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

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D3.1

Field Trial Demonstrator Designs

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Abbreviations

BEMI	Bidirectional Energy Management Interface
BRP	Balance Responsible Party
COTS	Commercial Off The Shelf
DPWS	Device Profile for Web Services
DSO	Distribution System Operator
ESS	ETSO Scheduling System
ETSO	European Transmission System Operators
ICT	Information and Communication Technology
MAS	Multi Agent System
PLC	Power Line Communication
RES	Renewable Energy Sources
RF	Radio Frequency
SH/SG	SmartHouse/SmartGrid
SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol
SQL	Structured Query Language
TCP/IP	Transmission Control Protocol/Internet Protocol
TSO	Transmission System Operator
UML	Unified Modeling Language
VPP	Virtual Power Plant
WCF	Windows Communication Foundation
XML	Extensible Markup Language

1. Introduction

This document describes the Demonstrator Designs of the three field tests of the SmartHouse/ SmartGrid project.

1.1. SH/SG Objectives

In order to achieve next-generation energy efficiency and sustainability, a novel smart grid ICT architecture based on Smart Houses interacting with Smart Grids is needed. This architecture enables the aggregation of houses as intelligent networked collaborations, instead of seeing them as isolated passive units in the energy grid.

The research project SmartHouse/SmartGrid takes a fundamentally different and innovative approach in this. The ICT architecture under development by the consortium introduces a holistic concept and technology for smart houses as they are situated and intelligently managed within their broader environment (see Figure 1). This concept seriously considers smart homes and buildings as (i) proactive customers ("prosumers") that (ii) negotiate and collaborate as an intelligent network in (iii) close interaction with their external environment. The context is key here: the smart home and building environment includes a diverse number of units: neighbouring local energy consumers (other smart houses), the local energy grid, associated available power and service trading markets, as well as local producers (environmentally friendly energy resources such as solar and (micro)CHP etc.)

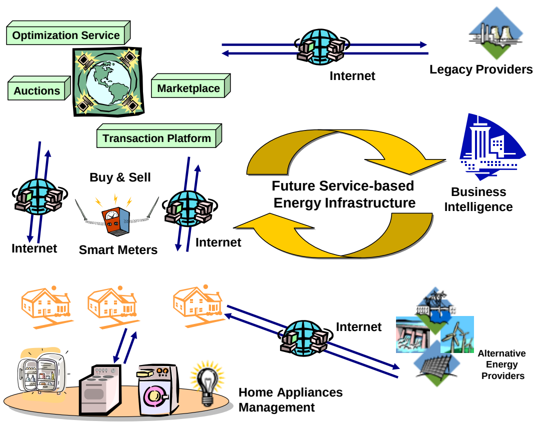

Figure 1: Service-based ecosystem based on Smart Houses and Smart Grids

1.2. WP1 Business Cases

For the functional scope of the SmartHouse/SmartGrid architecture, nine functional scenarios or business cases have been defined: one overarching system description and eight specific scenarios. A short description of each case is provided in the following subsections. Although described separately, these are all functionalities that need to be supported by the common ICT architecture. The full descriptions can be found in D1.1.

1.2.1. Aggregation of Houses as Intelligently Networked Collaborations

SmartHouse/SmartGrid concepts will exploit the potential that is created when homes, offices and commercial buildings are treated as intelligently networked collaborations. The SmartHouses will be able to communicate, interact and negotiate with both customers and energy devices in the local grid. As a result, the electricity system can be operated more efficiently because consumption will be better predicted and 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 SmartHouses or commercial consumers that have a contract with it and additionally deliver services to grid management performed by the network operators.

1.2.2. Variable-Tariff-Based Load and Generation Shifting

The key idea of this business case is a variable price profile given to the customer day ahead before the delivery by a retailer. This profile is considered fixed after transmission to the customer and, as such, the customer can rely on it. The price profile will look different for each day, reflecting market conditions that vary from day to day. These variations will likely further increase with expanding generation from fluctuating sources like wind power and photovoltaics.

Generally, this concept allows for integration of loads as well as of generation units at the customer site as it is up to the customer which devices are allowed to be managed according to the variable tariff. To enable in-home energy management, a suitable domotic system is required together with an automatic home management system coupled to an intelligent meter.

1.2.3. Energy Usage Monitoring and Feedback

In the "Action Plan for Energy Efficiency", the European Commission estimates the EU-wide energy saving potential of households at approx. 27%. As one important measure for realizing this potential, the action plan states that awareness must be increased in order to stimulate end-customer behavioural changes. A timely display of energy consumption is expected to have positive effects on energy savings. Personalized and well targeted advice on how to save energy can further help exploit the savings potential.

A portal or display that combines information about present and past consumption, comparisons to average consumption patterns, and precise suggestions how to further lower consumption, which are tailored personally to the customer, is expected to be the most effective way of realizing the targeted increase in households' energy efficiency.

1.2.4. Real-time Portfolio Imbalance Reduction

This business case is rooted in the balancing mechanism as used by TSOs throughout the world. In this context, a wholesale-market participant, that is responsible for a balanced energy volume position, is called a Balance Responsible Party (BRP). These parties have an obligation to plan or forecast the production and consumption in their portfolio, as well as notify this plan to the TSO. Deviations of these plans may cause (up-ward or down-ward) regulation actions by the TSO. The TSO settles the costs for the used reserve and emergency capacity with those BRPs that had deviations from their energy programs. On average this results in costs for the BRP referred to as imbalance costs.

This business case scenario focuses on the balancing actions by a BRP in the near-real time (i.e. at the actual moment of delivery). Traditionally, these real-time balancing actions are performed by power plants within the BRP's portfolio. The key idea of this business case is the utilization of real-time flexibility of end-user customers to balance the BRP portfolio. The BRP aggregates its contracted flexible distributed generation and responsive loads in one or more virtual power plants (VPPs), which perform the real-time balancing actions.

1.2.5. Offering (Secondary) Reserve Capacity to the TSO

Taking the previous business case scenario one step further, the BRP uses these VPPs to, additionally, bid actively into the reserve capacity markets.

1.2.6. Distribution System Congestion Management

This business case is aimed at the deferral of grid reinforcements and enhancement of network utilization to improve the quality of supply in areas with restricted capacity in lines and transformers. The DSO avoids infrastructural investments and optimizes the use of existing assets by active management using services delivered by smart houses. By coordinated use of these services, end-customer loads can be shifted away from periods at which congestion occurs and simultaneousness of local supply and demand can be improved.

1.2.7. Distribution Grid Cell Islanding in Case of Higher-System Instability

The main principle 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. The scenario has two main steps, the first occurring before a possible instability and involves keeping a load shedding schedule up-to-date. The second step is the steady islanded operation.

The transition to the island mode is automatic and neither end users nor the aggregator interferes with it. The ICT system manages the energy within the island grid and it is considered that all nodes within the islanded grid will participate in the system.

1.2.8. Black-Start Support from Smart Houses

The most important concept of this business case is to support the black start operation of the main grid. It is assumed that after the blackout the local grid is also out of operation. 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.

1.2.9. Integration of Forecasting Techniques

The volatility of the production level of distributed generators, like renewables and CHP, makes forecasting a necessary tool for market participation. The market actor with the lowest forecasting error will have the most efficient market participation. Moreover, the usage of intelligent management tools for handling the information about the uncertainties of large-scale wind generation will improve the system-wide operational costs, fuel and CO_2 savings. The ICT architecture under development must interact with these forecasting tools and additionally ensure accurate data collection for these tools.

1.3. WP3 Objectives

- Develop, deploy and operate three interrelated field experiments validating and demonstrating the technology developed in WP1 & WP2 in an environment of energy-neutral new or renovated home and working environments. Each of these demonstration projects (in the work content description called A, B, C) are carried out by one of the industrial partners in close cooperation with research institutes in three different countries.
- Validate the hypothesis of the project that the newly developed control strategies and network architectures (1) enhance energy efficiency, (2) improve efficient management of local power grids (e.g. improve network load factors) and (3) enable the integration of a larger amount of renewable energy resources with less carbon emission.
- Validate the WP1 business models for energy efficiency service provision in a real-world field environment from the stakeholder's viewpoints of industry, policy makers and end users.

1.4. Field Test Division of Work

Each of the trials has a main focus on one or two WP1 Business Cases as indicated in the table below.

