completely new hardware had to be developed which finally turned out to be very different from the previous prototype. In addition to the hardware development the new software platform OGEMA for energy management was designed. It provides a very flexible basis for linking the customer’s loads and generators to the control stations of the smart grid, while at the same time providing a customer display for user-interaction and local control capabilities.

Besides the development and test of the energy management equipment and its set-up, another main result of the field trial was to find out to which extent the households react to variable electricity prices, additional consumption information and introduction of the energy management system.

The result regarding customer behaviour changes were recorded for a period of twelve months (Sept 2010 to August 2011). However, for this limited number of especially interested customers these data are good for the first assessment, but the statistical relevance is limited. The recorded data were evaluated to an extent reasonably correlated to the data available, and in parallel remaining bugs and failures of the whole energy management chain were tackled, from the customer devices to the data storage and finally the processing in the back office of the Multi Utility MVV and the evaluation infrastructure.

The field trial measurements were implemented in three phases adding step-by-step tariff incentives and Energiebutlers from October 2010 to August 2011, with further ongoing data acquisition and documentation:

- The first phase with adding energy management / variable tariffs started in October 2010. The customers got a first variable tariff on a monthly basis and access to the MVV metering portal. The customers could shift their loads according to this first variable tariff manually.
- The second phase started in December 2010. As the Energiebutler was still not available at all customers, a new tariff model was introduced to keep the customers on track and to get a better statistic basis for the evaluation of the load shift potential. In parallel the Energiebutler was installed and tested, first at up to ten selected ‘friendly’ customers followed by the installation of the other 90 Energiebutlers with all peripheral devices (e.g. switchboxes, gateway/ modems, temperature sensors) starting in spring 2011. This included constant software improvements and installation of the most recent software updates on the Energiebutlers via remote access.
- The third phase started in May 2011 and lasted until August 2011 with activating the Energiebutler software allowing the customer to use the Energiebutler not only for manual but also for automated load shift.

This field test was implemented and co-funded by the E-Energy project MoMa – Modellstadt Mannheim. Within this project the developed set-up and devices will be used for an additional field trial with up to 1000 MVV customers and lasting a full year starting in the end of 2011. This test should provide better statistical relevance to define load shift and consumption change data under more sophisticated variable tariff models. Also more households with distributed generation and possibly electricity storage (e.g. using electrical cars) will be included seamlessly extending the SH/SG investigations.

To assess the load shift of the customers in a quantitative way the load curve with variable tariff (electricity prices) and without (as reference) need to be compared. However, the load curve for both cases cannot be measured for a customer at the same time and other options need to be used. It was decided finally to use modified standard load profiles considering the seasonal influence as the reference.

The billing of the variable tariffs was applied according to the Best-Price settlement; households, thus, had to pay as much as they would have paid under their previous tariff. Both tariffs were perceived by customers as saving electricity costs – savings in the order of 5 € or more were mentioned. However, even with savings of more than 5 € per month the participants were reluctant to pay for energy management. Approximately one sixth of the participants could at least imagine the payment of a monthly fee for the provision of additional power consumption information. About one third of the participants were willing to pay for the energy management system but none of them would use the system if it cost more than 4 € a month.

Typical load shift shown in Figure 13 is for the month of February 2011 and is representative for other months. The price scheme can be seen in the background. Even using “modified” reference profiles, there are several effects that need to be considered as to be influencing the load shift. Besides the seasonal and price effects, consumer awareness change, saturation or habitual effects could occur due to the tariff being constant for several months. Approximately 25% of the consumption data were not available due to ongoing problems. An extrapolation of the results is additionally difficult due to the lack of socio-demographic representativeness of the participants’ group.

Questionnaires and customer feedback showed that during the test, the majority of the participants used devices at convenient hours. The most commonly used appliances were dish washers, washing machines and clothes dryers. Two thirds of the customers indicated that they changed their electricity consumption behaviour since within the field test. The participants also indicated that they had set their electricity consumption according to the prices and estimated they would save more energy and pay in the order of 5 € less compared to fixed tariffs. Additionally, the motivation to reduce the consumption was very often correlated to the acknowledgement of the customer's contribution to the climate protection. Summarizing, two phenomena can be recognised in the self-reported consumption behaviour: firstly, absolutely less power consumption was reported, and secondly, the households indicate that the power consumption of white goods (e.g. household devices) was moved to more convenient hours.

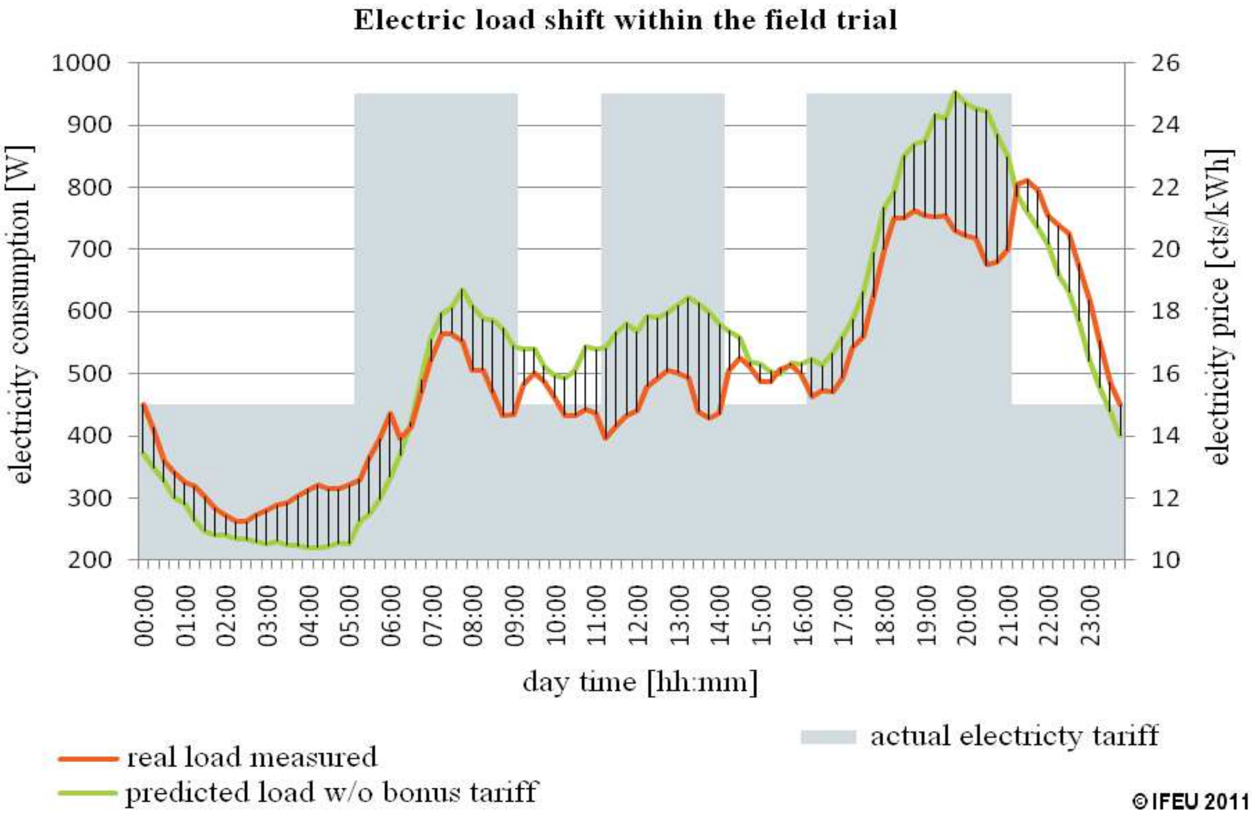

Figure 13: Load shift in the field test with variable tariff offered (here: February 2011)

Due to the limited time for collecting measured data suitable for further analysis in addition to the limited number of field trial customers and seasonal influences, a statistically sound evaluation is difficult and the data precision is limited. Data available indicates a shift of consumption to periods of low price in the order of 6-8%. Although reduced absolute electricity consumption is reported by the customers, no statistically significant changes can be stated from the limited data available (absolute values are more demanding than relative values and the trial was mainly set up to test the system). A similar trial allowing for much higher data precision will be repeated over a full year and for >500 customers within the MoMa project. In this trial, seasonal influences and reference group data do not need to be calculated but can directly be measured.

3.2.3. Key Findings and Lessons Learned of Trial B

A unique feature of the field trial B within SH/SG is that it involves many stakeholders acting profit-oriented in the unbundled market. In this trial, the development process of the back-office functionality has shown that it is a nontrivial task to integrate systems from different partners even if there are common protocols provided. An important lesson from this is that the emergence of these stakeholders from what once were single vertically integrated utilities greatly increases mediation issues when implementing smart grids. Within the project context, this is resolved by project management and common consortium decisions. However, if considering implementation of smart grids in the unbundled market of today, such a consortium would have to be replaced by a trusted cross-partner organization for mediation between conflicting partner interests which otherwise would hinder technical implementation. For example, giving the customer a tariff bonus for incentivizing a load shift for better utilization of the DSO's grid resources may be of advantage for the DSO, but is unattractive for the energy provider as of today. This is because the introduction of variable tariffs raises cost for establishing new billing procedures, yet does not yield direct income. However, without technical services provided by DSO and energy provider, the smart grid cannot prevail, which is of disadvantage for both.

3.3. Stable Grid Operation: Trial C

3.3.1. Trial Setup and Objectives

The Greek field trial demonstrated the ability of a decentralized system to handle critical situations such as the transition to island mode or the black start. Furthermore, it demonstrated the decentralized provision of ancillary services, i.e. load shedding support to alleviate network congestions. The trial was hosted in Meltemi, a seaside camping located 15 km north-east to Athens. Meltemi consists of 170 cottages used as a camping resort mostly during summer. Due to the small size of each cottage, the electrical consumption of each house is lower than that of an ordinary house in Greece. However, the electrical structure (all houses connected to the same MV/LV transformer) of the settlement makes it ideal for testing, especially those aspects related to emergency and critical grid situations. The installation of a 40kVA diesel generator and 4.5 kW of photovoltaic panels can form the Meltemi camping into a potential interesting micro-grid.

The system installed in Meltemi allows the DGs as well the household to negotiate in order to decide next sequence of actions. The system called MAGIC (Multi-Agent Intelligent Control) is a Java based software that implements the intelligent agents. A critical component of the MAGIC system is the intelligent load controller (see Figure 14). It is based on an embedded processor that runs Linux and is a system that can be used to monitor the status of a power line and take voltage, current and frequency measurements. It is designed for indoor installation and is equipped with a display in order to present messages directly to the consumer. The controller is expandable with several serial and a USB port and has the ability not only to control but also to monitor several appliances. In addition, the residents had online information about the status of the system, consumption and cost not only by the display on the controller but also through the web portal developed by SAP. This is also a critical part of the system, since the residents will accept such systems only when they realize the energy savings and the cost benefits.

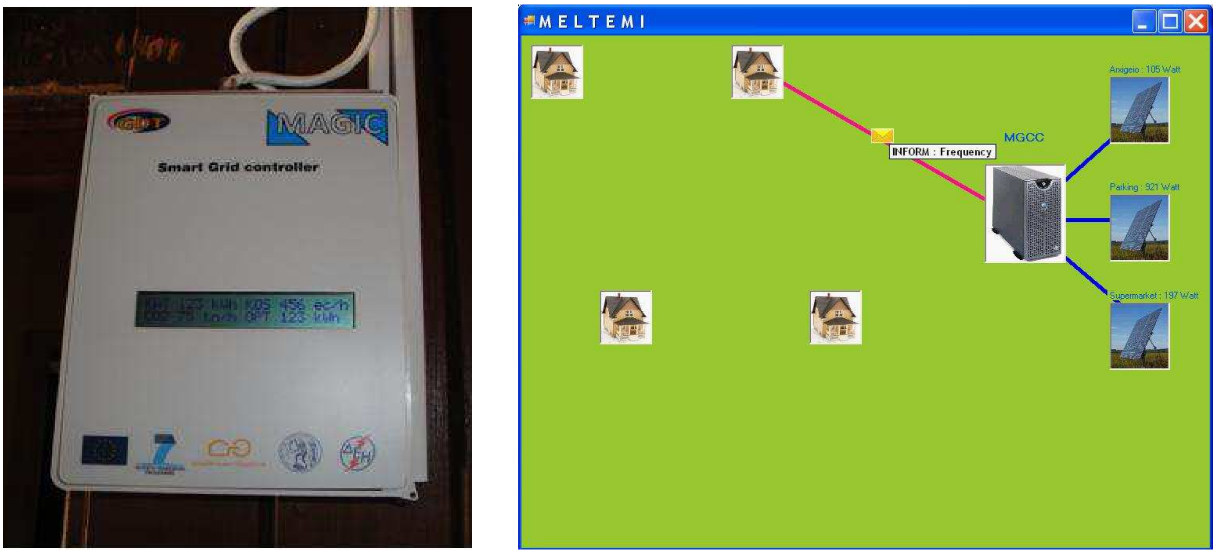

Figure 14: MAGIC load controller (left) and communication between controller and central agent (right)

3.3.2. Measurements and Results

The **Congestion Management** business case focuses on the monitoring of the transformer that feeds the camping site. The idea is that when the transformer is near critical level of overloading, then the DSO notifies the aggregator in order to proceed with load shedding. The system has two main steps in order to deal with the disturbance. During the first phase, the agents monitor the system and provide to the other agents and the aggregator with information regarding the status of the system, i.e. current fuel level, production, consumption, and voltage. The system should provide a list of loads that can be shed as well the units that are capable to black start the system.

The second phase includes the time period after the possible disturbance. The ideal response is to isolate the system. If a system disturbance provokes a general black out such that the microgrid was not able to separate and continue in islanding mode, and if the medium voltage system is unable to restore operation in a specified time, a first step in system recovery will be a local black start.

In order to evaluate the algorithm, a simple algorithm that only reacts to the various disturbances will be considered. The difference between the two approaches is described in Figure 15. During the event, the simple algorithm reacts to the event exactly when the system detects the overload. On the other hand the MAGIC system has the ability to predict the incoming event and act fast enough. A significant lesson learned is that 15min early warning is enough time to cope with the event.

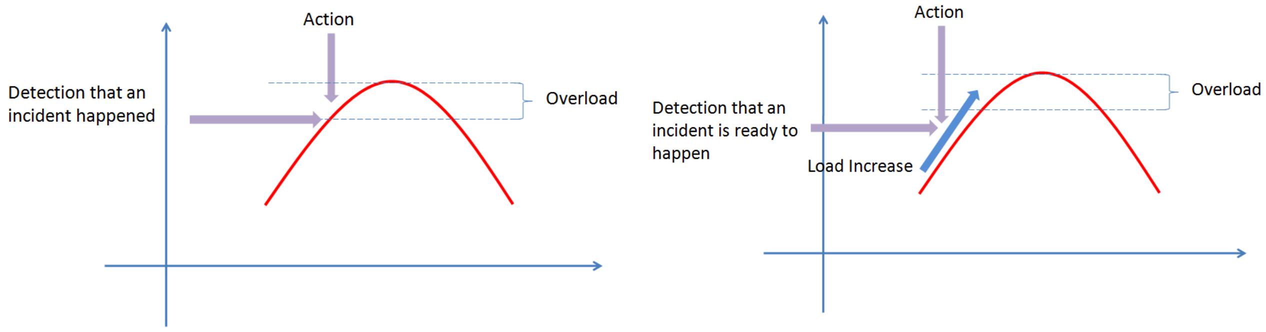

Figure 15: Operation of the simple (left) vs. advanced algorithm (right)

The **Islanding / Black Start Support** scenario has also two main steps: the first step takes place before the event that may occur and the second step is the steady islanded operation. During the first step, the system should monitor both the available distributed generation (DG) units and the loads, and should forecast the consumption as well the available power and energy in the next hours. A load shedding schedule should be created based on to the criticality of the consumption loads and on the customers' willingness to pay for running the appliance during the island mode.