	Trial A	Trial B	Trial C
Variable-Tariff-Based Load and Generation Shifting		X	
Energy Usage Monitoring and Feedback		(X)	
Real-time Portfolio Imbalance Reduction	X		

Offering (secondary) Reserve Capacity to the TSO	(X)		
Distribution System Congestion Management			(X)
Distribution Grid Cell Islanding in Case of Higher-System Instability			X
Black-Start Support from Smart Houses			X
Integration of Forecasting Techniques		(X)	(X)

Table 1: WP1 business cases covered by each of the three field trials[3]

[3] The main trial focus is indicated by 'X' and secondary foci by '(X)'

2. Field Test A: Aggregation of SmartHouses & Enterprise Systems Testing

2.1. Overview

- **Partners:** ECN (lead) & SAP
- **Focus**
  Automated aggregated control of end-user systems for energy efficiency combined with testing of information exchange with enterprise systems using data traffic at mass-application strengths.
- **Main Objectives:**
  - Validation of Multi-Agent Systems-based aggregation of smart houses for energy efficiency enhancement and electricity trade optimization utilizing real-time variable tariffs.
  - Testing the information exchange of such a system with enterprise systems (e.g. for billing) at data traffic levels of mass-application (~1,000,000 customers).

  and get information on:
  - business cases for "real-time portfolio imbalance reduction" and "offering secondary reserve capacity to the system operator";
  - interoperability between different platforms using service oriented architectures.
- **Location:**
  - Cluster of smart houses: Hoogkerk PowerMatching City in the Netherlands (connection with EU Integral project):
  - Data aggregators (control information, metering data): Laboratory at ECN, the Netherlands
  - Enterprise system servers: SAP Research, Karlsruhe, Germany.

Figure 2: Location of trial A in Hoogkerk

2.1.1. High-Level Description

The cluster of smart houses will be located in The Netherlands. The end-user systems integrated in the test installation will consists of (any combination of) micro-CHPs, heat pumps for domestic heating and electricity intense domestic appliances. To all systems an intelligent software agent will be associated, running for instance on a programmable intelligent meter. The agent communicates operating preferences to the aggregating level.

The chosen location for the trial is Hoogkerk, a suburb or Groningen in the Netherlands. The suburb officially began operating a microgrid and calling itself "the power-matching city" on March 10, 2010. The Hoogkerk microgrid includes 25 interconnected houses and is part of the SmartHouse/SmartGrid project and another research project carried out by ECN and further partners. The houses are outfitted as follows:

- Twelve have a combined heat and power (CHP) plants with high efficient 1 kW boilers running on natural gas
- The other 13 have a hybrid heat pump that combines an air-to-water heat pump with condensing boilers
- All 25 houses have smart meters from Itron
- Each house has twelve square meters of PV paneling for a total capacity of 1,400 W peak
- Ten houses have a smart washing machine and dishwasher from Miele
- One house has a plug-in hybrid Toyota Prius car and two others each have an all-electric Volkswagen Golf car
- One house has a standard lead-acid battery to store solar energy for later use

Together, these houses form a virtual power plant. Added community-based power will be produced by a 2 MW wind farm. The community will also have a 30 kW gas micro-turbine manufactured by Capstone. Data will be collected on how much energy participants use and on whether residents are willing to exchange comfort for flexibility based on financial incentives. Residents volunteered to be part of the program, showing a predisposition for flexibility.

2.1.2. Problem Statement

In field test A the business case "Real-time Imbalance Reduction of a Retail Portfolio" will be combined with the "Aggregation of Houses as Intelligently Networked Collaborations". A main challenge will be to integrate the infrastructure for near real-time control, requiring frequent and time-constrained communication via low bandwidth, with an infrastructure for variable tariff metering, information handling and billing, based on collection of large volumes of data on a non time-constrained base, e.g. once per month. Both application areas require a reliable and robust infrastructure that connects smart houses with enterprise systems, the so called smart grid.

The problem statement for field test A can be described as follows:

> *How can we connect and utilize mass scale aggregations of smart houses for support of business operation, such that the interests of different stakeholders are respected as much as possible and as fair as possible?*

Connection of aggregations of smart houses will focus on the smart grid infrastructure needed for communication and information exchange between the smart houses and the enterprise system(s). The main concepts that will be used are multi-agent systems and web services to communicate information. The infrastructure has to support mass scale participation of 100,000 to 1,000,000 households in an enterprise business application that focuses on near real-time control of household appliances based on variable tariffs. Qualification and quantification of the interests of different stakeholders has to be made, based on energy efficiency enhancement and cost / benefit improvement.

2.1.3. Solution Approach

The business case around Imbalance Reduction will be built upon an already existing demonstration field trial developed in the EU Integral[4] project.

In the EU FP6 Energy Program INTEGRAL project, a large scale heterogeneous field test has been designed for application of the software agent based PowerMatcher technology. The test is conducted in a residential area in Hoogkerk near Groningen in the Northern part of the Netherlands (http://www.powermatchingcity.nl)., This 'PowerMatching City' entails 25 homes with either a 'dual fuel' heating system (electrical heat pump with gas-fired peak-burners) or a micro-CHP. In this sub-cluster setting, PV is existent in a must-run generator and must-run loads are lighting loads. A power distribution agent monitors constraints on the LV-distribution network. Furthermore, a wind production facility and laboratory-placed nodes with electricity chargers for electric vehicles and electricity storage are part of the field test.

One of the goals of this Integral field test is commercial imbalance reduction, in which all loads and generators are considered as part of a commercial portfolio. The flexibility of the total cluster will be determined in the form of the total amount of control and reserve power that can be liberated as a function of time and of time-of-year. The achievable ramp-up/ramp-down speed of the cluster will be determined.

The PowerMatching City will deliver year-round data on the business case for commercial portfolio imbalance reduction, in the form usage data including variable prices for electricity consumption and production by the households. These usage data are the basis for automated meter readings from these smart houses. Apart from using a restricted number of real-world households, the SH/SG field test A will focus on data communication at mass-application level. For this ECN intends to combine the data traffic from the PowerMatching City with mimicked data sources, as depicted in Figure 3. For reasons of scalability the envisioned ICT Architecture will be tree-shaped. An expected number of 100 programmable intelligent meters are needed to install at the homes participating in the trial. Another 100 meters are needed for specific testing of data exchange scenarios. Each group of 100 meters will be communicating with one (level 1) metering data concentrator. At level 2 there are 100 real data concentrators, each representing ~10,000 (real and mimicked) Smart Houses. At level 1 there are ~10,000 data concentrators each representing ~100 smart houses. A number of 100 of these level 1 concentrators will be real, the rest will be mimicked.

In Deliverable D1.1 a number of high-level system requirements are formulated for the business cases a smart grid has to support. The following gives a short overview of the most important requirements addressed in field trial A.

The infrastructure has to be characterized by ease of operation and maintenance of hardware, software and the network. A hardware configuration will consist of meters, devices, home gateways, concentrators, having their physical locations and links between them. The system should enable the software installed on the hardware to plug and play. Monitoring should provide insight on the health and status of each component.

The communication infrastructure should be open and secure in the sense that only authenticated components should be accepted. Also components and communication should ensure availability, integrity, and confidentiality of data.

An open communication should lead to interoperability of applications from different vendors having different platforms and from different actors having different applications. A main challenge will be to prove the interoperability of applications through web services, in this case the Microsoft .Net/C# framework supporting the business case on imbalance reduction at the control side, and the Java platform that is used at the enterprise level. This will provide a validation for service oriented architectures as introduced in work package 2.

[4] Integral is funded by the European Commission under the 6th Framework Program (Project FP6-038576)

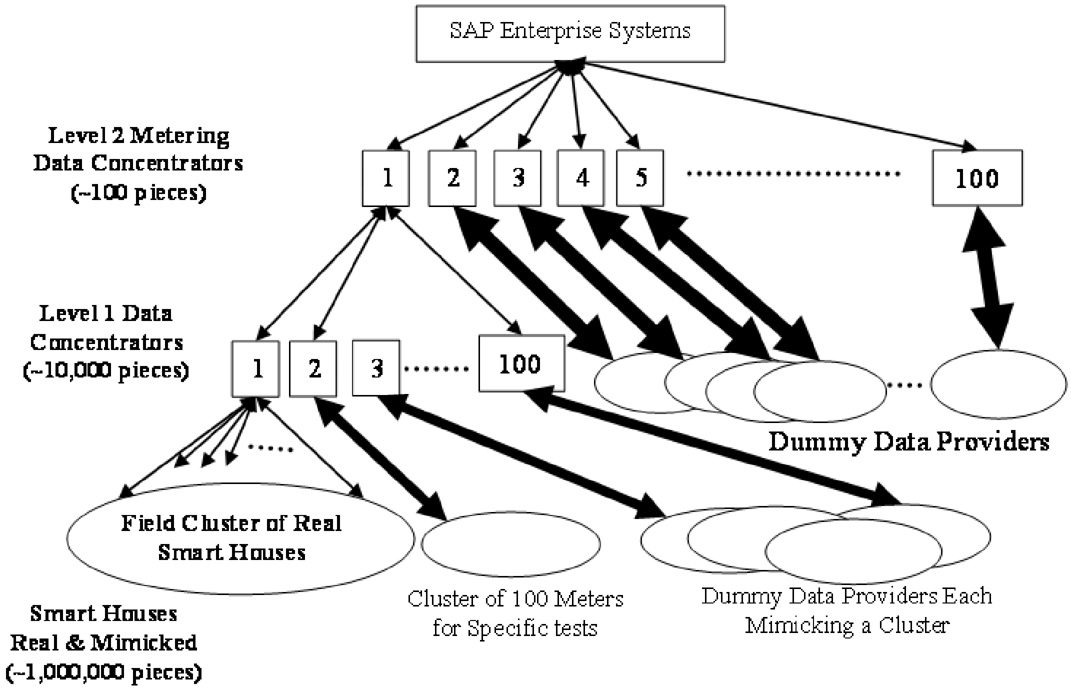

Figure 3: Tree-shaped architecture for data traffic for cluster of smart houses

The enterprise side of trial A will test how future business solutions will be able to adapt to high-volume data and still be able to deliver high-quality reliable services and near real time processing and views on the acquired information. As such, simulators will be built for several layers and will mimic their behaviour by e.g. amplifying in a non-deterministic way the data acquainted from real-field i.e. the real households.

2.1.4. Enterprise Integration Architecture

The enterprise integration, as depicted in Figure 4, is designed in a way that all trials can connect to it. 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. Currently, the main way to communicate among the platform and the different metering data-collections points is via web services. As such a concentrator, a smart meter or any other metering data entity can contact the necessary web service and submit the collected data. As illustrated in Figure 4, all the communications among the system components are designed to use web service (WS) calls. The major advantage is that by utilizing HTTP, the WS call can work in the network environment without requiring changes on the existed security settings (e.g. firewall filter rules). Another advantage is that the WS call provides interoperability between various software applications running on disparate platforms (e.g. .NET or Java).

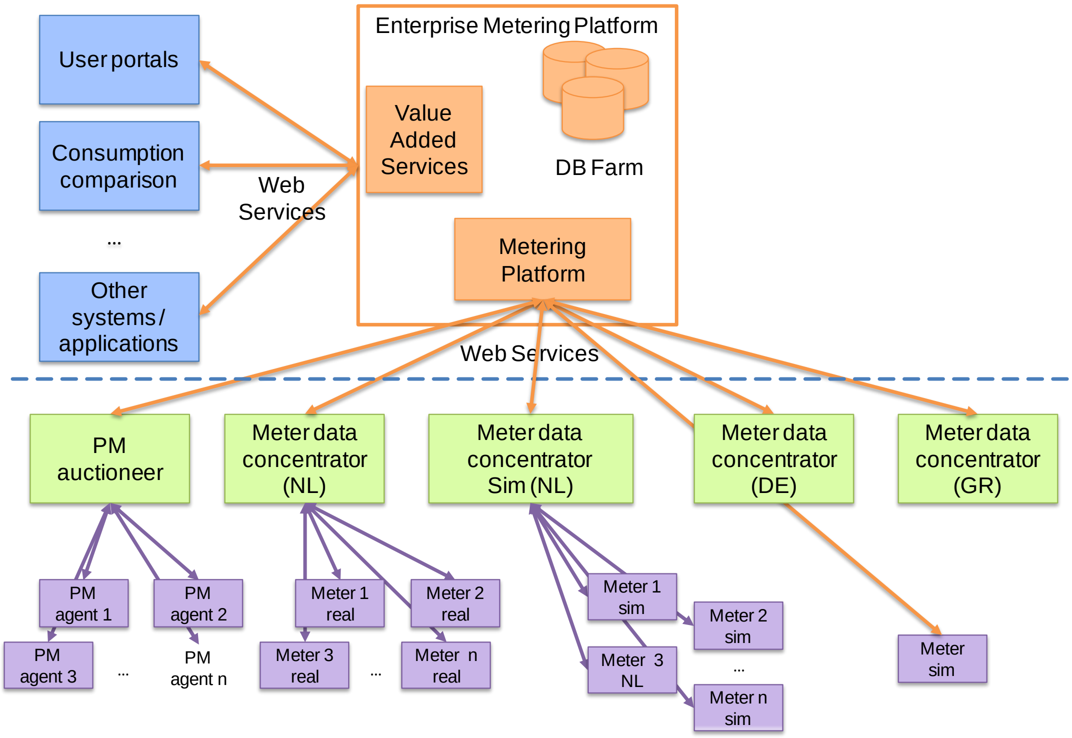

Figure 4: Smart metering trial overview

Server Cluster

As depicted in Figure 5, the component *server cluster* plays a central role in the whole architecture design, which deals with the WS calls from other external components. For instance, the *meter data concentrator* sends the real-time metering information to the *server cluster* while the *consumption comparison* retrieves the consumption information from the *server cluster*. Therefore, the *Server Cluster* is required to ensure its High Availability (HA). More specifically, HA includes both failover support and scalability support. The former ensures that a client will continued be served, without any interruption due to a node failure of the cluster, while the latter ensures the service maintains its quality of service (QoS) (e.g. response time of the service) in an increased load condition.

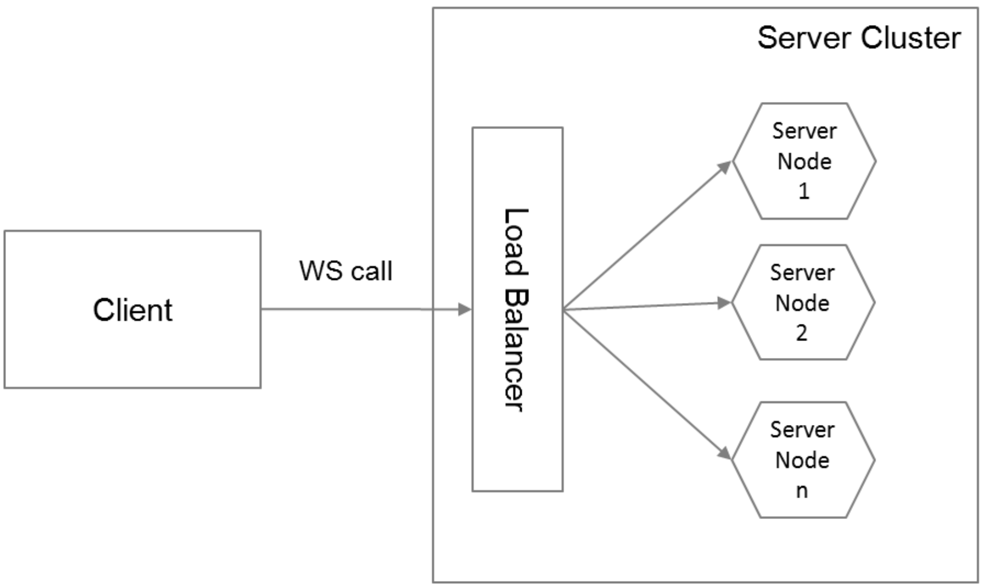

Figure 5: Server cluster architecture

As shown in Figure 5, the *load balancer* receives the WS call from the client and dispatches to a server node after analysing the status of all the available nodes. The load balancing option (selection of a server node) can be either "round robin" (randomly selected) or "first available". A potential problem with this architecture is that the *load balancer* itself is a single point of failure. It needs to be monitored closely to ensure high availability of the entire cluster services.

2.1.5. Research Questions

Mass scale integration of metering functionality:

- Infrastructure
- Reliability
- Access to meters
- Interval metering

Middleware for meter handling

- Performance

Combination of functionality at different time scales and different bandwidths

- PowerMatcher: near real-time time-constrained communication on low bandwidth
- Metering: non time-constrained handling of large amounts of information (variable tariff measurements), e.g. once per month

Interoperability of software:

- Microsoft .NET /C# local platform versus Java at enterprise level
- Validation of SOA

Business case development

- Commercial imbalance reduction with VPP
- Collaboration with Jacquard.

2.2. Functional Description

2.2.1. Summaries of Business Cases

Nine business cases have been defined in deliverable D1.1 within the scope of the SmartHouse/SmartGrid project. A short description of the business cases addressed in field test A is provided in the following subsection.

Aggregation of Houses as Intelligently Networked Collaborations

SmartHouse/SmartGrid concepts will exploit the potential that is created when homes, offices and commercial buildings are treated 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 SmartHouses or commercial consumers that have a contract with him.

The joint management of a collection of houses and commercial sites can be done in two ways. The aggregator might directly control one or several participating devices (e.g. deep freezers, air conditioning); this would require the end-users to allow direct access to the control of these appliances. Another way is that an aggregator can only provide incentives to the participating devices, so that they will behave in the desired way with a high probability, but not with certainty. The second option leaves the power of control to the end-user, i.e. the owner of the appliances, and might thus be more acceptable, and also easier to implement from a legal perspective.

One important concern in the aggregation of SmartHouses as intelligently networked collaborations is to avoid tipping effects in a mass application scenario: if all customers are controlled in a uniform way or all customers are given the same incentive at the same time, the overall system might destabilize by the sum of all reactions. This would compromise the objective behind the coordinated control, i.e. a more efficient operation of the energy system. Therefore, solutions for aggregating and jointly controlling SmartHouses have to deal with the implications of a mass use scenario and avoid tipping effects.