In the first minutes after the event, the DSO (simulated agent) allows the operation according to the criticality. If there is enough power to the islanded grid, no load shedding will take place. When balance and stability has been ensured the system decides how to manage the energy within the network. The transition to the island mode is done automatically and neither the end-users nor the aggregator interferes with it. The system manages the energy generation and consumption within the island system and it is assumed that all nodes within the islanded grid participate in the system.

During this scenario the Diesel was activated feeding six of the houses in Meltemi. Technically, the operation was successful, albeit not fully automated. For security reasons, the transition to island mode was done manually. Another issue was that the generator is quite big for six houses. Therefore, the evaluation considers the energy management of the PV during the event. The idea is that without an intelligent management system, an extensive load shedding would take place.

For the case of Meltemi if the incident happens during the midday, the critical loads can be easily fed by the PV. The MAGIC system only monitors power deviations. For example on the 2nd of August, a cloud reduced the PV production (see Figure 16). If the event happened during the black start or the load shedding, the MAGIC system would limit the controllable devices. The general conclusion is that the knowledge and the control of the devices can ensure less reduction of comfort for the house owners.

Regarding the speed/ reaction improvement it, is obvious that during the midday for Meltemi the loads can be server for long period. After 17:00 the PV energy is not sufficient thus load shedding should take place. Other islanding operation experiments have been carried out and are reported in deliverable D3.3.

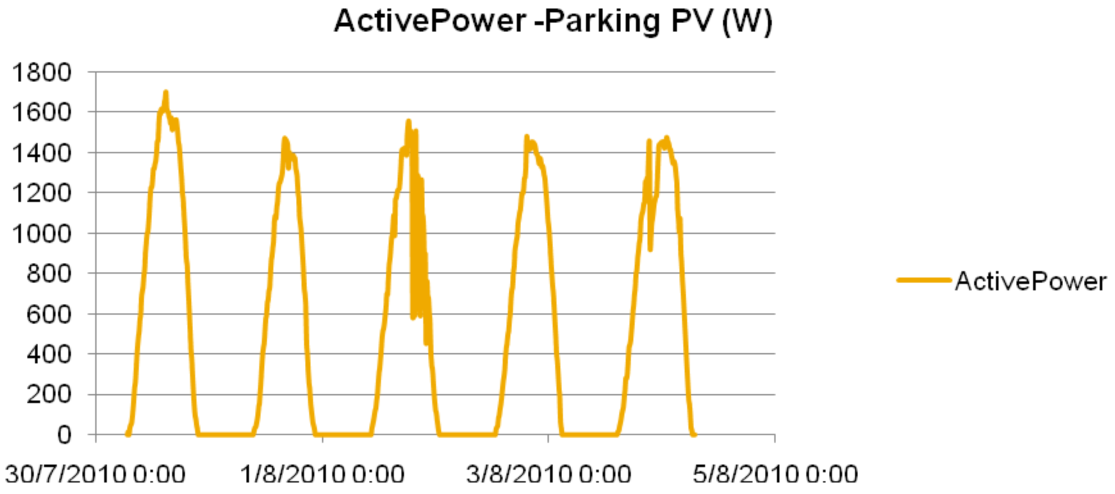

Figure 16: Measurement in the PV installed in the parking area

3.3.3. Key Findings and Lessons Learned of Trial C

The primary lesson learned from the implementation within the scope of the SH/SG project is that the system should further enhance the SOA capabilities. Large scale implementation will require the cooperation with enterprise information systems and, in consequence, an adaptation of the negotiation algorithms. Another important issue is the legal framework and the level of market deregulation. All the scenarios implemented in the field trial C require the existence of flexible tariffs and the ability of the aggregator/ESCo to make arrangements with the consumers DG owners. The current legal framework in Greece does not support this kind of operations nor provides incentives for load management. Moreover, due to low electricity prices, consumers are not used to paying much attention to their consumption and to save energy.

The next significant issue is the intelligent load controller. The new indoor version, equipped with a display is a significant part of the system since it gives the chance to the inhabitants to actively participate in the whole process. The interaction with the habitants revealed that the knowledge of the current cost and consumption makes them more conscious regarding energy savings and, as a consequence, solutions like the one proposed by SH/SG are more acceptable. Furthermore, the existence of the web portal is also significant, although it was not widely used in Meltemi (in a holiday camp, most of the people do not spent much time on Internet).

Regarding the energy efficiency and the business cases, the major lesson learned is related to the cost. The capability to provide ancillary services (black start, load shedding etc) was evaluated not only based on technical criterions but also regarding the cost. In Greece, electricity tariffs are very low and not cost-reflective (although this situation is changing currently). This means that the ancillary services in LV consumers are not cost effective in Greece. However, future estimation about the cost of energy reveals that these applications may be interesting.

Another significant issue is related to the load and wind forecasts. In the experiment design the goal was to integrate online forecasting capabilities but not to develop a new forecasting module. However NTUA is quite active in the area of load / wind forecasting and this installation provided some really interesting results. The main result is that for this type of applications stochastic forecast techniques should be used, thus it is not the scope to predict only the expected consumption/production but also the corresponding error (confidence interval).

Finally one lesson learned is related to the Jade technology used. Jade is actually the middleware for the MAGIC application, providing directory services and indexing. It was a good choice to build on this existing tool that has a large ten year old and active community that debugs the system and solves errors. This helped to speed up the trial site implementation, since most important functionalities were already tested.

4. Simulating the Mass-Scale Viability of SH/SG Technologies

Besides the development of the SH/SG technologies and their deployment in the field within the three trials, it was also the objective of the project to study and prove the validity and feasibility of the SH/SG concepts through simulations. Simulations were carried out for validating the three technologies, modelling a large number of customers in order to get some quantitative results and addressing central research aspects and measurable objectives of the project. The results of these simulations are reported in this section.

4.1. Raising the Accommodation Ceiling for Renewable Energies: Simulation A, Part 1

Within simulation A, two different simulation systems were used. The first is modelling a large-scale SH/SG cluster and considers ICT performance issues within a smart house to enterprise-level metering infrastructure. The second simulation system of ECN uses a small low-voltage network model to research the question how the operation of PowerMatchers in smart houses affect grid operation parameters within a single network feeder (see Section 4.2). This latter simulation is especially focusing on grid losses.

4.1.1. Simulation Setup and Objectives

In this simulation, the potential of the PowerMatcher technology was explored to accommodate mass integration of electricity produced by wind energy by adapting flexible household demand and supply to the availability of wind power. This has been done by running large-scale simulations under real-life conditions. In these simulation studies, the Dutch WLO-SE scenario [Centraal Planbureau/Plaanbureau foor de Leefomgeving 2006] has been followed, that foresees a strong increase in capacity of off- shore wind energy from 3 GW in 2020 to 10 GW in 2040 in the Netherlands. Results have been extrapolated to even faster wind energy growth scenarios as envisioned by the wind energy industry (e.g. We@sea).

The simulations are based on the WLO-SE scenarios on energy supply and demand with a time horizon up to 2040 (details are described in deliverable D4.1 [SHSG 2011]). The total envisioned electricity demand in WLO-SE 2040 is 582 PJ, the total household demand is 130 PJ. The industry demand and supply have been removed from this scenario for simplicity. Therefore, the renewable energy must be scaled down by approximately 0.22 (130/582) to account for lack of industry in the simulations. Table 6 shows the defined installed capacity in Dutch network in 2040. In the last column these figures have been scaled down from 8.6 million to 3000 households, which is the number we consider for our simulations.

Installed capacity	Total	Residential	3000 homes
Wind onshore	2 GW	0.44 GW	156 kW
Wind offshore	10 GW	2.2 GW	750 kW
Photovoltaics 2M m^2	2 GW_e	660 MW	231 kW
Fossil Fuels	---	15 GW	5.25 MW

Table 6: Installed capacity defined in the WLO-SE 2040 prediction

In the residential cluster, 1500 households are supplied with micro-CHPs and 1500 with heat pumps, for both space heating and tap water. Both devices have heat buffers of 120 litres (space heating) and 90 litres (tap water) allowing for flexibility in their operations. Since the architecture of the PowerMatcher technology allows for more or less independent sub cluster behaviour, the results from the simulations of 3000 households may be extrapolated to realize the potential on an entire Dutch scale.

A simulation tool specifically developed to run simulations with the PowerMatcher technology is used for this trial. A number of device and household agents and models were developed to run with two types of controller, a traditional, business as usual, controller ('fit and forget') and a PowerMatcher controller which has added intelligence to respond to price incentives. To show the added value of the PowerMatcher coordination a number of simulations were made with different wind capacities. As it is assumed in WLO-

SE that only the offshore amount of wind will increase significantly over time, the amount of offshore wind penetration in the different simulation runs was adjusted. Runs were made for a total offshore wind of 750, 800, 850, 900, and 1000 kW.

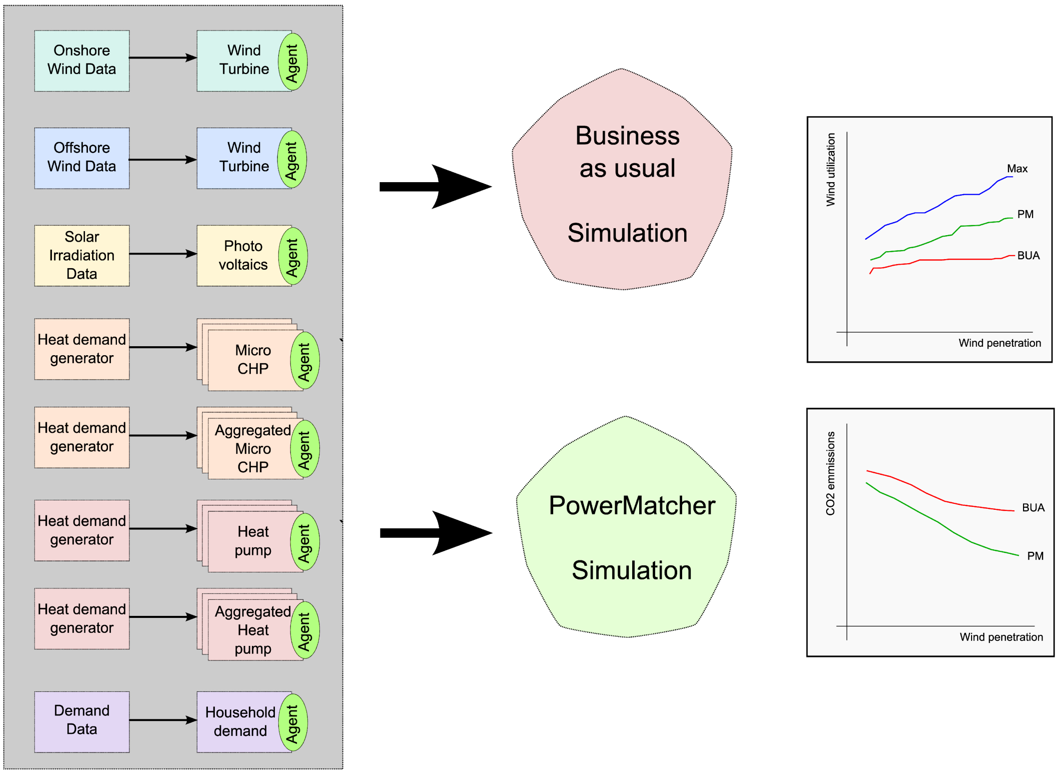

Figure 17: Setup of simulations: configuration, scenario's and resulting graphical comparisons

Household electricity demand profiles used in the simulations are randomly generated based on configurable parameters, like total annual electricity consumption of 4,300 kWh in 2040, number of persons in household, different lifestyles, with accuracy verified with real household. The wind power model uses annual wind velocity data from [KNMI 2010] to accurately model wind power. For the offshore wind availability a number of offshore sites were averaged to make an estimate of total offshore wind power.

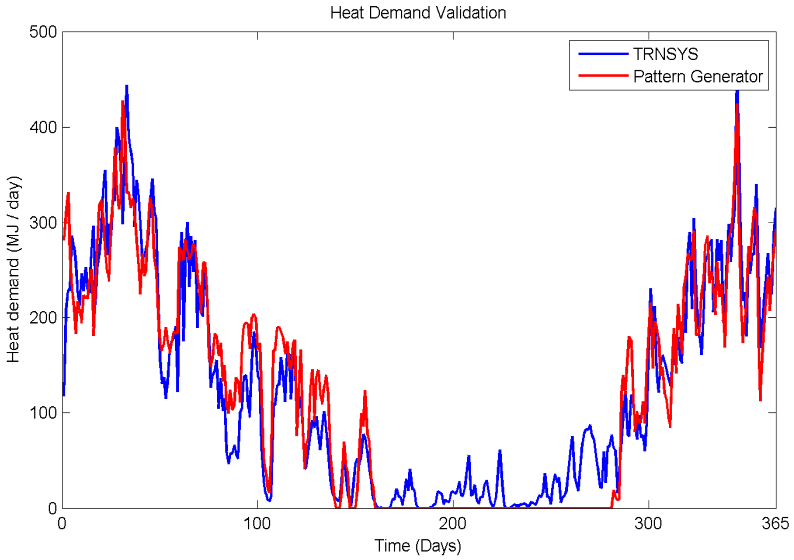

Figure 18: Heat demand generated validated by TRNSYS model

Micro-CHP models and heat pumps models were made to mimic the behaviour of a device which uses a space heater and/or tap water buffer with a heat demand which models typical household heating behaviour. The heat demand pattern generator is a simple linear regression model. It uses ten-minute based ambient temperature and (horizontal) solar irradiation data. Only one parameter is tuneable: the total annual heat demand in GJ. Accuracy of the heat demand simulated is verified by TRNSYS simulations, used widely in research communities as a simulation environment for the transient simulation of thermal systems (see Figure 18 below). Models for tap water and space heating buffers are described in more detail in deliverable D4.2.

As stated in the simulation setup section, the micro-CHPs and heat pumps are the main devices used for flexibility in this cluster used. Each device has two controllers: a traditional one which checks the level of the buffer and when it is near its minimum level turns on until the buffer is filled, i.e. business as usual, and a PowerMatcher controller. The PowerMatcher agent control logic for the micro-CHP and heat pump is based on the same generic structure with a slight variation for the heat pump. Figure 19 depicts the state of the heat pump based on the current fill level of the buffer and the price. Once the current fill level of the tap water and space heating buffer is received by the agent, using the below logic and accounting for minimum and maximum fill levels, a price for each can be calculated to create a bid curve.