Real-Time Imbalance Reduction of a Retail Portfolio

This business case is rooted in the Balancing Mechanism as used by TSOs throughout the world. The European variant of this mechanism is part of the ETSO Scheduling System (ESS) and is widely implemented by European TSOs. In this context, an actor that is responsible for a balanced energy volume position is called Balance Responsible Party (BRP). The Balancing Mechanism consists roughly of three parts:

1. **Balancing responsibility:** the obligation of BRPs to plan or forecast the production and consumption in their portfolio and to notify this plan to the TSO. The granularity of notified plan is given by the *settlement period* length, typically 30 or 15 minutes. The notification is done before some *gate-closure time*, a predefined period ahead of the start of the settlement period.

2. **Reserves for frequency response:** the TSO contracts generation capacity for primary, secondary and emergency reserve. Production sites of a certain capacity are obliged to make available a predefined portion of their capacity to the TSO. This offer is done in the form of a bid. In case of (smaller or bigger) system-wide imbalance, the TSO calls off the reserves available in the order of their bid prices, in order to restore the instantaneous system balance.

3. **Settlement of imbalance costs with the balancing responsible parties:** in a later stage, the TSO charges the actual costs for the used reserve and emergency capacity to those BRPs that had deviations from their energy programs. These charges are referred to as *imbalance costs*.

Depending on the nation-specific regulations, the plan notified to the TSO is valid for a certain grid area, referred to as a *control zone*. The BRP is obliged to provide a plan for each control zone it has contracted generation or load in, and needs to follow the plan for each zone individually. So, a BRP is allowed to compensate for an imbalance in one part of a control zone using units in another part of the same zone. Typically, control zones cover a large geographical area: The Netherlands, for instance, is one control zone, while the UK is divided in 14 of such zones.

As imbalance prices are very volatile, the system of balancing responsibility imposes imbalance risks to market parties. Among BRPs, this risk will vary with the predictability of the total portfolio of the BRP. BRPs with low portfolio predictability are faced with higher imbalance risks. For instance, parties with a high share of wind energy in their portfolio are faced with higher imbalance costs.

To manage imbalance risk, market participants undertake balancing activities. These activities can both take place before gate closure as well as in the settlement period itself:

- **Pre Gate Closure:** Typically, balancing activities before gate closure occur in the power exchanges. Market parties fine tune their positions close to real time by contracting with generators or suppliers to adapt their position according to short-term load forecasts.
- **Within the Settlement Period:** After gate closure each BRP is on its own: each trade with other market parties cannot be notified to the TSO and, thus, will contribute to the BRP's imbalance. The BRP can only

influence the producing and consuming units in its own portfolio to achieve in real-time the desired net physical energy exchange with the network for each control zone.

This business case scenario focuses on the balancing actions by a BRP during the settlement period. Traditionally, these real-time balancing actions are performed by traditional power plants within the BRP's portfolio. The key-idea of this business case is the utilization of real-time flexibility of end-user costumers to balance the BRP portfolio. 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.

Convergence of the Business Cases

Two main actors appear in the two business cases above, the smart house owner and the aggregator. The basic script to be followed consists of the following steps:

1. The smart house sends information to the aggregator in the form of a demand and supply bid. This bid is based on the state of the smart house and the flexibility for the device operation derived from that state. A bid can be issued at any moment in time, and replaces the previous bid.
2. The aggregator receives notifications on its current imbalance. The periodicity is near real time.
3. The aggregator calculates from the aggregated bids from all smart houses and from the current imbalance a set point price that leads to reduction of the imbalance.
4. If the set point price deviates form the previous set point price, the aggregator sends an update of the set point price to all smart houses.
5. The smart house calculates from the received set point price and its demand and supply bid operational commands for its devices.
6. The smart house controls its devices based on the operational commands.
7. The smart meter in the smart house stores the set point price, and the operational command and the actual operation of each device.
8. Once per month the aggregator collects the smart meter information in order to produce a monthly bill, based on the variable tariffs that follow from the set point price.

Notice that for the smart house system other actors appear in the picture: the devices and the smart meter.

2.2.2. Context

In field test A the combined business case requires two sub-systems to be integrated in order to achieve the business objective: the smart house and the smart retailer.

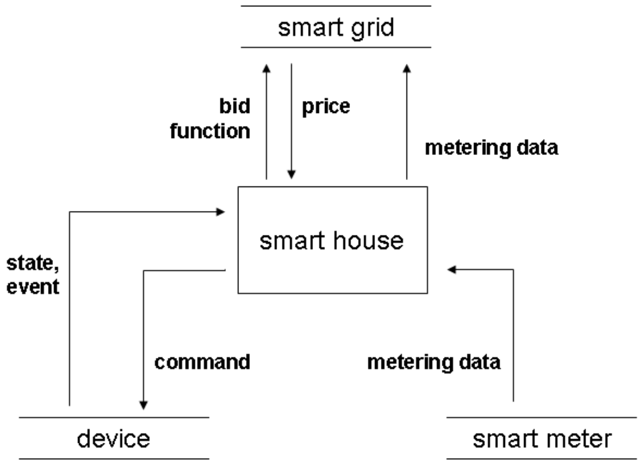

Figure 6: Context of the smart house system in field test A

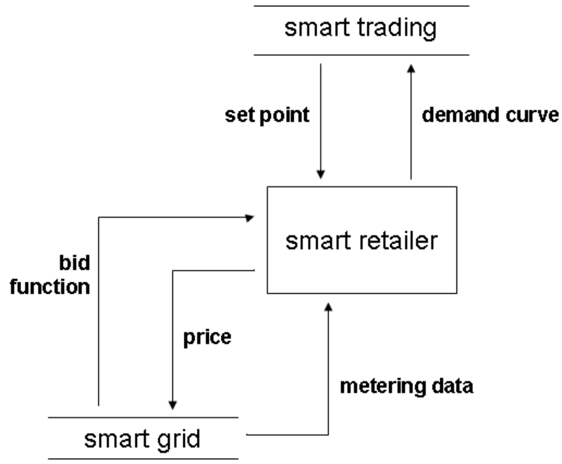

Figure 7: Context of the smart retailer (aggregator) system in field test A

Figure 6 shows the context of the smart house system. The "Imbalance Reduction" business case is supported by the smart house offering its flexibility to the smart grid as a *bid function*, and receiving the current *price* from it. The bid is based upon the *state* of the device (and its environment) and can be triggered by *events*. The price leads to a *command* to the device. The "Networked Collaborations" business case is supported by the smart house by providing the metering data. The smart meter functions as an autonomous entity, measuring the consumption and/or production in the household.

The metering data are still under discussion. The realized load is stored in the meter and is send to the smart grid on request. Validation of the "Imbalance Reduction" business case can only be reached if the billing system knows the contracted load and the variable tariff. The latter is known at the top end of the cluster at the Auctioneer. The contracted load is known at the Local Agent in the smart house.

In Figure 7, the context of the smart retailer system is shown. The smart retailer, as an aggregator, takes care of the market coordination leading to distributed real time control. It receives the *bid functions* from the smart grid and establishes a market *price* based on the *set point* received from the smart trading floor. It is also responsible for the handling of the *metering data* in its rating & billing system.

From both figures it shows that the smart grid has an essential role in both business cases, providing the infrastructure for the information streams between the smart houses and the smart retailer. Figure 8 shows the context from the smart grid point of view.

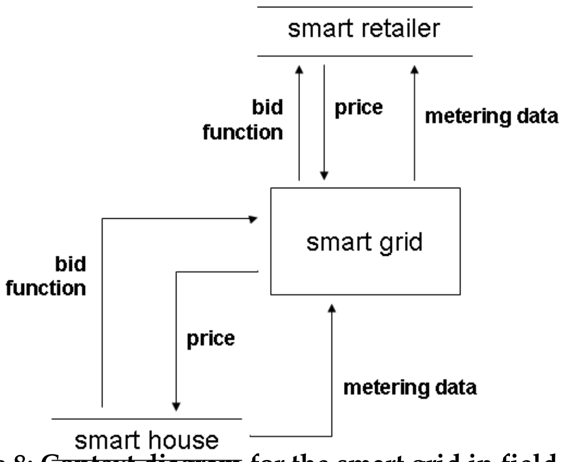

Figure 8: Context diagram for the smart grid in field test A

The context diagrams show the actor involvement based on main functionality of the business cases: real-time control and mass meter reading. A number of functionalities are not visible in the context diagram. These are:

- Issues concerning the management of the smart grid and the smart house, such as registry and discovery of services. Hereto standard elements of the SOA architecture can be used.
- Contractual issues between smart houses and the smart retailer.
- Monitoring of devices, smart meters and smart houses, and monitoring of data traffic / communication as far as required for solving some of the research questions.
- Normally the metering is done directly on the flow of the electricity grid. In the field test A the metering is done by the acquisition system within the smart house in order to avoid problems with lack of meter functionality.
- The billing itself is out of scope in field trial A.