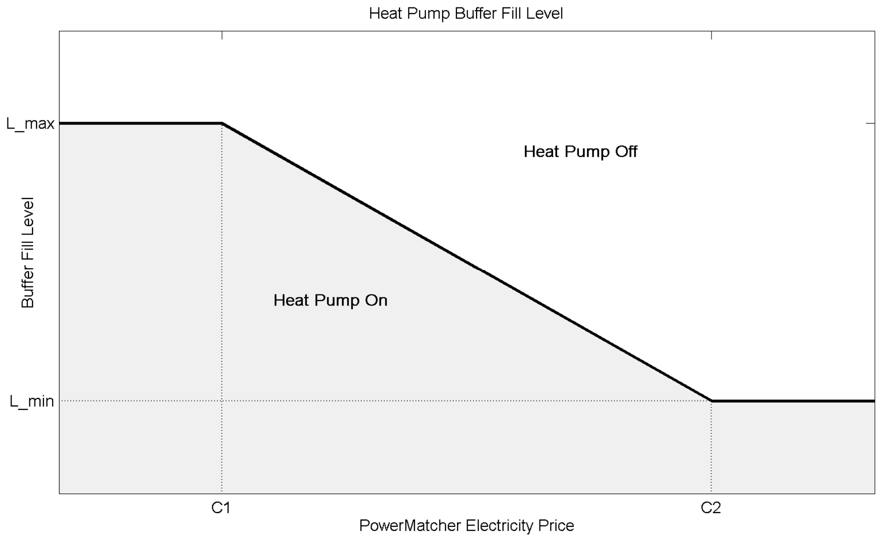

Figure 19: Heat pump intelligence based on fill level and price

4.1.2. Results and Key Findings of Simulation A, Part 1

The simulations cover a period of two weeks in the month of November. Five different scenarios have been calculated with total installed offshore wind capacity of 750, 800, 850, 900, and 1000 kW. All other energy factors have been left unchanged over the scenarios. A reference case in which a traditional control is exerted was compared to a scenario involving PowerMatcher-based control. The main findings can be found in Table 7. The table shows the total reduction in export of energy from the cluster and import into the cluster as a result of smart control. For all cases, there was an export reduction of well over 50%, even so high as 90% in the 750 kW wind case. In the Dutch scenario, this would mean less power export to the interconnected zones Germany, Belgium and Norway. The required import amounts that can be delivered from other zones, but it is more likely that these imports are delivered by one or more fossil-fuelled power plants delivering reserve capacity. The last column in the table therefore denotes both reduction in required reserve capacity and reduction in fossil fuel based primary energy or in CO_2 emissions, ranging from 14% for 750 kW of installed wind power to 21% for 1000 kW. Note that the reduction is not only in total but also in % increasing with increased offshore wind capacity indicating that any investment in the power matcher technologies increases together with enlargement of installed wind power capacity.

	Amount of total export needs for each case			Amount of total import needs for each case		
Offshore wind	Traditional	PowerMatcher	Reduction	Traditional	PowerMatcher	Reduction
750 kW	3370 kWh	328 kWh	90%	27389 kWh	23447 kWh	14%
800 kW	3841 kWh	583 kWh	85%	26287 kWh	22154 kWh	16%
850 kW	4349 kWh	900 kWh	79%	25218 kWh	20920 kWh	17%
900 kW	4882 kWh	1256 kWh	74%	24178 kWh	19739 kWh	18%
1000 kW	6048 kWh	2099 kWh	65%	22194 kWh	17478 kWh	21%

Table 7: Amount of total export for each case

In the scenarios with PowerMatcher, it was shown that the portion of the generated wind energy was better utilized by the cluster of households (see Figure 20). For the controlled case, wind generation (blue line) and power consumption in the cluster (green line) almost completely coincides. There are many instances in which not all wind energy is absorbed by the residential cluster unless smart control is exerted. This behaviour can be seen in all cases, except for short periods in the 1000 kW wind penetration case. In all other instances, the PowerMatcher coordination is able to accommodate all wind within the cluster, while in the business-as-usual case a large percentage would be exported or curtailed. The PowerMatcher cluster by far utilizes more energy produced in the cluster than that of business as usual which not only increases the amount of renewables that can be accommodated in the cluster but also decreases the amount of energy that would otherwise have to be imported from alternative resources (fossil fuels) to support the demand.

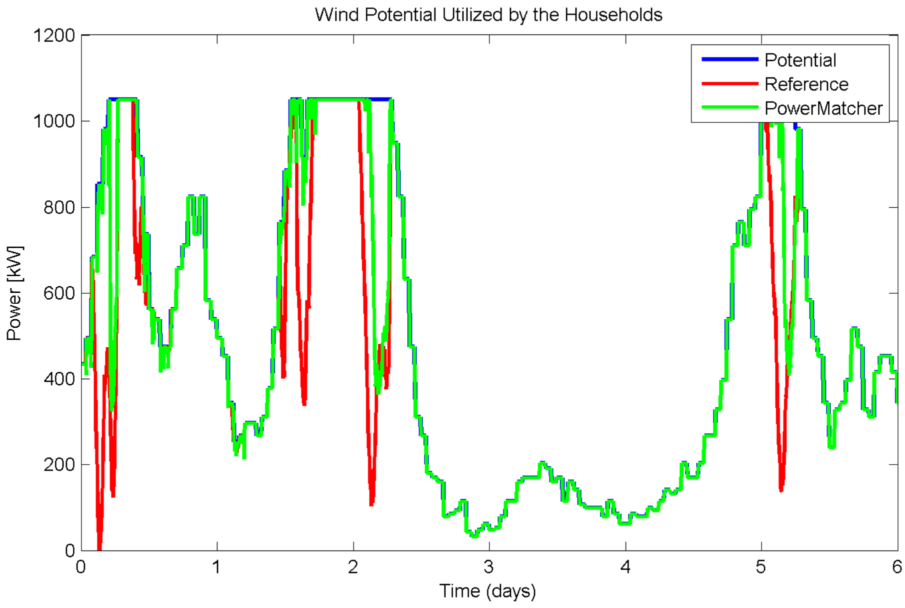

Figure 20: Wind potential and utilization with 850 kW installed off-shore wind capacity

The simulations conducted in this case study show that the smart grid offers a huge potential in utilizing flexibility of demand and supply in homes to accommodate mass integration of electricity produced by wind. For the Dutch situation, smart control of household devices leads to a large utilization factor compared with business as usual. The PowerMatcher technology additionally leads to a reduction in peak power. Note that the amount of flexibility in the cluster was limited to household heating devices. If other household appliances, such as fridges, freezers, dishwashers etc. are utilized in the same way, the flexibility in the cluster can be improved, leading to an even better outcome. Another interesting case would be if electric vehicles are also included in the cluster. It is expected that the inclusion of more device groups will further increase the positive impact of the PowerMatcher.

4.2. Support of Low-Voltage Grid Operation by Smart Houses: Simulation A, Part 2

4.2.1. Simulation Setup and Objectives

Recent studies indicate the potential of distributed coordination of demand and supply to reduce cable losses in the low-voltage grid (e.g. from the IMPROGRES project, http://www.improgres.org/). Simulations using the PowerMatcher simulation tool will focus especially on the simultaneousness of demand and supply by control of smart houses. The simulation results are fed into distribution network simulations to quantify the reduction of grid losses. These simulations focus on reduction of cable losses by increasing local sustainable demand and supply solutions. The simulation model comprises a low-voltage (LV) distribution system. A generator (positive/negative) is used to simulate the import/export power flow.

An LV network is defined with 25 households. Each of these households has an individual household load, representing the non-controlled loads. As controllable loads, the houses' heating systems (heat pumps and micro-CHPs) are modeled separately. The PowerMatcher simulation configuration consists of agents representing an auctioneer, concentrators, and households including heat pumps. This model is connected to a steady-state model of the electrical distribution system. The PowerMatcher simulation and the electrical distribution simulation run asynchronously, i.e. the results of the PowerMatcher simulation after a complete run are saved in text files which are then used as input files for the electrical distribution simulation. Figure 21 illustrates the grid model in which the households are clustered in groups of five.

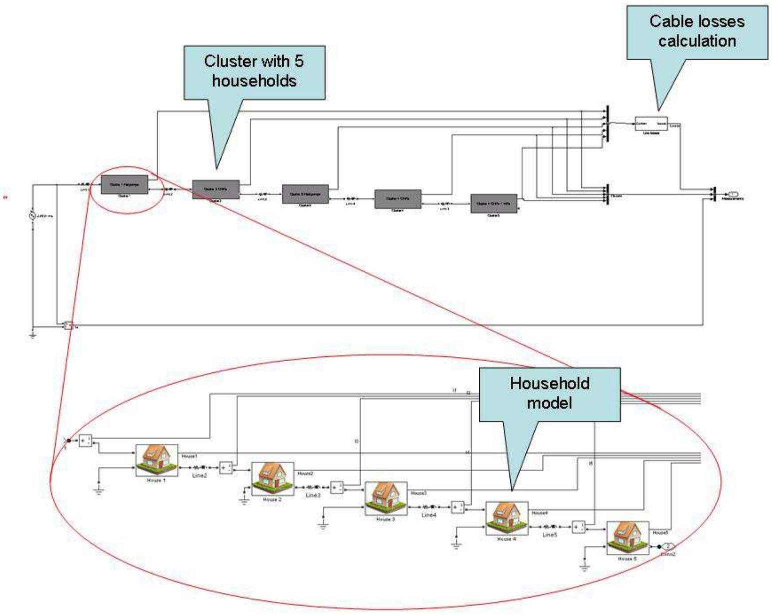

Figure 21: Grid model with clustered households

A random profile generator for the heat demand of individual houses has been developed. In this generator, a number of parameters can be defined upfront to obtain the heat demand profiles which include the type of house, and number of occupants. A similar approach has been applied for the generation of the households' consumption patterns.

The electrical distribution system has been developed in the Matlab/Simulink environment which also includes the SimPowerSystems toolbox. This toolbox contains dedicated models of electrical devices. For this study, controllable current sources (CCS) were used to represent the profiles as defined by the PowerMatcher simulation. This approach is applicable for the household, micro-CHP and heat pump profiles. The modeled profile controls the CCS directly, where the measured output is the current i_{CCS}. If in addition, the voltage v_{CCS} across the CCS is measured, the power P_{CCS} can be calculated as follows:

$$P_{CCS} = i_{CCS} * v_{CCS}$$

P_{CCS} should be equal to the power P_{PM} as defined in the PowerMatcher profiles. The mismatch between P_{CCS} and P_{PM} is defined as ε. In this study, only resistive energy losses in the cables were considered, ignoring other losses. At this stage of research, the focus is only on fundamental frequency cable losses. Losses involved with harmonics are not studied. This simplification allows the simulation to be executed fast whilst keeping ε equal to zero. Also, it allows for extending the simulated time and number of households easily. The resistive cable losses P_{cable_loss} can be calculated by the following equation:

$$P_{cable\_loss} = i^2 * R$$

where i is the modulus of the complex current through the cable and R the resistance of the cable respectively. R was assumed to be 0.494 Ω/km [Oldenkamp et al. 2004]. The cable length between the individual houses was assumed to be 10 m.

The described model has been run over a period of 24 hours. A typical day in January was chosen to represent the 24 hour simulation time. The electric and thermal power of the simulated micro-CHPs and heat pumps are 1 kW$_{elec}$ / 4 kW$_{th}$ and 1 kW$_{elec}$ / 6 kW$_{th}$. The space heating and tap water buffers, which are set to 120 and 90 litres respectively, are assigned their own tap and heat water patterns which updates the buffers for each household. In the base-case (case 1), a traditional non price-sensitive heating controller was modelled; the case 2 study considers the same day with the PowerMatcher control algorithm included.

4.2.2. Results and Key Findings of Simulation A Part 2

Figure 22 illustrates the results of the simulation where the red-dotted and blue-solid line represents cases 1 and 2, respectively. From this graph, it can be seen that the peaks for the PowerMatcher case are generally smaller and narrower compared to base case. Besides, the peaks are shifted in time. For example, at about 27,000 s (07:30 am), there is an increase in cable losses due to simultaneous electricity usage in the morning. The cable losses peak at about 450 W for case 1; for case 2, the peak is shifted and reduced to about 300 W.

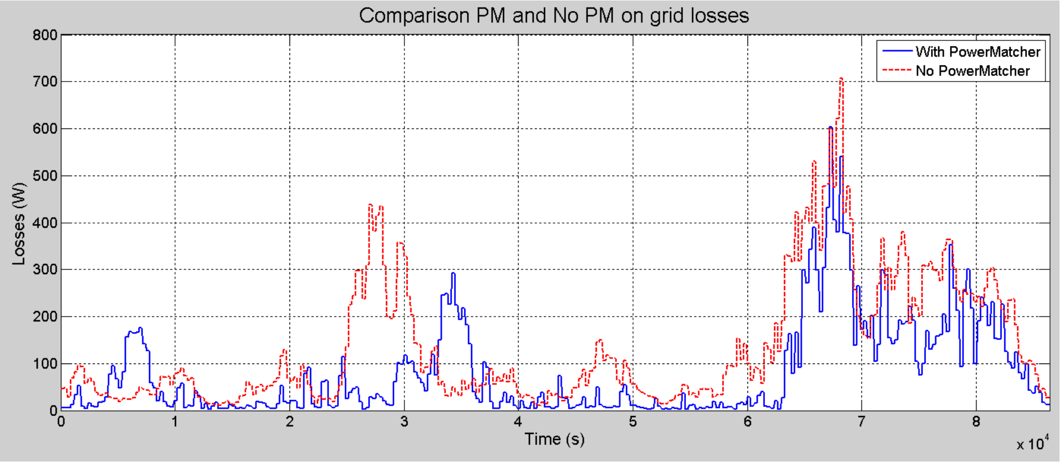

Figure 22: Cable losses with PowerMatcher control (blue) and without (red)

The accumulative energy losses across the cables over a period of 24 hour in this study are equal to 11.7 MJ and 7.0 MJ for case 1 and 2, respectively. This means that for the base case, the energy losses are 40.1% less compared to the energy losses for the PowerMatcher case. This reduction of 4.7 MJ equals 1.3 kWh of energy. Because the simulations are done with the data of a day in January, simple extrapolation to annual losses are not realistic, because heat-pumps and micro-CHPs are more active in the winter time. However, during the whole year, a significant amount of heat is used for tap water and shower. Although the complexity of the studies was limited to the steady-state analysis of 25 households, the potential of deploying an intelligent distributed control, such as the PowerMatcher, has been demonstrated successfully.

4.3. Low-Voltage Grid Support by Day-Ahead Schedules: Simulation B

4.3.1. Simulation Setup and Objectives

The set of simulations reported here model smart houses within a low-voltage network with high share of photovoltaic generation. The smart houses implement automated load management based on day-ahead schedules. This management is assumed to be implemented by ISET-*BEMI+* algorithms (described in detail in deliverable D2.2). The overall goal of the considerations is study if and how smart houses can support LV grid operations, especially how they can help increasing the accommodation ceiling for renewable energy and reducing line losses.

The simulation software developed by Fraunhofer IWES models the behaviour of smart houses equipped with **ISET-*BEMI+*** control in the electric distribution network. It is a discrete steady-state simulation with equidistant simulation steps. The simulation program used here comprises the two modules *BEMISim*, which models individual smart houses, and *BEMI_DSIF*, an interface module to professional grid calculation software (see Figure 23).