Some remarks:

- The measuring of flexible production / consumption may constitute a challenge. In order to set up a sound business case the response to the request for flexibility should be measured or checked. This implies that the contracted volumes should be part of the metering data as well as the realized volumes.
- The business cases are based on real-time tariffs, which implies that prices can change at any moment in time. The billing may be based on integrated volumes and prices over fixed periods, e.g. 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.

2.2.3. Entities and Actors

The entities actors in the combined business case are summarized in Table 2. Note that the smart house and the smart grid appear as actors in each other's environment, but both subsystems must be designed in detail in the following chapters.

Actor	Description
Prosumer	The prosumer owns a smart house that operates a number of devices and is coupled to a smart meter. His main objective is to lower the energy bill and to operate its devices in an energy efficient way, without losing functionality or comfort.

<table>
<tr><td rowspan="5"></td><td>Entity</td><td>Description</td></tr>
<tr><td>Device</td><td>Produces and/or consumes electricity. The device communicates with the smart house: event and state information and (soft) operational commands.</td></tr>
<tr><td>Smart meter</td><td>Registers realized electricity volumes based on variable tariff structures, e.g. 15 minute resolution. The smart meter transfers metering data to the smart retailer.</td></tr>
<tr><td>Local agent</td><td>Controls the devices and communicates through a home gateway with the smart retailer: demand bids and price incentives.</td></tr>
<tr><td>Home gateway</td><td>Intermediator / concentrator between the local agents and the smart grid.</td></tr>
<tr><td rowspan="5">Smart Retailer</td><td colspan="2">A smart retailer operates a cluster of smart houses through the smart grid. The smart grid consists of components that facilitate the communication with smart houses and implement intelligence to enable smart decisions.
The smart retailer makes use of the services offered by smart houses in order to reduce energy cost.</td></tr>
<tr><td>Entity</td><td>Description</td></tr>
<tr><td>Auctioneer</td><td>The market auctioneer is responsible for the price forming for the cluster of smart houses. It receives demand/supply bids from the smart houses and an objective agent and determines the variable market price.</td></tr>
<tr><td>Billing</td><td>The rating and billing is responsible for handling metering data, including the variable tariffs.</td></tr>
<tr><td>Smart trading</td><td>From the smart trading control center the set points are submitted to the smart retailer that are used by the market auctioneer. The objective agent within a start retailer is used as an intermediate.</td></tr>
<tr><td rowspan="3">Smart DSO / Smart Grid</td><td colspan="2">The smart grid consists of the infrastructure that enables smart operation of the grid and the communication between smart houses and retailers. It is made of a stack of concentrators that transmit and condense information streams.</td></tr>
<tr><td>Entity</td><td>Description</td></tr>
<tr><td>Concentrator</td><td>Entity that has to achieve operational goals and translates these goals in objectives that an aggregator can use.</td></tr>
<tr><td rowspan="3">Smart Trading</td><td colspan="2">The smart trader is the actor that is interested in the flexibility of demand and supply offered by smart houses, in order to achieve operational goals: operation of power plants in a cost efficient way.</td></tr>
<tr><td>Entity</td><td>Description</td></tr>
<tr><td>Plant dispatcher</td><td>Entity that has to operate power plants (including the VPP) in a cost efficient way and determines the set points for plant operation.</td></tr>
</table>

Table 2: Actors and entities for the control and metering process of smart houses

The **Smart House** subsystem consists of a Home Gateway Concentrator that communicates with the outside world to offer flexible load services to a utility or system operator. The implementation of these services is based on intelligence in local agents who convert the local state of a device and local events into supply and demand bids and translate the market outcome, or settlement, to device commands. This allows implementation of business cases that utilize the flexibility of aggregations of smart houses as if it were a virtual power plant.

The **Smart House** also contains a smart meter that measures the total household supply and demand. The functionality of these measurements has to be elaborated on. Depending on the business case one might be interested to measure the behavior of separate devices. A monitoring functionality might be coupled to the smart meter to allow the customer to monitor the energy consumption of the house. The smart meter allows implementation of the metering and billing on mass scale, being one of the goals for field test A. Field test A does not comprise extensive monitoring.

Smart System Operation should provide the infrastructure to allow scalable mass application of both real-time control and non-time-constrained automated meter reading. It contains concentrators on two different levels: the PowerMatcher concentrators aggregate supply and demand bids from the smart homes, and distribute the market settlements to the smart homes for implementation. Communication can be narrowband, but requires fast and reliable throughput. The Metering Data Concentrators are responsible for reading the smart meters and provide this information to the enterprise (utility). Condensing information is not possible, since each household should be provided with a separate bill based on variable tariffs. Communication therefore must be broadband and reliable. Communication speed is less essential.

The **Smart Retailer** on one hand operates the market auctioneer that contains the coordination algorithms for the cluster of smart houses, and on the other hand is responsible for the rating and billing process. The auctioneer receives (aggregated) bids from the smart houses and from the objective agent and communicates the market settlement to the smart houses. The market status can be requested by the objective agent and the variable price history is delivered to the rating and billing process.

On the **Smart Trading** floor the operator has to fulfill a predetermined load schedule, e.g. based on the energy program. Deviations form the program can be tackled by changing the setpoint for one or more power plants. These operations are based on cost-benefit, i.e. those power plants are rescheduled that operate under minimal (marginal) cost. The cluster of aggregated houses will function as a virtual power plant and the aggregated supply and demand curve from the cluster delivers the (marginal) cost of this virtual power plant. Thus the operator can reschedule the virtual power plant leading to a setpoint change that an objective agent translates into a bid on the retailer market.

Concentrators may be duplicated in several layers, with the same interfaces for handling bids, settlements and metering data. For the real-time control the first layer Concentrator is equivalent to a Home Gateway, and establishes together with the local agents and devices the components of the Smart House for PowerMatcher based coordination. The other Concentrator layers, together with the Auctioneer, establish the components of the Smart Grid that are needed for PowerMatcher based coordination.

2.3. Application Architecture

2.3.1. ICT Hardware and Software

The following services are implemented by the PowerMatcher technology at the different components in the PowerMatcher Multi Agent System (MAS) network. These services are meant to be used within the PowerMatcher application and in principle are not addressable by external components.

PowerMatcher Auctioneer	**Implements Market Services**	**Pull Market Status**
	Implements Matcher Services	**Push Bid**
	The PowerMatcher auctioneer implements the electronic market algorithm. It either requests bids form underlying components, or these bids are pushed forward towards the auctioneer based on autonomous bid changes by local agents. For the latter the "Push Bid" service is available.	

	After having performed a market optimization the auctioneer sends the market settlement result to its underlying components in the form of a settlement price. A business agent can request for market info, such as prices, volumes traded and market flexibility, using the Pull Market Status service	
PowerMatcher Concentrator	**Implements Matcher Services**	**Push Bid**
	The PowerMatcher concentrator aggregates bids from underlying components. These bids either are requested from underlying components, or these bids are pushed forward towards the concentrator based on autonomous bid changes by local agents. For the latter the "Push Bid" service is available.	
	Implements Agent Services	**Pull Bid** **Push Settlement**
	The "Pull Bid" service is used by the controlling component (either another concentrator or an auctioneer) to collect the aggregated bid for the market. Using the "Push Settlement" service the controlling component can send the market result to the concentrator.	
PowerMatcher Local Agent	**Implements Agent Services**	**Pull Bid** **Push Settlement** **Push Event**
	The "Pull Bid" service is used by the controlling component (either a concentrator or an auctioneer) to collect the aggregated bid for the market. Using the "Push Settlement" service the controlling component can send the market result to the agents.	

For the business case on imbalance reduction the following additions are made to the core PowerMatcher setup. An objective agent is added that is operated by a trading floor operator. This trading floor can be specified by a Plant Dispatcher that controls the programmed load schedule and - based on the auctioneer's market data (demand curve, current setpoint) - determines the new setpoint for the objective agent.

PowerMatcher Objective Agent	**Implements Agent Services**	**Pull Bid** **Push Settlement** **Push Setpoint**
	See PowerMatcher Local Agent. There is no fundamental difference between the two, except for the external interfaces. The Push Setpoint is the equivalent of a Push Event.	
Plant Dispatcher	**Implements Dispatch Services**	**Push Schedule** **Push Demand Curve** **Push Setpoint**

For the advanced metering the following services are defined:

Smart Meter	**Implements Metering Services**	**Pull Metering Data**
Metering Data Concentrator	**Implements Metering Services**	**Pull Metering Data**
Rating & Billing	**Uses Metering Services**	
	The rating & billing process initiates the meter reading process from the smart houses and collects the variable price history from the market auctioneer. The billing itself is out of scope in the field test A.	

Field Test A Application

The services for real-time coordination and for mass meter reading are shown as interfaces in the UML component diagram in Figure 9. The green components are part of the PowerMatcher technology that is described in detail in Deliverable 2.2.