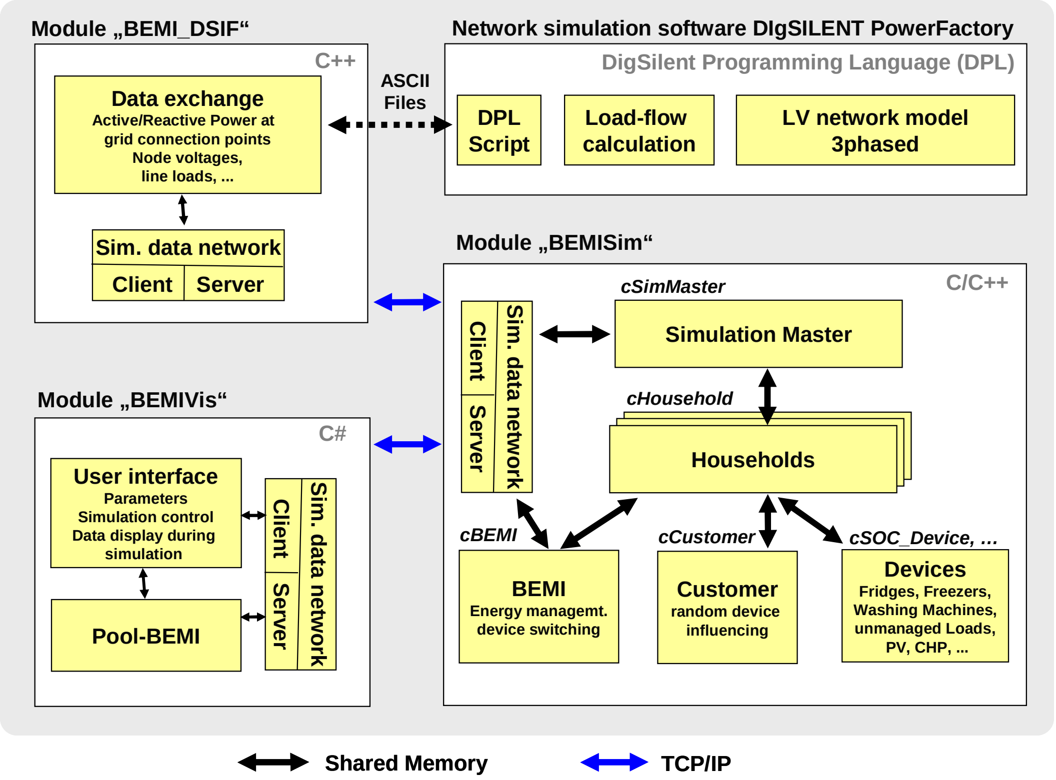

Figure 23: IWES simulation system block scheme

The *BEMISim* module includes different device classes for typical households: state-of-charge (SOC) devices (e.g. freezers) and fixed-program-schedule (FPS) devices (e.g. washing machines). Customer usage of devices was simulated using statistical approaches, which ensure that many individual household load profiles add up to known standard profiles. Photovoltaic generators were modelled using measured solar irradiation data. For tariff-based optimization, the simulation uses BEMI's energy management algorithms.

The *BEMI_DSIF* module interfaces the simulation system to the professional grid calculation software PowerFactory from DIgSILENT. This enables all PowerFactory functions to be used by the simulation, thus allowing for most flexible graphical distribution grid modeling. For the SH/SG simulations, the load-flow calculation functionality was used in order to automatically calculate steady-state grid node voltages, line and transformer loads and losses after each simulation step. The simulations included the following steps:

1. Input of network topology and customer data as provided by MVV into the simulation system
2. Performing pre-simulations by applying fixed loads to each network connection point (PCC) and carrying out load-flow calculations in order define network configurations for further simulation
3. Defining parameters for the household simulation BEMISim and performing the actual simulation runs, resulting in trajectories of load-flow calculation results
4. Calculating characteristic values from the trajectories for quantitative result analysis and comparison

It was assumed that each of the households was equipped with controllable appliances – two state of charge (SOC) devices and three fixed-program schedule (FPS) devices. For the FPS devices, the simulation uses a stochastic model. For the SOC devices, results from laboratory and field tests were analyzed. Maximum switch-off and switch-on times along with parameter variation intervals were chosen based on these measurements. On the generation side, a high amount of infeed by PV was to be assumed in order to see if smart houses could benefit grid operation in such cases. The simulations only considered active power infeed; thus, PV generation was modelled with cos phi = 1.

The simulation runs were carried out for six subsequent simulated summer days with a simulation step of five minutes. As shown in Figure 24 left, there is almost no disturbance of the PV infeed by clouds during four of the six days. The load follows the VDEW H0 profile and shows typical peaks. Except for the simulated Sunday (second day), the load curve shows poor correlation with the generation curve.

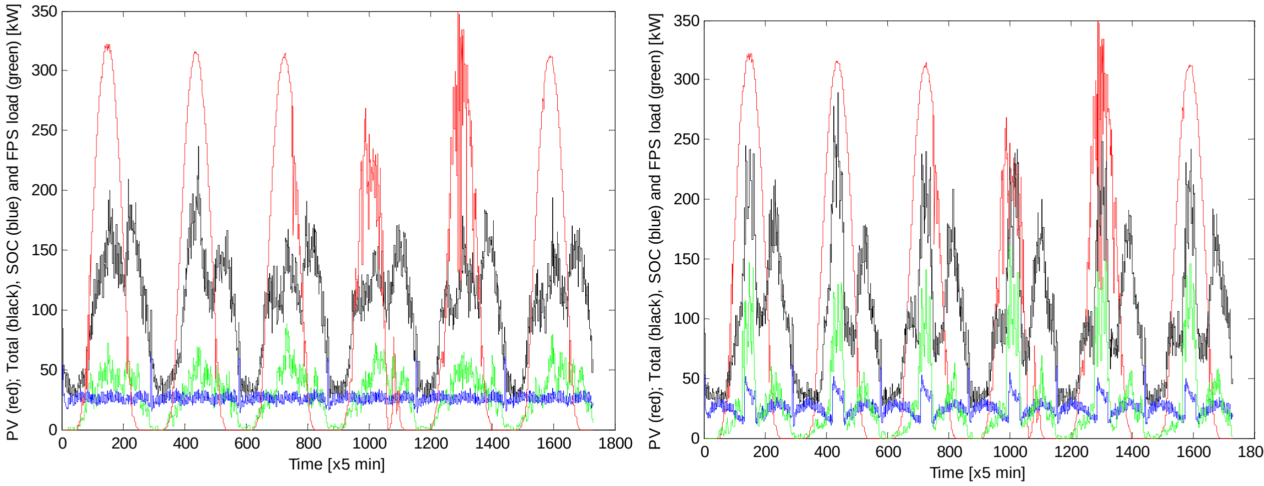

Figure 24: PV infeed (red) vs. total (black), SOC (blue) and FPS (green) load with flat tariff (left) and PV tariff (right)

A case with assumed flat tariff is taken as the reference scenario. For the SH/SG scenario, the tariff profile is designed in a way that smart houses have an incentive to shift as much load as possible into times of highest PV infeed. From simulation results with the flat tariff, it was expected that such a *PV tariff* would also yield positive effects on line losses, line loads and node voltages.

In the following sections, the time interval of 11:00-13:59 of each simulated day is designated as *low price time*, while the rest of the day is designated *high price time*. Figure 24 right shows the simulation result for the PV tariff. A significant load shift to the low price time can be observed when compared with the left figure. The load shift is mainly attributed to FPS devices. The maximum load switched on during low-price times as compared to the base tariff case is in the range of 300 W per household. In order to quantify the load shift effect, the residual load power P_res can be used, which is defined as:

$P\_res(t) = P\_load(t) – P\_gen(t)$,

where P_load is the total load and P_gen is the total generation power

Thus, values of *P_res(t)* near zero indicate a better match between load and generation; negative values indicate that there is a power flow leaving the considered network area (exports).

4.3.2. Results and Key Findings of Simulation B

The results for the individual simulation runs are trajectories of grid operation parameters over time. Figure 25 left gives an example. Here, line losses are shown for a simulated day. Trajectories for the flat tariff and PV tariff are compared. It can be observed that line losses are smaller in the PV tariff case during the low price time, but at other times exceed the line losses in the unmanaged case. Concerning the line loss energy, a reduction of about 8% was reached in this simulation run, hence line loss savings are predominating.

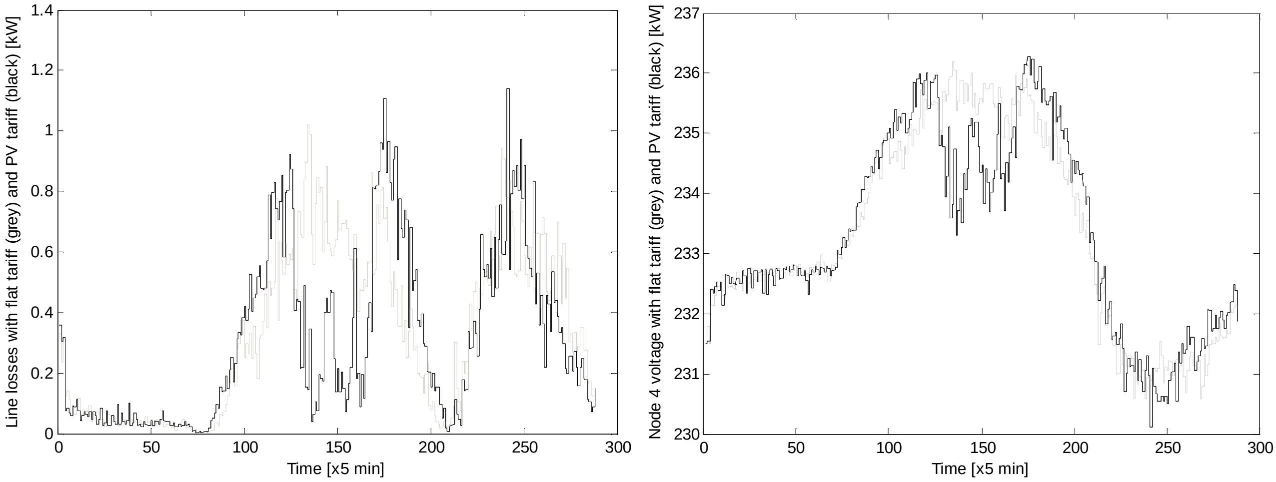

Figure 25: Line losses (left) and absolute phase-ground voltage (right) with flat tariff (grey) and PV tariff (black)

As another example, Figure 25 right shows the absolute average phase-to-ground voltage as result of the same simulation run. It can be observed that the node voltage in the low-price time of the PV tariff is reduced as compared to the flat tariff situation. However, the overall maximum voltage for that day is not reduced in the PV tariff case. Instead, a new maximum was created outside the low price time that even exceeds the maximum of the flat tariff case originally created by high PV infeed. Hence, it is concluded that the chosen tariff is not suited for reducing voltage maxima in the network. However, the PV tariff could still contribute to voltage control in the network and lower the need for implementing other measures, e.g. reactive power infeed by PV generators. This again could yield economical benefit in total and should be subject to further research.

From the results, it can also be assumed that any load-shifting tariff has to be designed in order to meet a certain goal and that reduction of line and transformer losses, loads as well as voltage control and load-generation balancing each define individual goals. Thus, individual tariffs are needed to meet the given goal optimally.

From the simulation results, it can be concluded that the introduction of a PV tariff does increase the locally used PV and decrease energy imports into the network area. However, these changes are marginal: over all simulation runs, the average import savings are 3.7%, PV export decreases by an average of 5% and locally consumed PV increases by average 3.7%. This small effect can be attributed to the fact that the used tariff only has a short low-price time, which was chosen to reach a higher effect on grid losses. The PV tariff is indeed reducing network line active power losses. The loss savings are in the order of about 8-9%, depending on the studied grid topology. On the downside, the savings in transformer active power losses are around 1%. Though marginal, they can be considered to be caused by the tariff change. Still, transformer losses exceed line losses. Transformer loads are reduced more significantly during the low price times.

Overall, the simulations indicate that the PV tariff met the expectations, but in some cases merely marginally changed the characteristic values. Contribution to reducing line losses is significant, because the PV tariff was specifically designed for this. Judged from voltages, line and transformer loadings, the results indicate that weaker grids benefit more from the tariff effects. The merely marginal effect on decreasing energy imports and increasing locally used PV can be attributed to the high PV installed power and the restricted long-term load management potentials indicated by BEMI testing in a private household and preliminary field trial results from Mannheim.

4.3.3. Conclusions for Application of Load Management in Sandhofen and Feudenheim

The relevance of the simulations reported above for a utility was demonstrated in an additional investigation where the existing low voltage grid was investigated for potential bottlenecks in a future grid with more distributed generation. MVV studied the capacity of two urban quarters in Mannheim, i.e. Sandhofen and Feudenheim, to host distributed generators and charging stations for electric vehicles. Both suburbs had a structure and user profile comparable to the low voltage grid simulated in the previous section.

The idea was to check if any capacity bottlenecks can occur in a very strong and meshed low voltage grid typical for Mannheim and similarly developed sites in Germany (and neighboring countries). In order to validate the use of the Smart House/Smart Grid approach for demand response, one result of this study is the amount of load shift that would be necessary to avoid critical voltage and current situations in the grid.

The technical parameters of low voltage grids are normally not known in such detail as middle and high voltage grid. However, there are several grid SCADA and asset management software systems available which can be used for low-voltage grids after some modifications. ABB’s NEPLAN software was used and the needed modifications to low-voltage grid specifications were developed in a first step (in cooperation with ABB). In the next step the low-voltage grid of the three suburbs of Mannheim were mapped by transferring low voltage grid data from the global information system into NEPLAN.

The team first elaborated scenarios for distributed generation and electric vehicles regarding to their technical potential and potential bottlenecks – for today as well as for the years 2030 and 2020. Load flow calculations were performed in order to identify critical impacts on voltage. An example of such a bottleneck is the case of high penetration of photovoltaic in a low-voltage supply line with at the same time low demand. Such a case was identified in a residential area at times with high solar irradiation and consequently high PV in-feed during times when inhabitants left for long weekends or vacation. The bottleneck was detected by load measurements at different locations in a low-voltage grid during very sunny days (= high PV in-feed) with low consumption during the Eastern weekend – a long weekend with many inhabitants leaving on vacation or for excursions during the day.

A combination of measurements and simulations resulted in potential bottlenecks for a strongly meshed grid already today. Even if the technical potential for distributed generation and electric vehicles will not be reached in total for a whole city, experience has shown that there is a high probability that whole neighborhoods decide to install PV systems on their roofs. It is expected that the technical potential for single feeders will be reached in the near future. For MVV, it is a valuable result that the grid planning team is now enabled to quickly calculate impact of distributed generation and electric vehicles on those grid segments that have been studied in the context of this project. The grid ‘vulnerability’ for bottlenecks will increase considering a future trend to less meshed grids (due to cost reasons the number of low and medium-voltage feeding points will be reduced), higher penetration of distributed generation (e.g. more micro CHP) and in particular any effects of electric mobility. It should also be noted that there are many regions in the EU with much less meshed grids, showing the same effect more dominantly.

With a high penetration of distributed generation and electric vehicles, grid planners must consider demand response in their planning rules to achieve optimal grid design and operation. Together with the simulations presented in the previous section, it was shown that an energy management system will be a valuable tool to remove or reduce potential upcoming bottlenecks in low-voltage grids caused by increased distributed generation in particular for less-meshed grid.

4.4. Support of Medium-Voltage Grids by Smart Houses: Simulation C

4.4.1. Simulation Setup and Objectives

In order to examine the contribution of the mass application of intelligent control to the optimized operation of the electricity grid, the autonomous power system of Crete is simulated. Various levels of intelligent control penetration are considered. For each one of them, a steady-state analysis of the system is performed. The software package Eurostag is used as a simulation tool. Eurostag performs load flow analysis as well as simulation in the time domain. Modelling of the system includes the components of the transmission system (lines, transformers, loads) as well as its dynamics such as generators, voltage and frequency regulators and renewable energy sources. Prior to the load flow analysis, an economic dispatch algorithm is applied, while the simulation is performed on an hourly basis for an entire year. Apart from the steady-state simulation, transient analysis is performed in order to examine the ability of controllable loads to contribute to the stability of the system during emergencies. Two cases are examined: one day of low load level and one day of maximum load level.

Since the target year of the study is 2030, the configuration of the Cretan system is modelled based on projections regarding the electricity consumption, units decommissioning program as well as the expected integration of new production units forecasted for 2030. For the transmission network topology, only the necessary grid reinforcements are considered. The simulation input includes annual hourly time series of the power system load, renewable energy sources (RES) annual hourly time series, wind power penetration limits, a generator merit order, technical minima of the generators, the units’ maintenance programs, fixed, variable and fuel cost data for each unit, and spinning reserve requirement data.