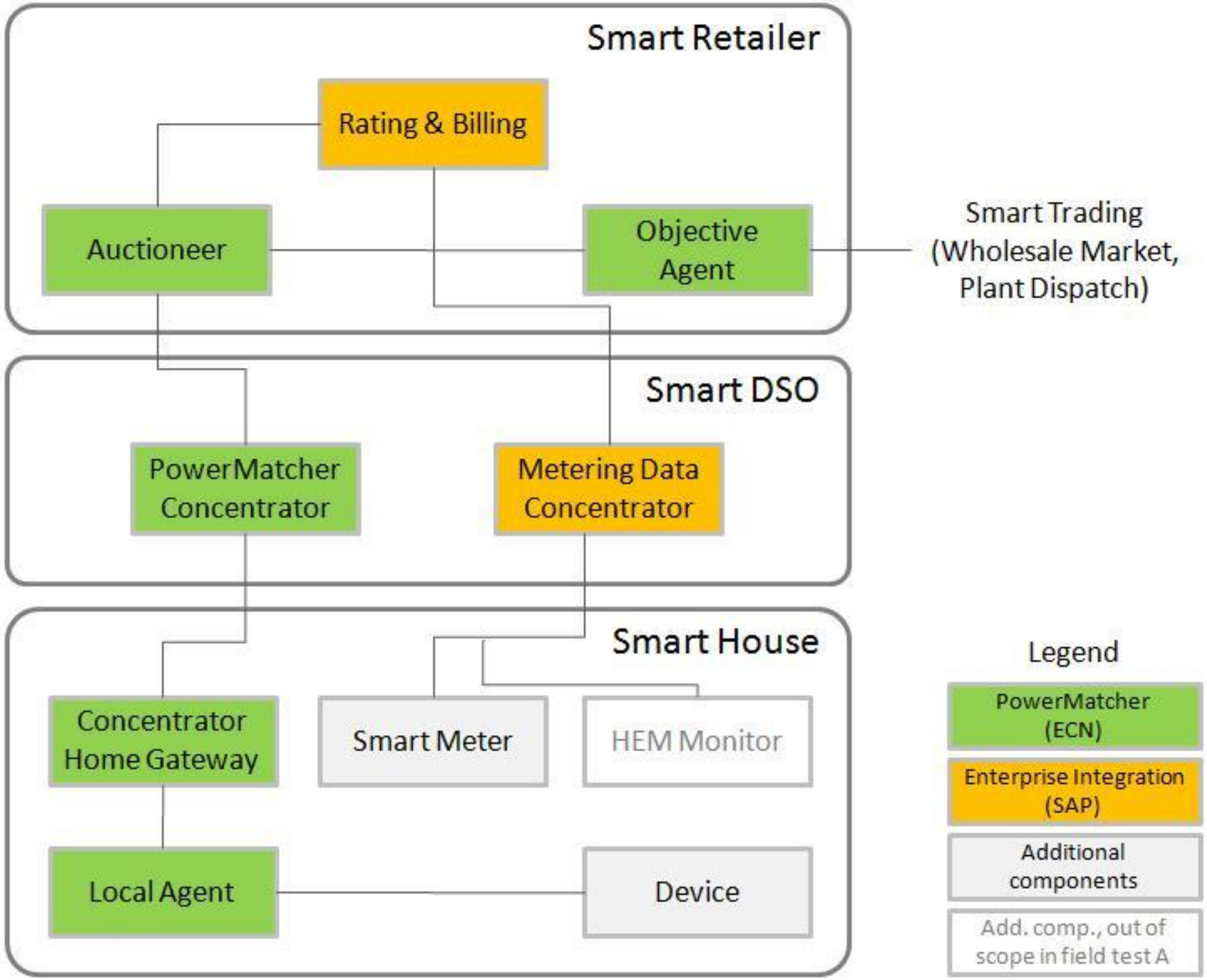

Figure 9: Interfaces for the SmartHouse/SmartGrid in UML component diagram

2.3.2. Devices

These entities form the lower end of the PowerMatcher control chain. Sensors are used to obtain direct measurements from the environment, e.g. room temperature, or presence detection. Actuators are entities that can receive a signal for implementation, e.g. a switch.

Devices are more complex systems of sensors and actuators. They can provide information, e.g. about their status, and they can receive control commands. As an example, a battery can provide their state of charge, and can receive a charge or discharge command including information about the required speed of (dis)charge.

Local Device	**Implements Device Services**	**Pull Measurement**
		Push Command
		Subscribe to Event

Field Test Application

Currently not many devices exist with DPWS functionality. The Field Test A in SH/SG is built upon an existing infrastructure, implemented in the Integral[5] project. In this project a different approach has been taken in measurement and control of the local environment, as shown in Figure 10.

A Local Database has been installed at each home. A Monitoring & Control component takes care of getting information from the device and sending commands to it. This information is handled by the Database Control component, that translate the push and pull requests into SQL statements and stores and retrieves them in/from the local database. The local agent polls the Database Control component and determines whether or not an event has taken place. The event handling as described in D2.2 ("Push Event" and "Subscribe to Event") is not implemented.

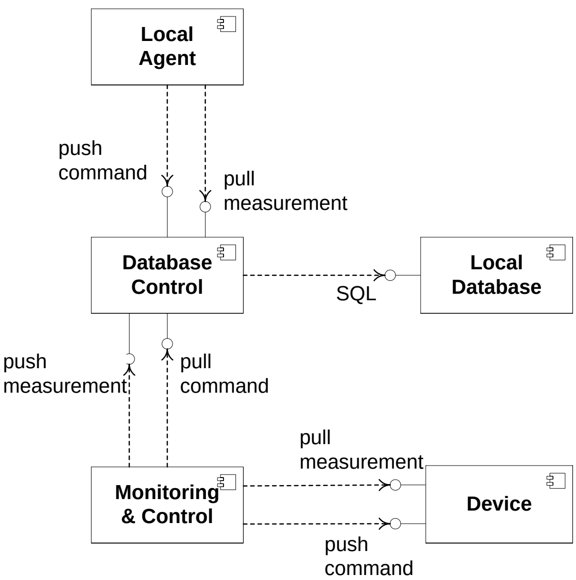

Figure 10: UML component diagram for monitoring and control

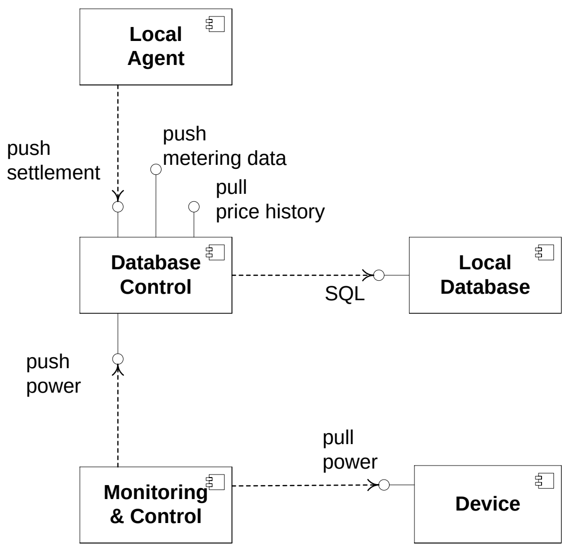

Figure 11: UML component diagram for metering & control

[5] The Integral project is funded by the European Commission under the 6th Framework Programme (Project FP6-038576); website: http://www.integral-eu.com/.

Metering Issues

In Figure 11 the services related to the metering process are singled out. Two services are provided to the external smart grid world: *pull metering data* and *pull price history*. The first one is implemented within the smart houses; the latter - as specified in Figure 9 - within the auctioneer.

Since all information from field test A will be available in the local database, we can create a virtual meter component that implements the 'pull metering data' and 'pull price history' services by retrieving the information from the local database of the smart house and auctioneer, respectively.

2.3.3. Tools to be Used

The field test A combines not only two business cases, but also brings together two development environments:

- The business case "Imbalance Reduction" is based on the PowerMatcher technology developed by ECN. It is based on Microsoft Windows and developed using the Microsoft .NET 3.0 Framework and Microsoft Visual Studio C#.
- All information from the field test is stored in a Microsoft SQL Server 2005 database.
- The business case "Networked Collaborations" will connect to SAP Research enterprise software running in a Java environment.

2.3.4. Standards to be Used

- Web services will be used on various levels of communication. Web service is a standard communication mechanism based on SOAP and WSDL. Note that web services enable smooth interoperability between the ECN Windows environment and the SAP Research Java environment.
- The PowerMatcher protocol already is build on SOAP and WSDL. This protocol may eventually be the basis for a PowerMatcher protocol standardisation process.

2.3.5. Developmental Stages

The field test A will make use of the Integral configuration provides the basis for "Imbalance Reduction". The smart trader dispatch process has to be developed to provide the set point for the objective agent, based on the current demand curve and an external trade/production schedule.