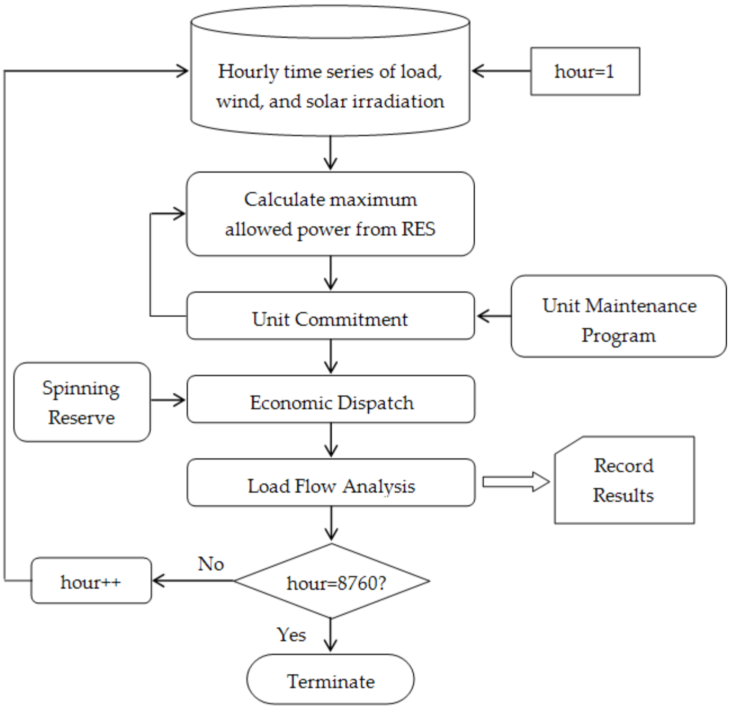

Figure 26: Hourly simulation flowchart for the steady-state analysis

Figure 26 illustrates the flowchart of the hour-by-hour simulation of the power system for the steady-state analysis. For each hour of the year, data regarding electricity consumption, wind velocity and solar irradiation patterns are combined with a recursive procedure that takes into account the technical minima of the committed units. Here, the maximum allowed power from RES that ensures secure operation of the autonomous system is 40% of the total load. Furthermore, unit commitment and economic dispatch is performed taking into account the unit maintenance program and the necessary spinning reserve.

With the transient analysis, the capability of controllable loads to contribute to the stability of the system during emergencies is examined. Such an emergency is a fault (a short circuit for example) that lasts only a fraction of a second, but which is capable of leading to major problems if not cleared immediately. Since PVs do not have fault-ride through capability, in case of a fault, PVs have to be disconnected from the grid, thus deteriorating the condition of the system, since a part of the load can no longer be served. In order to avert a more generalized propagation of the imbalance, the problem is solved locally by means of load shedding.

Two cases are examined: one with low load level (April – case 1) and one with high load level (September – case 2). In each case, we consider the time of the day during which PV production is maximum (12:00-13:00) and we perform simulation of the transient response of the Cretan system considering two sub-cases: no load shedding is available (sub-case A), or maximum available load for shedding equals the sum of the load of the water heaters and the air conditioning during the specific hour of the day (sub-case B).

The disturbance under study is a short circuit on Heraklion 150kV node with duration 150 ms. The imbalance between production and load caused by the loss of PV production leads to under-frequency. This deviation is recognized by a four-step under-frequency relay that triggers the necessary load shedding when the frequency drops under 49.8 Hz, 49.6 Hz, 49.4 Hz, 49.2 Hz. $Load_{i,2030} = \frac{E_{2030}}{E_{hist}} \cdot Load_{i,hist}$

In order to illustrate the impact of controllable loads on the operation of the electricity system, we define two basic scenarios: in the first one no load control actions are considered (business as usual, BAU); in the second scenario various levels of controllable load are considered. In the latter scenario, levels of 10–30% of controllable load are considered. In scenario 2A, load control is performed equally in all regions of Crete; in scenario 2B, load control is performed primarily to the households of Chania and Heraklion, which are the most populated cities of the island. As controllable loads, water heaters and air-conditioning devices have been modelled, considering winter, spring, summer and autumn hot water / cooling demand profiles.

Figure 27 illustrates the result of the application of load control actions described previously on the load of a substation for a time span of 72 hours (scenario 2A-10%) in comparison to scenario 1. The load control action is merely load curtailment during the hours when the substation load reaches its peak. The load not served during peak hours is shifted to the hours before and after the peak. By this way, a reduction in the peak demand is achieved, which can be as high as 4.49% (annual average) depending on the scenario considered.

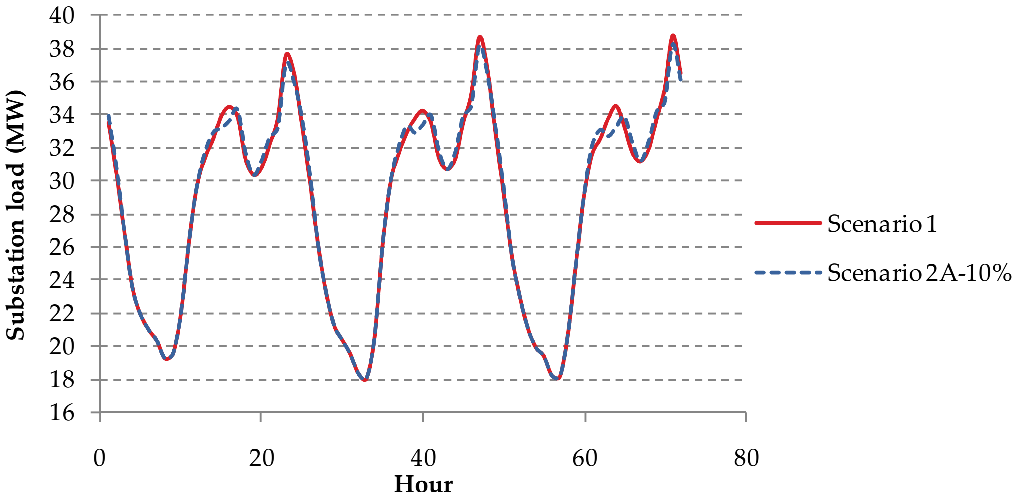

Figure 27: Load curve for a selected substation for a time span of three days w/o load control

4.4.2. Results and Key Findings of Simulation C

The results indicate that controllable loads improve the operation of the electricity grid during normal operation in economical terms, while in cases of emergencies, they contribute to averting a generalized outage. A comparison of the scenarios considered is performed for transmission line power losses, operational cost of the system and CO_2 emissions. The power losses on the transmission lines are obtained as a result of the load flow analysis (Table 8). An improvement is observed with higher levels of controllable load for both scenarios A and B. Furthermore, in scenario B in which the majority of controllable loads are concentrated in the two largest cities of the island, line losses similarly decrease with higher levels of controllable load, but already at lower penetration levels. Regarding the operational cost of the system of Crete (Table 9), a similar linear relationship with the penetration level is not observed. It seems that there is an optimal level of controllable load that ensures lower costs during the operation of the system. This observation can be attributed to the type of load control that is applied: load shifting changes only the shape of the curve, while the total energy demand remains the same. Given the fact that the load not served during peak hours is shifted to the hours before and after the peak, for high penetration of load control the peak might not eliminated, but it is shifted similarly. The CO_2 emissions reduction in scenario 1 ranges between 624 and 4.613 tons (-0.04% and -0.31%, respectively) depending on the scenario (Table 10). The same observation as with the line losses can be made here: for scenario B, where load control is primarily applied to the two largest cities, the same improvement on the emissions is achieved but for lower levels of controllable load.

	Scenario 1	Scenario 2A		Scenario 2B	
10%	6.871%	6.851%	-0.020%	6.839%	-0.032%
20%		6.845%	-0.026%	6.837%	-0.034%
30%		6.837%	-0.035%	-	

Table 8: Line losses as a percentage of the production per scenario – comparison to scenario 1

	Scenario 1	Scenario 2A		Scenario 2B	
10%	215,957,553	215,204,940	-0.35%	214,455,919	-0.70%
20%		212,843,853	-1.44%	214,720,126	-0.57%
30%		213,694,172	-1.05%	-	

Table 9: Operational cost of the system (in €) per scenario – percent change compared to scenario 1

	Scenario 1	Scenario 2A		Scenario 2B	
10%	1,468,351	1,467,728	-0.04%	1,465,906	-0.17%
20%		1,466,253	-0.14%	1,463,738	-0.31%
30%		1,464,271	-0.28%	-	

Table 10: CO_2 emissions (in tonnes) per scenario – percent change compared to scenario 1

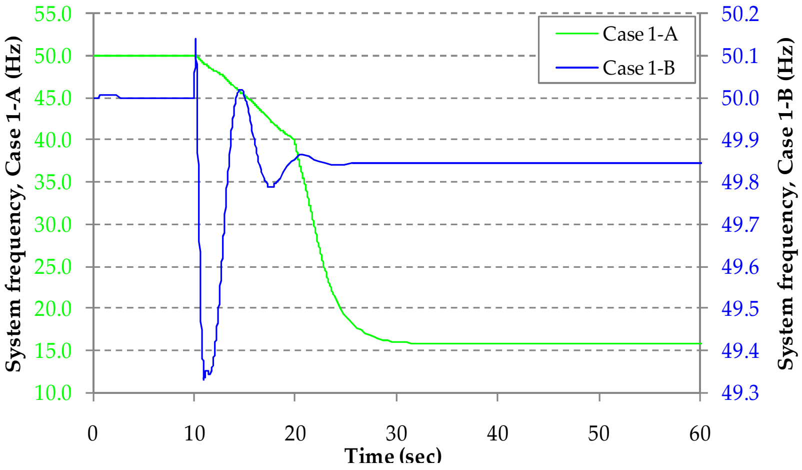

Figure 28: System frequency for the low load case

Figure 28 illustrates the frequency of the system for the case of low load level (case 1). When there is no load shedding, the disconnection of many PV plants and wind turbines causes the frequency of the system to dip to levels below 48Hz. This frequency dip, in turn, causes the conventional units to disconnect, resulting in a generalized outage of the system (Figure 28 left). In case 1B, the loss of RES production is compensated by the load shedding that occurs. The initial frequency dip causes load shedding which results in the restoration of the frequency to a level close to its nominal value (49.85Hz). The frequency does not reach levels below 49.33Hz. Although the power generation of the units fluctuates during the transient period, it is restored to a level close to the initial (Figure 28 right).

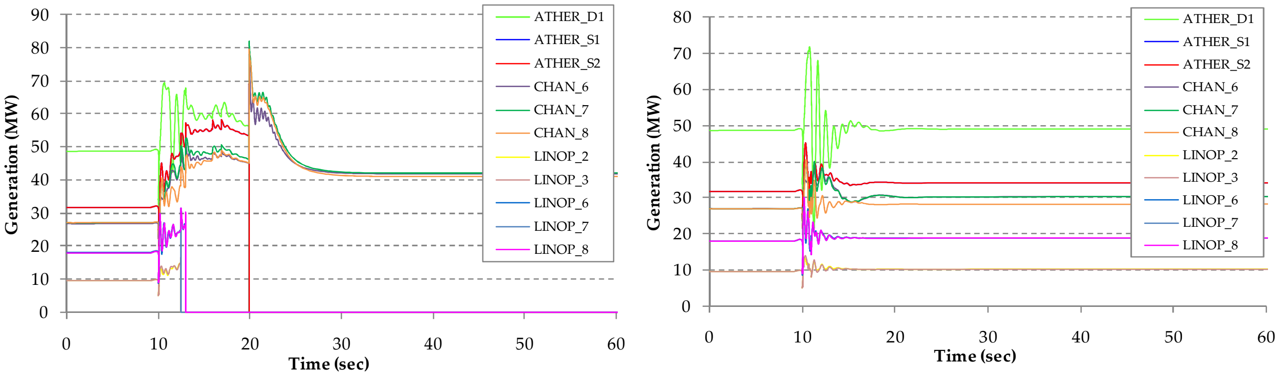

Figure 29: Active power production of conventional units with (left) and without load shedding (right)

In the second case, the disconnection of PVs and wind turbines causes a frequency dip. However, in this case the system is characterized by high inertia due to the greater number of generators that provide support to the system frequency. Thus, the frequency does not reach levels lower than 49.54Hz (Figure 30 left, case 2A). The conventional units increase their production in order to compensate for the loss of RES generation (Figure 30 right) and the frequency is restored (49.76Hz). When load shedding occurs (case 2B, not depicted), the initial frequency dip causes load shedding which results in the restoration of the frequency to a level close to its nominal value (49.96Hz). In that case, the production units need not increase their output, since the loss of PV plant and wind turbine production is compensated by the load shedding. Although the power generation of the units fluctuates during the transient period, it is restored to a level close to the initial.

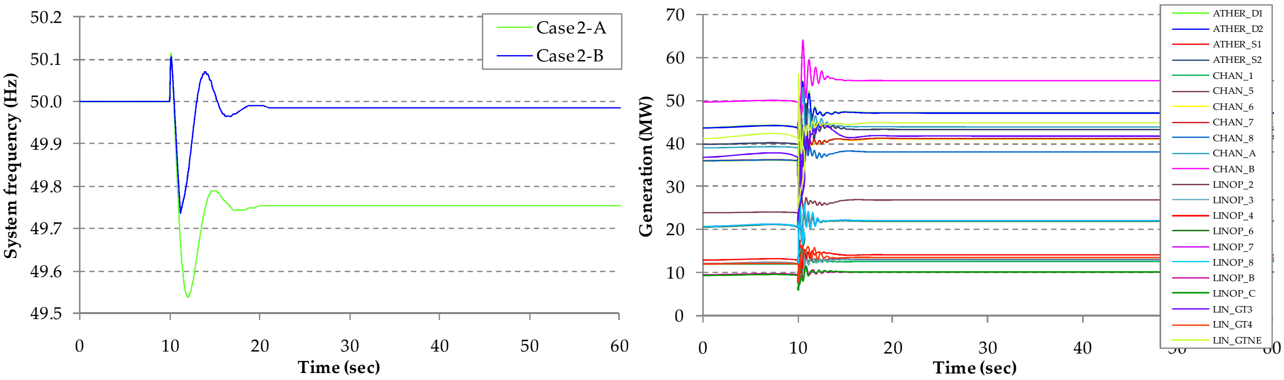

Figure 30: System frequency (left) and active power production (right) for case 2A

Regarding the steady-state analysis, the power line losses in the transmission system do not seem to be greatly affected by the level of controllable load. Rather an improvement in CO_2 emissions and the operational cost of the system is observed. The latter effect, however, does not increase with the number of the participating households: it seems that there is an optimal penetration level, above which no further improvement can be achieved. It is observed that lower levels of controllable load suffice to induce the same improvements as long as they are concentrated in the most populated urban regions. Another significant contribution of controllable loads is in the operation of the system during emergencies: it helps reducing the spinning needed from conventional units and minimizes the discomfort of a generalized black-out.

4.5. Viability of the Defined Business Cases

In an economic analysis, it was investigated how possible business cases in a smart grid environment work out financially and to what extend the investment costs in ICT infrastructure can be refinanced by the accompanying savings. In order to reflect all technologies developed within this project, several business cases have been analyzed.

Due to some constraints from data availability, the business cases worked out in deliverable D1.1 were slightly altered from their initial definition. Where necessary, a detailed description of the considered cases is given here. Three representative business cases, each representing one of the three technologies developed within SmartHouse/SmartGrid, have been defined. These are the following:

- Case 1: Real-time imbalance reduction in a balancing area
- Case 2: Procurement cost minimization via variable tariff based load shifting
- Case 3: Distribution grid cell islanding in case of higher system instability

For all investigated cases, reference scenarios have been defined that include all important parameters for the individual cases. On this basis, an investment analysis applying NPV for all actors is provided. The results are then tested by altering key parameters of the reference scenario in a sensitivity analysis.

One common assumption for all cases is the ten year horizon for the investments. As there is no empiric data about the lifetime of the technologies included in the business cases, the ten year time frame was chosen based on expected lifetime of smart metering components which can be seen as a complementary technology for the present technologies.

The investment calculations have been done under the following assumptions:

- The capital market is efficient with a flat interest rate structure of 5 %. This discount rate was varied in a sensitivity analysis, but the main characteristics of whether a business case is viable or not did not change with a variation of interest rate.
- The initial investments are financed cash, so no interest payments are made.
- Tax effects are neglected.

The formula used for the calculation of the net present values is $C_O = -I + \sum_{t=1}^{T} R_t * (1+i)^{-t}$, where I is the initial investment, T is the number of periods (years), R_t is the cash flow in period t and i is the interest rate.

At the core of **Case 1** is the balancing responsible party (BRP) with its standard load profile customers, i.e.: households within its balancing area that deliver flexibility services to the BRP via the PowerMatcher technology and thus minimize the costs for balancing power. For estimating the possible savings by avoided balancing power, data from three German distribution system operators have been analyzed. The costs for balancing power induced by the load deviation of standard load profile customers are assessed under the following most relevant case that the price for balancing power is positive and there is a shortage in the balancing area, i.e. the suppliers seeks to avoid this shortage through real-time control.

A reference balancing area was modeled and the average load deviation per 15 min interval in a shortage situation induced by all standard load profile customers was estimated based on data from the German market. 10,000 households are supposed to be equipped with the PM technology, and different flexible loads were modeled.

The result from the analysis of this business case with investment costs that can be assumed for a mass-scale roll-out of the PowerMatcher technology is that the gains from load management largely exceed the needed investments, leading to a positive business case.

Case 2 was dealing with variable electricity tariffs in combination with automated demand response, such as enabled by the bi-directional energy management interface BEMI. The financial analysis of this business case included power procurement costs resulting for a load curve under a flat tariff in comparison with the load under the optimized variable tariff (analyzed data was taken from the German EEX). On the other hand, the possible load shifting potential was estimated. Calculations based on [Block et al. 2010] as well as data [Nestle 2007; Ringelstein 2010] was taken as the basis for the business case assessment.

Resulting from the potential savings and the investment costs related to the given business case, it must be stated that with current wholesale price spreads, it is hardly possible to refinance the necessary investments into the technical infrastructure. However, if additional applications such as peak load reduction and balancing power provision can be provided with the same hardware, as proposed in [Ringelstein 2010], then positive business cases can be realized with higher probability.

Case 3 deals with the improvement of the security of electricity supply in areas of unstable grid operation. Here demand and supply side flexibility can contribute to restoring operation in critical situations and can deliver black start support; this potential is leveraged by the MAGIC technology. It is assumed that the MAGIC equipment can be operated by a commercial aggregator who manages a grid segment and helps the DSO to ensure stable grid operation, including setting segments to islanding mode or reconnecting them to the grid. As a reference case, a grid segment behind two average 10 MW feeders at the 20 kV level was modeled including a defined number of residential as well as small, medium-sized and large commercial customers. Average interruption costs, normalized by the annual peak demand (kW) and a four hour outage have been estimated for the above mentioned groups based on the willingness to pay for avoiding interruptions (with data taken from the literature Average interruption times in Greece are above four hours (~4.8 hours per year), so the interruption costs of a four hours outage represents the lower bound for the willingness to pay of the customers. It is assumed that in a situation of unstable grid, the local demand should be met by local distributed (mainly renewable) generation.

If overall savings are put into the context of the necessary investments into the technical infrastructure for the given scenario, then the NPV turns out to be negative. However, hardware cost reductions in a mass roll-out scenario are probable. Further sensitivity analyses with unchanged hardware costs show that an above average interruption time per year (>12 hours) would yield a positive NPV for the installation of the system.

In summary, it can be stated that not all possible business cases for smart grids end up profitable for an investor. In some cases, the investment costs dominate possible earnings. The reduction in balancing power costs is the only case that contains the financial potential to justify the investment in the underlying technology. In summary, the findings of the investment analysis suggest:

- The deployment of SmartHouse/SmartGrid technologies definitely entails business opportunities that have potential to help refinancing the investments.
- In order to make the implementation of a business case profitable, the initial hardware and IT integration investments must be brought down considerably.
- Some SmartHouse/SmartGrid technologies can only be applied if the regulatory framework is changed or the availability of data on current grid situations is enhanced.
- (Real-time) balancing and power supply enhancement are interesting applications for SH/SG technologies, whereas it is less interesting to only focus on procurement cost minimization for an energy retailer.

This shows that the introduction of smart grids is not obvious. In parallel to promotion schemes for (fluctuating) renewable and decentralized energy generation, the regulatory framework must be designed properly and support should be given to development activities that help to bring the implementation costs of the technologies down considerably.

5. What SH/SG Technologies Can Achieve

5.1. Measurable Objectives Revisited

Four categories of measurable objectives have been defined for the SmartHouse/SmartGrid project. These have been introduced in Section 1.2. In this section, the outcome of the measurements and analyses carried out to evaluate the measurable objectives is presented. Table 11 through Table 14 summarize the objective again and specify in which trial or other activity of the project the objective was measured. After each of the tables, the explanation of the actual measurements and a summary of their outcomes are given.

Measurable Objective A: The developed ICT technical functionality works under real-life field conditions.						
		Trial A	**Trial B**	**Trial C**	**WP 4**	**D1.2/ D5.3**
Objective A.1	Scalability of the intelligent communication and negotiation architecture, such that it is able to handle on the order of thousands of energy devices simultaneously. The scalability of the device-to-device communication and e-market negotiation technology and architecture is especially verified in the Netherlands field test. It is furthermore verified by means of additional large-scale scenario simulations that will be carried out.	x				
Objective A.2	Ease of use and responsiveness to end users, in particular home customers. The adequacy of energy end-customer and home-user interaction is specifically verified in the German field test. Verification will be done by surveys, focus group meetings, and interviews of involved home customers participating in the test. An additional, triangulating form of verification is foreseen by means of keeping electronic traces and logs of customer interaction and corresponding energy system events.		x			
Objective A.3	Real-time control flexibility and optimality of the developed agent-based mechanisms for decentralized energy network-level control. This objective is field tested in particular in the field experiment carried out in Greece through running a so-called microgrid in islanding mode.			x		

Table 11: Mapping of measurable objectives A to field trials and simulations

For measuring the objectives A, the following measurements and analyses have been carried out:

- **A1**: A latency tests across SH/SG-Integral cluster has been carried out. In parallel, metering simulations have been conducted and mass metering data from trial A has been accommodated with the same metering data infrastructure. The overall delays between setting a set-point for the PowerMatcher cluster and the final reaction by the smart houses has been measured. The delays for the distinct levels of the infrastructure were distinguished for allowing more precise statements. For the trial A metering infrastructure for one million households, parameters like bulk size were varied and the effect on overall performance was measured.
- **A2**: It was only in trial B that customers actively interacted with the developed technology, so this objective is mainly answered for the BEMI portal. For evaluating the ease of use and responsiveness of the technology, the project relied on an evaluation of incoming calls by trial participants to the MVV call

center and customer surveys. Besides, MVV has commissioned a customer survey among the trial participants (this activity was not done in the framework of SmartHouse/SmartGrid, however), but it is briefly summarized in D3.3.

- **A3**: The real-time control flexibility was a focus of trial C. It has to be stated here that the “optimality” of the load control cannot be measured in the field, because there are too many unknown factors influencing demand that there is no solid baseline case that the smart operation can be compared to. The efficiency of the algorithm can be shown theoretically; also, a comparison between the simple algorithm and the distributed algorithm can be evaluated. In the trial, the system response to sudden changes in transformer conditions was analyzed, and the reaction speed to the changes (e.g. voltage dips) was measured.

The results from the measurements and the conclusion that can be drawn from the results are summarized in the following. More detailed results for the objectives are also discussed in the deliverables D3.3 and D4.2, which describe the field trial results and the simulation results, respectively.

- **A1**: The scalability objective has been tested in trial A only, so conclusions of scalability can only be drawn for the PowerMatcher technology and the studied metering infrastructure. It can be stated that the PowerMachter is actually capable of delivering flexibility within balancing period for a cluster of one million households, so it is sufficiently scalable for meeting the requirements of the business cases that were studied. Moreover, the metering infrastructure chosen in the trial was also easily scalable and sufficient for handling metering data for one million households. There are only few applications in other domains in which so large amounts of data will be pushed into databases frequently as in the smart metering and/or smart grid domain, so the requirements for these applications will be high and different from current applications; parameters like the bulk size need to be carefully set in order to meet these new requirements.
- **A2**:
  - Software side: It was found that the more information the customer receives, the more questions she/he has about her/his energy consumption and related characteristics. For example, customers were not aware of their fridge inside temperature before; with the BEMI, they could observe how the temperature evolves over time, and they started worrying whether the BEMI chooses the best possible operation. Given the number of questions (and complaints), it was decided to hide that information to the customer. It was also found that the BEMI portal was not intuitive enough, and even experts had difficulty setting the desired parameters. When they did not succeed after a few trials, they stopped using the BEMI functions and preferred to do manual load shifting. Overall, there was much more manual load shifting than expected. It was concluded that graphical user interfaces must be paid special attention – they should use easy terms to describe what can be set, give precise information about what the BEMI will do, make it easily understandable for a broad public, make it fun to use and use state-of-the-art professional GUI technologies that meet the expectations also of sophisticated customers. One experience from the BEMI implementation was also that the customer is easily annoyed by error messages that he does not need, so this will be changed in a later version. The overall experience is that customers are willing to respond to variable prices, but prefer to know them in advance and get a good bonus for load shifting.
  - Hardware side: On the hardware side, it was found that the large switchboxes that were used are quite annoying for customers, because at some places (especially in kitchens), they didn’t have any appropriate space where they could put them. All adjustments that involved cabling were very uncomfortable, so there should be as much wireless control as possible. Regarding the connection of appliances, it was found that many of them are too smart for control vial switch boxes, because they have their own electronic control that is reset when power supply is interrupted (which is the case when the switch box is in the off state).
- **A3**: The measurements for sudden changes in transformer conditions revealed that the MAGIC technology was capable of providing support for solving the problem, e.g. voltage dip, through

controlling parts of the loads of the smart houses in the cluster. From this, it can be concluded that it is technically possible to provide ancillary services with the MAGIC technology. Warnings that arrive in the order of 15 min before an event are sufficient to improve the comfort level during the event through the MAGIC technology, because it leads to a shedding only of the low priority appliances and not of the complete feeder.

Measurable Objective B: The developed ICT technology is affordable.						
		Trial A	**Trial B**	**Trial C**	**WP 4**	**D1.2/ D5.3**
Objective B.1	The developed technology is affordable in terms of the knowledge and time resources required from end users. It is known from studies that only a limited fraction of home users is capable and/or willing to spend significant effort in ICT-based energy saving and home automation actions. This is actually one reason why today's domotics has only achieved limited penetration in homes in Europe. The affordability of the technology in this human-resource sense is verified by the customer experiences especially gained in the German field test.	**x**	**x**	**x**		
Objective B.2	The developed technology is affordable in terms of financial investment and operational costs. Today's smart energy technology suffers from many proprietary system components that have difficulty in achieving the necessary big-scale interoperability. This makes it simply too complex and costly; it is in fact another major reason why today's smart energy technology has only achieved limited penetration in Europe's residential, SOHO and commercial building markets. The verification of this objective is carried out by the project through demonstrating that one can build Smart House technology on (i) using available open industry standards in both the ICT and energy sectors; (ii) employing communication and computing capabilities that are already in widespread use. In other words, the project's strategy is "piggy-backing" its smart-energy applications on infrastructure that already exists (often typically for non-energy purposes) in mainstream home and working environments.	**(x)**	**(x)**	**(x)**	**x**	

Table 12: Mapping of measurable objectives B to field trials and simulations

For measuring the objectives B, the following measurements and analyses have been carried out:

- **B1**: For all technologies, the steps that the user has to perform in order to install the PowerMatcher, BEMI or MAGIC technology in the house was reflected in combination with the required time and skill level. However, it should be noted here that in the trial, most of these steps were done by staff specifically trained for this task.
- **B2**: For objective B2, all costs that are involved with the necessary devices to be installed at the customer site, and also with the infrastructure needed at the DSO or utility (or energy service provider) level have been enumerated. The costs that occurred in the trial are of course largely higher than those that would

apply in a mass roll-out; therefore, costs for large roll-outs have been estimated based on the project members' best judgments. All numbers are given in deliverable D4.3.

The results from the measurements and the conclusion that can be drawn from the results are summarized in the following. More detailed results for the objectives are also discussed in the deliverables D3.3 and D4.2, which describe the field trial results and the simulation results, respectively.

- **B1**:
    - For the technician: As most of the steps for installing the SH/SG technologies were done by the project members or trained staff, the skills required from the end users is limited. However, it would be more relevant to specify which level of skill a technician has to have in the future so that he is able to install the technology in the houses. In trial B, it was found that the ordinary installation staff of a utility (here MVV) does only have skills concerning electric component and usually has neither knowledge nor experience in installing ICT systems. Therefore, they got special trainings for doing the field trial installations. In trial C, the installation was done by researchers who are involved in the development of the technology, so here as well, their skill level is not representative for the average technician. The combination of electric and ICT skills required for installing SH/SG technologies goes beyond that of many technicians. One remark here is that the labor cost of an installer (in terms of hourly rate) is more than twice as high if software skills are also required, as compared to no software skills required. Therefore, it is concluded that the current versions of SH/SG technologies are not yet affordable in terms of skills and time. A development towards plug&play is necessary to make it very easy to connect all appliances to the SH/SG control.
    - For the end user: On the level of the end user technology, the requirement was that the technology should be as easy to use as a browser or smart phone application of average complexity. It was found that for those applications offered to the end user (smart metering portal in trials B and C and the BEMI portal in trial B) the users had not much difficulty using the functions offered, because the requirement mentioned before was met. However, some functions in the BEMI portal were very unintuitive for the users and would require more knowledge about what the system actually does. It has to be mentioned here as well that the requirement that the systems should be as easy to use as a browser of smart phone app already exceeds the skill levels of those customers that usually do not work with computers or the Internet (although this group of people is becoming smaller). In conclusion it can be said that for the end-user, as long as the installation is either done by a technician or is plug&play, affordability in terms of skills and time is met for the tested technologies.
- **B2**: From the costs that occurred in the trial, it can be seen that the SH/SG technologies are currently very expensive, because special fabrication was needed for the respective controllers. Besides, the electricity installations in old houses need to be upgraded in order to be suitable for participating in a cluster of smart houses, which involves much effort and high additional costs (this was often the case in the Greek trial). In trial A, separate ADSL lines were installed for reliability reasons; this illustrates that there is a trade-off between costs and reliability considerations in the SH/SG technologies. Another trade-off can is given between costs and security – for example in trial A, a separate virtual private network was set up, which again raises the costs of setting up the system. It was concluded that the design of a dedicated gateway only for energy management is no viable solution for large roll-outs; in contrast, "smart hubs" may establish, like e.g. TV sets or Internet routers that combine several functions and that connect via WiFi to appliances. In this case, the cost of an additional energy management function comes down to that of an additional application, and now extra hardware costs occur. It should be noted here as well that OGEMA shows that standard technologies can be used for the energy management (e.g. Java, OSGi, Z-Wave, CIM, ZigBee), which also contributes to cost savings potential.