In Figure 12 a number of subsystems for "Networked Collaboration" can be distinguished:

- Field test configuration: concentrator controlling a number of real households. For this part of the field test a connection will be made to the Integral field test 1, by providing a database wrapper for the smart house databases that implements the "pull metering data" service.

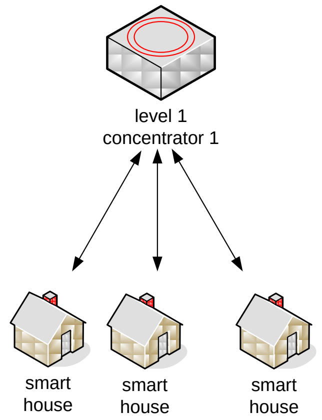

Figure 12: Field test configuration

- Smart meters configuration: concentrator controlling a number of smart meters.

  The smart meters are delivering 15 minute data based on programmable loads that are connected to the meters. , and where is the data originating from?

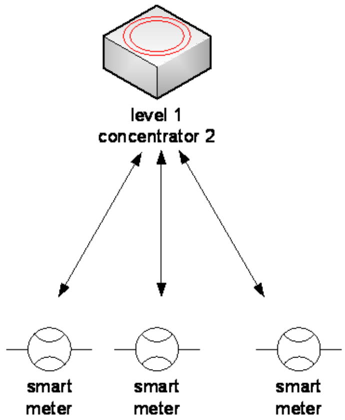

Figure 13: Smart meters configuration

- Simulated cluster configuration: concentrator controlling a dummy data provider that simulates the metering data volume for a cluster of households.

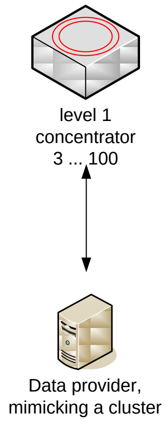

Figure 14: Simulated cluster configuration

- The concentrator level infrastructure need to be developed to transport the data to the enterprise level: level 1 concentrator, level 2 concentrator and enterprise concentrator.

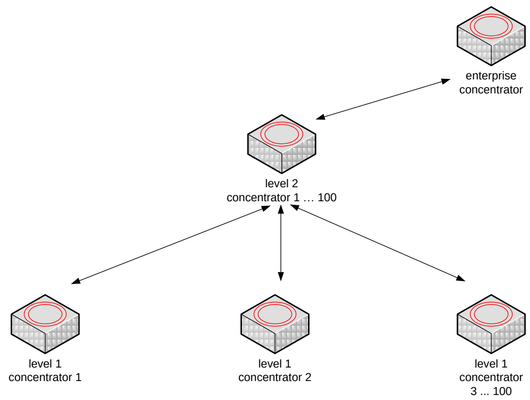

Figure 15: Concentrator level infrastructure

- Enterprise evaluation: at the enterprise level the rating and billing process needs to be developed. For this the "pull price history" service has to be provided by the auctioneer.

2.3.6. Deployment Schemes

The "Imbalance Reduction" business case will rely on the existing roll-out of the Integral field test.

The following tables the hardware nodes are described that will be used for the “Networked Collaboration” business case.

Component	Location / node	Responsibility
Server PC	Enterprise portal PC	Running AMR
Virtual Server PC	Compute server	Running the PowerMatcher simulation
Virtual PC	Concentrator level 2	Running concentrating metering data
Virtual PCs	Concentrator level 1	Running AMR
Regular PC	Concentrator level 1	Running AMR
Small form factor PC	Domestic concentrator	Running AMR
		Running the local database

Table 3: Hardware nodes for networked collaboration

Component	Location / node	Responsibility
Regular PC	PowerMatcher Auctioneer	Running the market algorithm
Regular PC	PowerMatcher Concentrator	Running Agents
Small form factor PC	Domestic Concentrator	Running the local database
Power meters	Household, lab	Sagem meters
Central Solar panels	KEMA Lab	Siemens
Virtual Solar Panels	Households	Assigned shares from central solar panels
MicroCHP	Households	WhisperGen
Heat pump	Households	Samsung

Table 4: Hardware nodes reused from the Integral project

The hardware nodes in the system are depicted in the Figure 12 to Figure 15 in the previous paragraph. At all levels (virtual) PC technology will be used.

In the household a choice was made by Integral to use a small form factor PC as home concentrator. The reasons are:

- A PC offers flexibility required in a experimental setting, e.g. the storage of additional data, remote updates of the software, etc
- A PC is COTS (Commercial Off The Shelf). In future a dedicated home controller may be developed and produced in high quantities to reduce the costs. For the Integral field test however this would be a very time consuming and costly development.

For software development standard state-of-the-art PC technology and development technology will be used by the developers.

2.4. Design of Experiments

The design of the experiment will focus on the value of electricity as a means to provide a more efficient utilization of the electricity network. This value may vary in time, due to global or local market movements, the position of a program responsible party in the market, or the availability of electricity from renewable resources such as wind and solar; and it may vary in place, due to e.g. network congestion. Special focus will be on the imbalance reduction of a portfolio as described above. The PowerMatcher technology will be applied to a cluster of smart houses, leading to variable tariff schemes for the households.

In order to enable business cases based on variable tariffs automated meter readings are an important issue, since the consumption and production data for electricity have to be known at a periodicity of hours to minutes. So the main focus of the field test A will be on the handling of these meter readings an mass-application strength.

2.4.1. Test Scenarios & Verification Scheme

The field test A combines two subsystems, the PowerMatcher for control and the SAP Enterprise system for metering and billing. Both systems have proven their mechanisms, so verification of these subsystems is straightforward.

Technical verification consists of the following steps:

1. The PowerMatcher system is verified by checking:

- information streams between agents, concentrators and the auctioneer: this information consists of 'upstream' bid functions and 'downstream' price information.
- availability of metering information, either on the smart meter or in a separate monitoring system; the metering information contains granular usage data and variable tariffs.
- behaviour of the smart houses with respect to their comfort: the main comfort is thermal comfort delivered by heat pumps and micro-CHP. Other comfort may be the on-time charging of electric vehicles.

2. The interfaces between the smart meters / monitoring system will be verified:

- verification of web service interfaces between the Microsoft.NET platform and the enterprise Java platform.

3. Operational data will be collected on the amount of data transmitted.
4. The following non-technical verifications will be made:

- translation of variable tariff electricity prices to billing (based on fixed periods, e.g. 15 minutes).
- validation of the actual operation of the households with respect to the expected contribution to the business case. A quantification will be made of the benefit for both the household (efficient energy use, smaller bill) and the enterprise (less operational cost for imbalance).
- The energy efficiency quantification will have to be made at the system level as a whole, not at the individual household level.

From the enterprise system view, scalability must be done horizontally and vertically. The collection and processing of meter readings as well as the performance of value-added enterprise services are of key importance.

From an enterprise system’s point of view, the most interesting point is clearly reliable data reception (database input) and the user report services (database query execution). In between these two points, there have to be provided some measurement results for certain measurable objects.

Firstly, important points that will be measured on data reception are following:

- Duration – time for the data to reach the web service (or web server)
- Reliability – how reliable is the data reception, e.g. packet loss
- Payload impact
- Network performance – comparing the interest in networks with the different bandwidths

- Single meter vs. concentrator – comparing the efficiency of data reception from *n* smart meters (equals to the *n* HTTP/SOAP requests) against the data reception of *n* smart meters, but from one concentrator (equals to the one HTTP/SOAP request)

Secondly, measurements once the data reaches the web server are following:

- Throughput – test if server is actually capable to retrieve that amount of data
- Processing time – required time to process one web service request
- Payload impact
- Scalability – how fast system should scale, e.g. load balancing

The next important point is where data reaches the database. Of course, this highly depends of the database software, underlying hardware and "local" network. Measurements are the following:

- Throughput
- Store performance – INSERT operation
- Retrieve performance - performance for DB READ operation
- Storage estimation - an estimation of the storage dimensions in the overall system i.e. the data from one million smart meters

Finally, once the data is stored the users will be provided with the web portal where users can see their "real" time consumptions and billing status. Following points should be measured:

- Throughput
- Time – it has to be confirmed if there can be provided a real time service, or at least to have a timing approximation for user to reach its consumption data
- Service performance – the web service should be stressed in order to see how many request can be provided in a certain period

2.4.2. Final Objective Verification Procedures

The Description of Work mentions four key objectives that have to be addressed by the field tests.

Objective A: The developed ICT technical functionality works under real-life field conditions.

Field test A will verify the scalability of the intelligent communication and negotiation architecture, such that it is able to handle in the order of thousands of energy devices simultaneously. The device-to-device communication and e-market negotiation technology will be addressed using the PowerMatcher technology. The metering data at mass-application strength will be handled in a separate thread using the same topology.

Objective B: The developed ICT technology is affordable.

The service oriented approach in the field test A will verify that Smart House technology can be based on open industry standards in both the ICT and energy sectors and existing infrastructure.