Measurable Objective C: The developed technology has significant potential for mass application across Europe.						
		Trial A	**Trial B**	**Trial C**	**WP 4**	**D1.2/ D5.3**
Objective C.1	Low entry barriers regarding adoption and diffusion of the technology. Innovation adoption and diffusion theory in the social sciences has identified a number of different factors that hamper the social success of technological innovations. Mass affordability (see Objectives B.1 and B.2) is one main factor. The project will verify this objective by carrying out in detail scenario simulations for mass adoption that build on and expand the energy efficiency and customer interaction use cases investigated in the field trials.					x
Objective C.2	There is a solid business case for energy utilities and energy service providers to step into ICT-enabled energy-efficiency technology. The technology must not only be attractive for the demand side (cf. Objective C.1), but also for the supply side. ICT-enabled technology will not be successful on a big scale in Europe unless the energy industry sector starts to support and deliver it to its markets as part of its normal service bundles. The project will verify this objective as part of the business scenario studies underlying the road map to mass application that will be an outcome of the project.				x	

Table 13: Mapping of measurable objectives C to field trials and simulations

For measuring the objectives C, the following measurements and analyses have been carried out:

- **C1**: The three aspects considered here as important for adoption and diffusion of the technology, which constitute a barrier if they are not met, are adaptability, availability and usability. Regarding adaptability, the state-of-the-art of interoperability options for smart grid was analyzed, reflecting currently available standards. With respect to availability, a market analysis was carried out regarding relevant products and vendors in the smart grid domain. This helps to better understand the availability of needed products to set up SmartHouse/SmartGrid scenarios. Finally, the usability aspect was already covered in objective A2 (and, to some extent, B1).
- **C2**: For the analysis of the viability of business cases, three representative business cases have been studied in more detail regarding their investment characteristics. Costs and possible gains have been set into relation via the Net Present Value method.

The results from the measurements and the conclusion that can be drawn from the results are summarized in the following. More detailed results for the objectives are also discussed in the deliverables D4.3 and D5.3, which describe the economic study and the market survey, respectively.

- **C1**: The analysis of the available standards facilitating smart grid interoperability revealed that there are several parallel initiatives that develop standards for specific aspects of the smart grid, like e.g. smart metering, or for single countries, but that there is, so far, little coordination between the different initiatives. The EC has recognized this problem and reacted via issuing the standardization mandates M/441 and M/490 for smart metering and smart grid. This would lower the entry barrier that is currently still present, because vendors have more certainty about which standards they should support. The study of availability delivers a diverse picture. There a number of start-ups that offer solutions which could either facilitate SH/SG concepts or which are similar to SH/SG. However, these companies are all still quite small and it is not sure how they perform in the long-run. After publication of the market study (deliverable D5.3), two large IT players have announced their withdrawal from the smart metering / smart home business, i.e. Google (with their Power Meter) and Microsoft (with MS Hohm). This shows that the market is quite immature and vulnerable.

- **C2**: The investment analysis of three SH/SG business cases reveals that there are business cases that can be viable under the assumption of hardware and installation costs that can be assumed for a mass roll-out of the SmartHouse/SmartGrid technologies. However, even under the assumption of such decreased investment costs, there are some business cases that will not justify the investment. It has been shown that the real-time business cases (e.g. balancing a real-time portfolio) are more viable from their basic characteristics than the day-ahead load shifting scenarios; real-time flexibility can avoid the use of expensive balancing energy, whereas load shifting based on day-ahead price profiles only decreases electricity procurement costs, but the price variations currently present in wholesale markets don't make this latter option attractive enough. Hence, these results indicates that a combination of business cases may be a way to increase overall system viability, given the fact that hardware and ICT infrastructures for implementing the business cases are quite similar.

Measurable Objective D: The developed technology is able to achieve aggregate energy efficiency gains > 20%.						
		Trial A	**Trial B**	**Trial C**	**WP 4**	**D1.2/ D5.3**
Objective D.1	Efficiency gains through interactive feedback to users on optimal energy use (approx. 10%).					
Objective D.2	Gains as a result of optimized energy management of devices (about 5%) and of specific energy technologies in use (e.g. reduction of heat waste in commercial and home CHP units by better ICT-based control, CO2 reduction potential).				x	
Objective D.3	Reduction of power grid losses by increasing local sustainable demand and supply solutions (4-8%).				x	
Objective D.4	Gains through raising the accommodation ceiling of local networks for integration of local generation. Today's "fit and forget" connection policy for local environmentally friendly energy resources puts a ceiling at the share of local generation to be accommodated in local power grids. The technology lifts this ceiling to allow a substantial greater share of DER/RES in distribution grids, reducing centralised fossil-fuelled power generation. (>10%)				x	

Table 14: Mapping of measurable objectives D to field trials and simulations

For measuring the objectives D, the following measurements and analyses have been carried out:

- **D1**: The measurement of the direct effect of a feedback on energy usage for end-users has actually not been planned as a study element in any of the field trials. As the trials only involved a period in which the respective SH/SG technologies were deployed (and energy feedback was given), there was no way of distinguishing between the effects based on the SH/SG technology itself or on the availability of consumption data. In trial B, however, there was a limited period in which only smart meters were deployed (without variable tariff), followed by periods with variable tariffs offered together with smart meters and a metering portal (giving feedback to the users), allowing first for manual and then manual and automated load shift. A load shift in the order of 6-8% towards low tariff times was observed, but within the uncertainties no significant overall consumption reduction was observed. The limited precision of data is due to limited measuring time (with of seasonal influences), number of clients, also not allowing for measuring a reference group timely in parallel, and data affected by remaining technical failures. Consequently, the precision of the final results is very limited (the trial was mainly set up to test the system). A similar trial allowing for much better data precision will be repeated over a full year and for >500 clients within the moma project. Then seasonal influences and reference group data do not need to be calculated but can directly be measured. There are, however, many studies carried out in this domain, which the interested reader is referred to.[14]

- **D2**: For estimating the efficiency gains as a result of optimized energy management in a smart house, simulations were carried out in work package 4 and the load shifting behavior was analyzed in trial B. In the simulations, business-as-usual scenarios without energy management were compared with cases in which the PowerMatcher, BEMI or MAGIC technologies were deployed, respectively.
- **D3**: Calculations of grid losses as a function of the penetration level of distributed generation have been done in all three simulations A, B and C in order to measure the objective of reduced grid losses, focusing on different grid areas.
- **D4**: The raised accommodation ceiling for renewable generation was especially focused on in simulation A. Here, the curtailment in a large-scale wind accommodation scenario has been simulated, comparing the situation with and without use of the PowerMatcher. In scenarios B, the local use of local generation was regarded, also providing insights into how much renewable generation can be accommodated by a grid cell with smart houses. In simulations C, only rough calculations of increased renewable penetration were done for the case of Crete.

The results from the measurements and the conclusion that can be drawn from the results are summarized in the following. More detailed results for the objectives are also discussed in the D4.2, which describes the results from the simulations carried out in work package 4 of the project.

- **D1**: See comments given above.
- **D2**:
  - Findings based on trials: It should be noted here that the data basis from the results of trial B does not allow a proper quantification of the load shifting effects for several reasons: the trial duration was less than one year, so the seasonal aspect of power consumption forbids a generalization for the entire year; besides, only the consumption was only measured for some months before the trial started, so there is also no reliable data available for the baseline comparison. However, the load profiles of BEMI customers displays some characteristic patterns of load increase (decrease) at the points in time at which the tariff changes from low to high (high to low), thus giving an indication of the load shifting potential. The change in consumption just before and just after a change from low/high to high/low tariff was significant.
  - Findings based on simulations: The goal of the SH/SG technologies was not primarily to reduce energy consumption, but to better adapt it to the supply side, which also reduces load peaks that are met by inefficient peak plants. Therefore, mainly the possible reduction in peak loads was analyzed in this objective. In the simulations A, a peak load reduction of 15-20% was observed. In simulations C, the possible reduction in peak loads was substantially lower, because only water heaters were considered as flexible loads. In simulations B, it could be shown that with BEMI operation, less energy had to be imported into the grid cell, signaling a better use of local generation (3-5% less imported energy, depending on the scenario; 4-6% less PV generation had to be exported to neighboring grid cells).
- **D3**: In the simulations, grid losses (power line losses) between ~1% in the Crete scenario (simulation C), ~10% in simulations B, and up to 40% in the scenarios investigated in simulation A have been measured.

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[14] [Darby 2006] provides a good overview of available studies.

The reason for the large differences between the simulated values lies in the different perspectives taken in the simulations. Simulation A considered a single, small low-voltage line feeder and the energy management potential assumed was relatively high. Simulation B considered a low-voltage grid resembling a real grid topology and did only consider load management potentials from white goods controlled by BEMI. In simulation C, the focus was on the support of medium-voltage operation by smart houses, so it regarded a larger part of the energy system and focused on events of unstable grid situations. It can be concluded that all three considered technologies can significantly contribute to reducing grid losses. The exact level of the reduced grid losses, however, depends a lot on what scenario is considered and on the studied grid topology.

- **D4**: In simulation A, it could be shown that for the modelled grid cell with high local wind generation, the exports that occur from the grid cell is reduced by 65–90% when applying the PowerMatcher technology, depending on the assumed local wind generation capacity, and the required import into the cell are reduced by 14–21% for the same scenarios. This is a strong indication that the accommodation ceiling for renewable generation can be raised considerably if SH/SG technology allows for better using the local generation. In simulations B, the effect is much smaller for a grid cell with local PV generation, because less energy management potential was considered and less PV capacity in relation to the loads was assumed.

5.2. Project Impact

The impact that can be achieved with a widespread use of SH/SG technologies has been studied in work package 4 and is reported in D4.2, D4.3 and in this report (see especially Section 5.1) on the outcomes of the measurable objectives). Many of the technologies most closely related to SmartHouse/SmartGrid are still in an early phase of market adoption. This means that most of them are in the time-scale of five to ten years until mainstream adoption. This is a challenge, but also an opportunity, as technologies shaped within the project can be brought to the market in a timely manner. They have the potential to establish market leadership, thus shaping the directions in which the market follows. Some steps towards a commercialization or larger scale adoption of the developed concepts have already been done for BEMI/OGEMA, PowerMatcher and MAGIC, and some demand side management features are also planned for enterprise software implementations at SAP.

One activity in the domain of standardization for smart grid solution is the **OGEMA** initiative mainly driven by Fraunhofer IWES. IWES uses and further develops the OGEMA standard and reference implementation in SH/SG and further currently active projects (RegModHarz and REV2020). Furthermore, several projects using OGEMA are currently starting. In the project PINTA, OGEMA will be used for implementing an energy management in office buildings with special regards to the energy efficiency of the office's IT infrastructure. An interface to the building management system will be developed. In the European project BEAMS, OGEMA is to be used for energy management in a football stadium and a university campus. Furthermore, there is a project "OGEMA 2.0" planned which aims at further development of the framework itself as well as interfacing to contemporary smart grid and E-Energy technologies, e.g. EEBus[15] and OpenMUC[16]. A co-operation was started with one of the leading OSGi companies ProSyst regarding a commercial implementation of the OGEMA framework suitable for mass application. The OGEMA alliance currently has six confirmed members. There are currently over 20 parties who are evaluating OGEMA. Furthermore, OGEMA is in contact with the University of California, Berkeley regarding integration of the OpenADR[17] framework. Further standardization activities are currently being planned. Official foundation of OGEMA is yet to be decided amongst the alliance partners.

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[15] www.eebus.de

[16] http://www.openmuc.org/

[17] http://openadr.lbl.gov/

Some SH/SG project partners have been and will be involved in the context of CIGRÉ, more specifically in the Study Committee (SC) C6. The **CIGRÉ SC C6** has been created in 2002 with the mission to facilitate and promote the progress and the exchange of knowledge in the field of system impact of distribution systems integrating DG, by synthesizing state-of-the-art practices and developing recommendations. The goal of SC C6 is to assess the technical impacts and requirements which a more widespread adoption of distributed generation and which a larger proportion of undispatchable power generation could impose on the structure and operation of transmission and distribution systems. In parallel, the SC also assesses the degree to which such solutions are likely to be adopted in the short, medium and long term and, consequently, the practical importance and timing of the technical impacts and requirements mentioned above. Other activities that SmartHouse/SmartGrid project members are involved in include **ICT4SmartDG**, the "Thematic Network on ICT solutions to enable Smart Distributed Generation" (thematic network that fosters and promotes large-scale integration of domestic and distributed micro generation and improvements in energy efficiency through the implementation of innovative ICT solutions into local smart power grids) and the **European Energy Research Alliance Joint Program** (EERA JP) on Smart Grids network (who promote a continuous dialogue with EEGI/EII (European Industrial Initiative), focusing on how to harmonize and align the EERA (JP) on Smart Grids and EEGI programs.

The fact that many of the business cases described for SmartHouse/SmartGrid are not (yet) profitable due to still high costs, unfavorable regulatory frameworks or too low economic incentives motivates a continuation of the research that has been carried out in this project. In fact, all project partners remain engaged in follow-up research projects, which are listed in the following.

- **NOBEL** (SAP): The NOBEL project will develop an energy brokerage system through which individual energy consumers can communicate their energy needs directly with both large-scale and small-scale energy producers, thereby making energy use more efficient. The brokerage system will use a middleware system to communicate relevant data and IPv6 technology to interconnect the middleware with sensors and energy meters on individual devices. In this project, SAP will investigate requirements, technologies and use cases for energy monitoring and market driven interactions in neighborhoods and develop enterprise services for support of energy communities within the smart grid vision. The project has already started in early 2010 and a joint workshop between NOBEL & SmartHouse/SmartGrid has been carried out for the cross-fertilization of results.
- **MIRABEL** (SAP): MIRABEL is the new name for MIRACLE, which stands for Micro-Request-Based Aggregation, Forecasting and Scheduling of Energy Demand, Supply and Distribution.[18] Its main goal is to develop an approach on a conceptual and an infrastructural level that allows energy distribution companies to balance the available supply of renewable energy sources and the current demand in ad-hoc fashion. A regular exchange of idea between the researchers in MIRABEL and those in SmartHouse/SmartGrid has been carried out in order to make sure that SmartHouse/SmartGrid ideas are reflected in the newer MIRABEL project. In the latter project, energy forecasting using large data sets from smart meters using High Performance Analytic Appliance (HANA) is in the focus. Therefore, MIRABEL is a complementary activity that can be combined with SmartHouse/SmartGrid ideas, especially in the domain of forecasting.
- **Green eMotion** (SAP, PPC, ECN): The aim of Green eMotion is to enable mass deployment of electric mobility in Europe by (i) creating and demonstrating a European commonly accepted and user-friendly framework consisting of interoperable and scalable technical solutions and ensuring that the smart grid development and innovative ICT solutions will be taken into account for the implementation of the electric mobility framework. The goal is to develop technical and policy solutions which are interoperable, scalable and standardized and will enable a mass market rollout of electric vehicles as part of a smart grid. For this, the basic concepts of SmartHouse/SmartGrid can also be taken into account

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[18] The name of the project had to be changed due to issues linked to the right to a name.

and will be brought into the discussion. Three of the project partners will be engaged in Green eMotion, which will start supposedly in Q2 2011.

- **Pinta** (IWES): The next research project including OGEMA will be Pinta. It is one of ten projects of the German national funding scheme IT2Green..
- **Model City Mannheim *moma*** (MVV, IWES): This research project is funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) as one out of six national "E-Energy" – projects. It has started in parallel to SmartHouse/SmartGrid in 2008 and runs through October 2012. Experiences gained in the currently ongoing SmartHouse/SmartGrid field test in Mannheim will be used in the following field test with a higher number of participants in moma.
- **Merge** (ICCS, PPC): the "Mobile Energy Resources for Grids of Electricity" project is a major EU-financed project to prepare the European electricity grid for the spread of electric vehicles (EVs). Its mission is the evaluation of the impacts that EVs will have on the EU electric power systems regarding planning, operation and market functioning. The focus will be placed on EV and smart grid / microgrid simultaneous deployment, building on technologies that were tested in SH/SG.
- **BEAMS** (IWES, ICCS): The strategic goal of the BEAMS project is the development of an advanced, integrated management system which enables energy efficiency in buildings and special infrastructures from a holistic perspective. The project will include an open interoperability gateway that will allow the management of diverse, heterogeneous sources and loads, some of them typically present nowadays in spaces of public use (e.g. public lighting, ventilation, air conditioning), some others emergent and to be widespread over the next years (e.g. electric vehicles). BEAMS will be a user driven, demonstration oriented project, where evidence of the energy and CO_2 savings achieved by the project's technologies will be collected.
- **EcoGrid EU** (ECN): The key objective of the EcoGrid EU project is to demonstrate the efficient operation of a distribution power system with high penetration of many and variable renewable energy resources. The demonstration will take place on the Danish island Bornholm with more than 50% electricity consumption from renewable energy production. A real-time market concept building upon the PowerMatcher will be further developed to give small end-users of electricity and distributed renewable energy sources new options (and potential economic benefits) for offering TSOs additional balancing and ancillary services.
- **Web2Energy** (ECN): The project Web2Energy is directed to implement and approve all three pillars of "smart distribution", i.e. smart metering, smart energy management and smart distribution automation. Besides, communication channels covering the last meters to the participants are considered that link all three pillars of smart distribution.
- **G4V** (ECN and, as part of the Scientific Advisory Board, SAP): The Grid for Vehicle project G4V will provide a set of recommendations which will help to evolve the European power grids to an intelligent power system which can serve an educed mass market of EVs and PHEVs in whole Europe. With this physical "backbone", several stakeholders could offer their customers individually different kind of services and products.
- **PowerMatching City 2** (ECN): This project is a sequel of the joint Integral and SH/SG field trial in which the PowerMatcher technology has been tested. The project is currently under preparation and will start very soon.
- **SEESGEN** (ECN, IWES, SAP, NTUA): The SEESGEN-ICT project "Supporting Energy Efficiency in Smart GENeration grids through ICT" sets out to produce a harmonized set of priorities to accelerate the introduction of ICT into the smart distributed power generation grids, investigating requirements, barriers and proposing solutions. SEESGEN-ICT will produce policy recommendations, identify best practices and draw scenarios and roadmaps for the next generation of electric distribution network.

- **DERri** (ICCS, IWES, (ECN)): "Distributed Energy Resources Research Infrastructure" is a collaborative research project under the European FP7 program between 15 partners from twelve countries distributed all over Europe. All partners have exceptional and supplementary DER research infrastructures and leading DER expertise. DERri provides external European research communities the opportunity for transnational access to the DERRI partners research infrastructures, free of charge. It is a follow-up activity of the DERlabs in which ICCS, IWES and ECN have been engaged before as well.
- **IEA task on demand response** (ECN): ECN is involved in demand response studies for the IEA, building on their SH/SG experiences and the PowerMatcher developments.

5.3. Recommendations for Fostering SH/SG Technologies

The experiences gained from the SmartHouse/SmartGrid field trials showed that there are still a number of barriers and problems that currently limit the possibilities for the large-scale dissemination of the technologies. One outcome of the project should therefore also be a list of recommendations where policies or regulations can be changed or into what direction further research should focus, so that the framework conditions become more favorable for the realization of a smart grid with many smart houses.

The recommendations from the project team are grouped into the four categories policy and regulation (Section 5.3.1), technology and markets (Section **Fehler! Verweisquelle konnte nicht gefunden werden.**), research and development (Section 5.3.3) and standards / interoperability (Section 5.3.4).

5.3.1. Policy and Regulation

The policy and regulation recommendations are specific to those conditions that were given in the field trials, i.e. the national legislation and regulation of the Netherlands, Germany and Greece, respectively. Most recommendations come from trial B, because it involved the largest number of trial participants, who also experienced financial implications from the use of the energy management system (although it was assured that these were always positive, so that no customer had a disadvantage from participating in the trial). Consequently, the recommendations are only valid for those countries where similar regulation applies.

- One obvious obstacle for realizing business cases from variable tariffs is that energy suppliers always have to procure electricity for their customers according to a standard load profile which doesn't take into account their actual consumption. Through this, the supplier does not have any advantage when his customers consume less power during times of high wholesale prices. SH/SG technologies will only be applied if balancing of household customers is based on actual consumption, not on standard load profiles. This requires, of course, that household consumption is measured in 15 minutes intervals through electronic meters.
- The German Calibration Act was creating a lot of trouble for introducing variable tariffs. It was only possible to circumvent the strict calibration rules through ensuring a best-price billing for the customer that guarantees that he does not pay more with the variable tariff than if a flat tariff were applied. The German Calibration Act requires that a customer can always calculate his energy costs by looking at the meter and multiplying his consumption with the known tariff. This involves a separate register for each possible tariff. Variable tariffs would be very complicated to realize to meet all of these requirements. Therefore, the calibration law should be adapted to make smart metering and variable tariffs applicable more easily.
- Clusters of smart houses offer the possibility to bundle the flexibility for participating in balancing power markets. However, today's balancing power markets in many countries require high minimum capacities for being allowed to participate. Lowering the minimum required capacity for balancing power market participation would open new opportunities for energy service providers to make use of the flexibility that smart houses can offer.

5.3.2. Technology and Markets

The energy supply industry, the manufacturers of household appliances and devices as well as the operators of marketplaces and power exchanges can all contribute increasing the chances for SmartHouse/SmartGrid to become successful. Some necessary actions are summarized in the following.

- For making most use of the flexibility provided by smart houses, the energy supplier should be able to procure and sell electricity at shorter time scales. With more short-term (intra-day) energy trading options it would be easier to trade demand response on wholesale markets. Therefore, exchange markets should offer products that are closer to real-time, consists of shorter time blocks or, in the extreme case, are even event-based.

- One important prerequisite of SmartHouse/SmartGrid technologies to be deployed in the field is their ease of use for end customers. This requires manufacturers of white goods and other flexible appliances to get involved into developing the "smart grid ready" technologies and facilitate that they can be included into the home energy management in a plug&play manner. Manufacturers of such goods should form alliances and agree on common standards in order to support smart grid operations of the future.

- One important aspect for mass roll-outs of SH/SG technologies is to enthuse end-customers and gain their acceptance. This can be done via several strategies. One way would be to involve consumer organizations and stress the environmental value of the technology so that people actually want to participate in smart grids. Another way would be to directly direct approach end-customers through large marketing campaigns, raising the desire to be part of the smart grid.

- The best way to push SH/SG technologies is to create a hype about it. It is, of course, difficult to induce such hype and there is a lot of chance in it. However, industry should focus on finding the killer-app(s) for smart grid devices that make everyone want to step into making their houses smart.

- There is an increasing interest by people to generate their own electricity and be self-sustained in their energy supply (e.g. documented by the term of "power to the people" given by Jeremy Rifkin). However, most people will remain connected to the grid in order to be sure to always have a back-up supply. Energy suppliers should ride on the motivation and possibilities of people to create their own electricity when motivating them to make their houses smart and smart grid ready.

5.3.3. Research and Development

- From looking at the cost of installing a dedicated gateway device at customers' homes it can be concluded that extra hardware for smart grid sensitive energy management is no solution for a mass-scale roll-out. Instead, the SH/SG concepts should piggy-bag on other devices that have a widespread use in households. Therefore, the focus of further research and development in the SH/SG domain should focus on the software for energy management, not on any specialized hardware. The software should be so flexible that it can run on many possible devices. It could, in the future, be integrated into routers, switches, Internet-connected TV sets or other devices that are connected to the Internet and can communicate with other devices via wireless technologies.

- One aspect that has not much been researched on yet is the consumer behaviour side of the smart grid. Little is known on the conditions of usage for specific devices used (e.g. water heater, air-conditioning, washing machines…) and the characteristics of their flexibility. Consequently, estimations of demand elasticities based on price signals are very weak. Also, the conditions for smart grid acceptance and the possible motivations for participating should better be researched in order to derive the best strategies for successful roll-outs.

- One important field of development is also the definition of standard device models for all types of typical household appliances. There should be an open source collection of device models that energy management developers can draw from and which are shared within the developers' community.

- In recent years, a number of smart grid models have been developed and simulations have been carried out. It would be worthwhile comparing the simulation results of these different smart grid models and provide guidelines for model verification. This would strengthen the knowledge basis and provide a solid ground for further analysis of smart grid systems. We also strongly encourage carrying out more holistic simulations of grid losses. This is a complex topic that involves many parameters, so large research teams should be built up that develop appropriate models for such holistic analyses
- From those field trials and roll-outs that have already been carried out in the smart grid field, there should be a sound analysis of technological smart grid best practices that facilitates a convergence of competing technologies and an integration of complementary technologies. Narrowing down the technological possibilities helps software vendors to focus on the most relevant options and new entrants to design business cases based on these options. However, if the best technological choice cannot be determined for some aspects, it makes sense to wait until the picture gets clearer, and to continue developing competing options.
- Ensuring stability in a multi-stakeholder environment is especially important for smart grids, which involve several different industries. It has to be made sure that there are no contradicting signals and that all roles work together in an effective way. This can be accomplished, e.g., through defining priorities and tasks more clearly and assigning responsibilities to different market roles (e.g. what is the role of the DSO? What information does the metering service provider have to provide to which other market role? Who should set up what part of the infrastructure?).

5.3.4. Standardization and Interoperability with Respect to Control

The true benefits of smart grids will only come about if device and component are seamlessly interfacing, and interoperability exists across all stakeholders in the energy value chain. This issue of seamlessness is now a major market barrier for the breakthrough of smart grids, since the many diverse stakeholder interests encounter each other most directly, from end-customer smart devices and buildings, equipment manufacturers, suppliers, ESCO's, aggregators, utilities, to grid operators. Further developing standard interfaces towards household appliances and other smart grid able devices is, therefore, of key importance.

An agreed-upon open standard for uniform and seamless interfacing and interoperability covering all the diverse (incl. end-user) devices and nodes in the smart grid is a "conditio sine qua non" for the commercial breakthrough of smart grids. Some initiatives towards standardization are already going on, most notably the initiatives following the Mandate M/490. From the project's point of view, it is therefore a key success factor that standards are consolidated and that different initiatives join forces to discuss the future smart grid jointly. So far, the discussion is quit fragmented, making it difficult and risky for stakeholders and investors to choose which technology or upcoming standard to rely on. Offering end-to-end solutions and plug&play functionality will push the smart grid and offer the basis that SH/SG technologies can build on.

Some ideas of how this interoperability can look like are already developed in the project. One example is the PowerMatcher architecture: although an open protocol for communication between components and devices in the smart grid still is lacking, the PowerMatcher conceptual setup, using web services and objective agents, makes it possible to smoothly interface different components at different stakeholder systems along the electricity value chain into one, seemingly seamless, control chain. Nevertheless these workarounds may influence the total control feedback loop and hence the underlying business case.

Another example for interoperability technology is the Open Gateway Energy Management Alliance (OGEMA), which provides an open software platform for energy management that links the customer's loads and generators to the control stations of the power supply system and includes a customer display for user-interaction. All developers and involved parties can turn their ideas for more efficient energy usage by automation into software for the gateway platform. Activities for developing the OGEMA specifications further are also run in the framework of the SmartHouse/SmartGrid project.

Impressions

Figure 31: The project team with two participants of field trial B at a review meeting, 2011

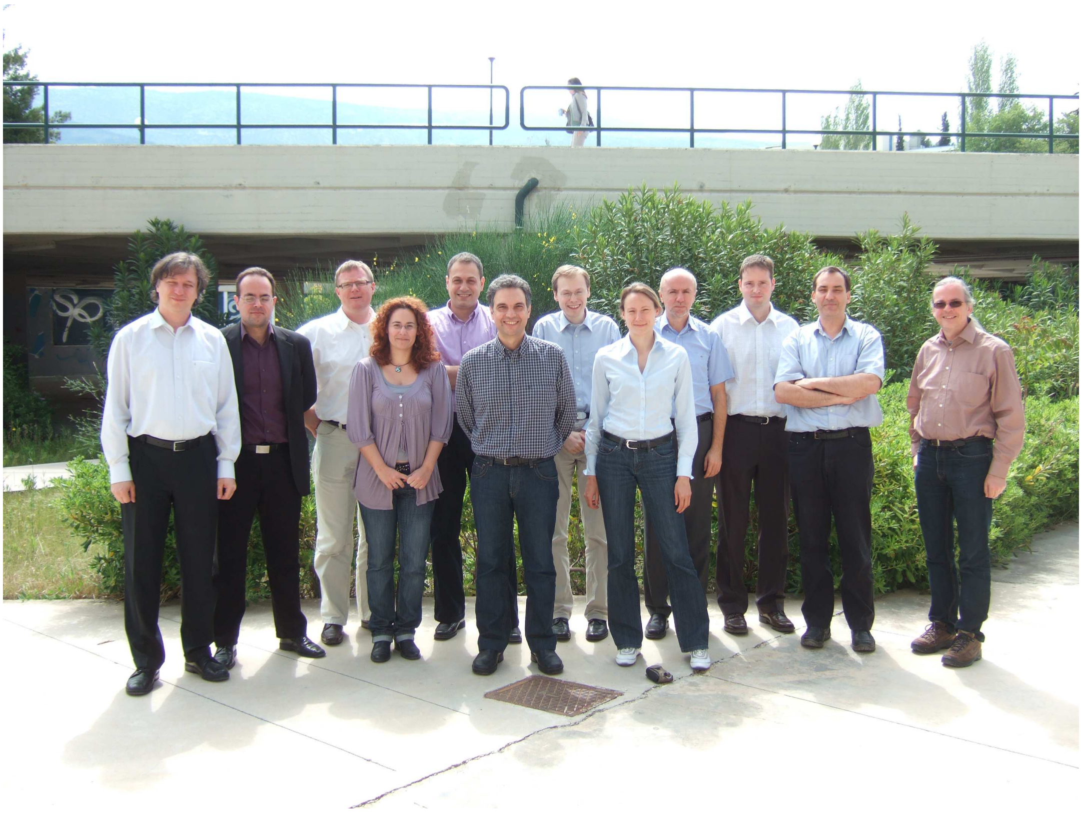


Figure 32: Photo from a project meeting in Athens, 2009

Figure 33: Visit of the ICCS-NTUA lab in Athens, 2009

Figure 34: SH/SG booth at the ICT4EE event in Brussels, 2010

Figure 35: Visit of SAP's CEO at the SmartHouse/SmartGrid boot at the ICT 2010

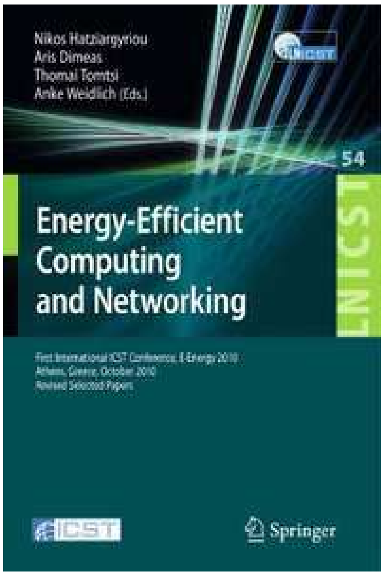
First Best ICT For Energy
Efficiency Project Award 2010

Brussels, 23 February 2010

Finalist
SmartHouse/SmartGrid
Project

On behalf of
The European Commission

Figure 36: Finalist certificate of the "Best ICT for Energy Efficiency Project Award 2010"



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Energy-Efficient
Computing
and Networking

First International ICST Conference, E-Energy 2010
Athens, Greece, October 2010
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Figure 37: Book cover for the proceedings of the E-Energy conference in Athens, 2010

Smart Houses interacting with Smart Grids to achieve next-generation energy efficiency and sustainability

SmartHouse/SmartGrid – Next-generation energy efficiency and sustainability

- Customer-interactive in-house technology for energy management
- Interaction with the smart grid
- Distributed control on the basis of price signals
- Electronic markets and software agent technology

www.smarthouse-smartgrid.eu

Figure 38: SmartHouse/SmartGrid poster

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