Objective C: The developed technology has significant potential for mass application across Europe.

An evaluation of the business case for "real-time imbalance reduction" will verify whether this is a sound business case with respect to investments in ICT-enabled energy-efficiency technology and the benefits for energy utilities and energy service providers and for the end-users.

Objective D: The developed technology is able to achieve aggregate energy efficiency gains > 20%.

For the business case of field test A energy efficiency gains are expected to be achieved on a system level: better integration of renewables in the energy markets, avoidance of inefficient peak power plants, etc.

3. Field Test B: Domestic Cluster Mannheim - Wallstadt

3.1. Overview

- **Partners:** MVV (lead) & ISET
- **Focus**
  Create win-win-win situations with a domestic cluster of **ISET-*BEMI*+** in selected grid segments with end-users in order to improve energy efficiency, energy supply cost and grid operation.
- **Main Objectives**
  - To test a real system of customer or automated response on price signals in respect to practicability, IT architecture, client response and the cooperation of many involved stakeholders
  - Check the possibilities for load shifts based on price incentives and automated energy management

  and to get some information on:
  - End-user's: improvement on energy efficiency (complementing other projects)
  - Local generation: Optimize economic benefit and efficiency
  - Energy retailer: Implement new business model to reduce energy cost
  - Network operator: Improve security of supply and reduce network operation cost
- **Location:**
  - Residential settlements in Mannheim, Germany, such as the ecological residential settlement Mannheim – Wallstadt

Figure 16: Overview of trial suburbs in Mannheim

3.1.1. High-Level Description

Mannheim field test sites will provide a cluster of some 100 SmartHouses, preferentially in the ecological residential settlement Mannheim-Wallstadt but also in other sububs. Settlements in Mannheim are typical residential sites of a German city. Many end-users of electricity are ecologically interested. Some of the customers already know the topic of energy management through prior experiments or information provided. We will search preferentially for end-users that are co-operative and interested in innovation. A subgroup own and operate distributed generation devices (mainly PV and CHP) and the interest of owners of DG is to use energy efficiently (directly) and to maximise economic benefit from generation.

Representative users are identified in ecological settlements and in additional electricity grid segments and to see if we could observe differences in behaviour between more and less ecologically oriented customers, and to detect difference in actual load patterns and load profiles. However, these design questions also depend on the mix of customers that can be motivated to participate in the field test.

The energy supplier MVV currently has regular energy supply contracts with the end users that are invited to participate in the SH/SG trial. In the field test, MVV will implement a new business model and provide variable tariffs in order to reduce energy costs from the pre-supplier e.g. through load shifting. This is expected to create a win-win-win situation, because energy efficient behaviour will pay for the consumer, the supplier and the grid operator while contributing to efficiency increase by direct visualisation/feed back as well as indirectly, e.g. through reduced spinning reserves. For the automated system any difference in price would influence operation start/end of household devices. The end users' behaviour will be influenced by the price difference and thus this price difference must by sufficiently high. The project team will evaluate end users´ reaction concerning incentives given by variable tariffs, and possibly additional customer information and interaction.

The DSO MVV validates the functionality of the **ISET-*BEMI*+** in the field and prove that a representative number of **ISET-*BEMI*+** in selected grid segments can benefit to lowering operation cost while maintaining or improving security of supply. The field test will further contribute to the validation of the hypothesis that load management can be used for efficient integration of a high number of DG and RE in electric networks. Herefore, a substantially improved ***BEMI*+** and supporting equipment is currently under development and testing.

The challenge for research consists in determining to what extent an intelligent system for automatic energy management at customer's premises can be kept stable in a fully decentralized way with bidirectional energy management interfaces (BEMI's), with local agents enabling Smart Houses to be active on energy markets and ancillary services as well as with local services under highest requirements at security and availability. After actual pilot projects for testing the functions of BEMI's with small numbers of items, the future central point of the research will consist in examining the behaviour of smart power grids with highly scaled BEMI's and agents under real-time conditions. Also, developing new transactions platforms for new market mechanisms, defining requirements for further service developments, communication standards, ontologies for the communication in a heterogeneous environment and regulation algorithms, as well as investigating the robustness, scalability and security of infrastructure services need to be considered. The field test in project SmartHouse/SmartGrid is contributing to preparing those further research activities. As detailed in a future report and exceeding the originally DoW objectives, it was decided to not only develop new middle ware (software) but also the whole hardware platform. This is made possible by using synergy effects with a parallel ongoing R&D project[6]

Research contents in the project SmartHouse/SmartGrid are thereby in particular the investigation of the ability for controlling a network of smarter energy devices in a fully decentralized way for the increase of the energy efficiency on an aggregated level (decentralized control algorithms) connected with a high degree of security and the use of software agents and electronic markets for automatic trade, communication, optimization and control, as well as for automatic balancing of bids and offers of energy.

3.1.2. Problem Statement

The main technical goal of field test B is to develop the complex hardware and to use it to demonstrate how private customers can be motivated to adjust their consumption by load-shifting when they are offered variable electricity tariffs on a day-ahead basis, and how to organise such a system to be applicable for a larger number of customers. The load shifting of non user-controllable loads (e.g. freezers) will be carried out automatically by a system situated at the customer's premise, the **ISET-*BEMI*+.** This system comprises a computing core, switching elements for automated load switching and for load supervision (switch boxes),

[6] MoMa = Modell City Mannheim (or in German *Modellstadt Mannheim*) using German government funds

and a visualization functionality. The latter allows the customer to view the variable tariff and thus to manually optimize the operation of user-controlled loads (e.g. cooking appliances) in addition to the automatic optimization. Customers also receive up-to-date information on their energy consumption and cost based on at least hourly values (total) and high-resolution data based on single-device-measurement from loads connected to switch boxes. This is expected to additionally raise customer's awareness on the topic of energy efficiency.

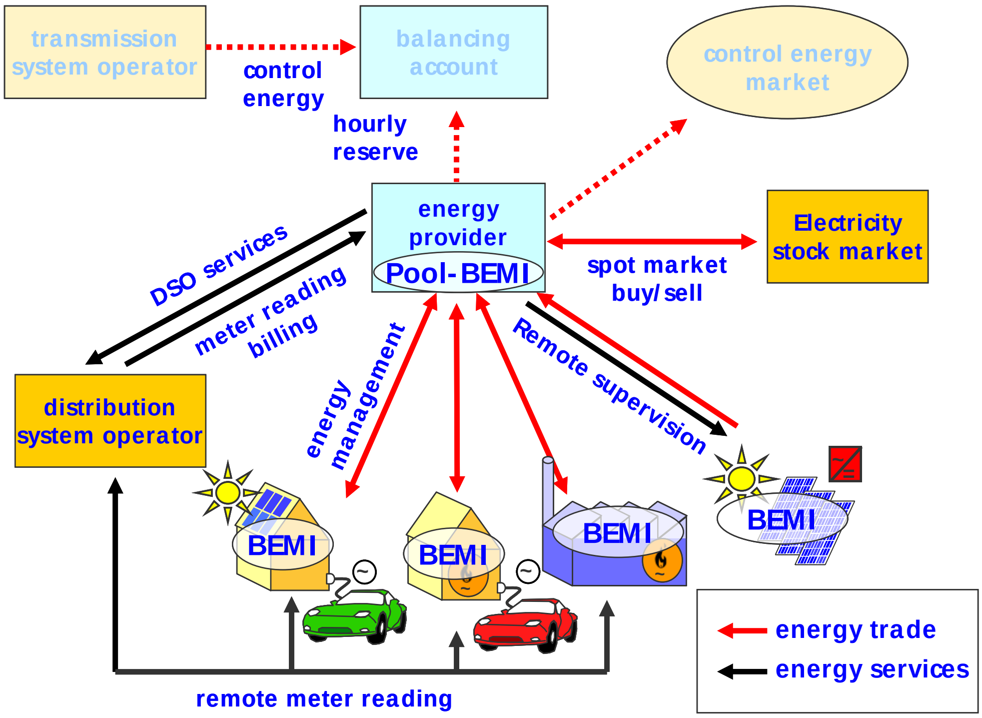

Figure 17: Field test B basic market context

Figure 17 gives an overview of the basic approach to be tested. Here, the BEMI-equipped customers are given a variable tariff by an energy supplier which operates a "Pool-BEMI". The details of the variable tariffs given to the customer are still under discussion but will be based on day-ahead hourly power prices. By operating devices in times where these prices are low, the customer gets the opportunity to optimize his energy cost. The ISET-***BEMI+*** is designed to finally automatically carry out this optimization. This shall cause an overall load shift into times where prices from energy markets are low, thus demonstrating that the cost for energy procurement carried out by the energy supplier is lowered as well. It has to be considered that energy costs per kWh generated is low if fed-in from generators with zero fuel cost, e.g. wind turbines. Variable tariffs allow the customer also to profit from price fluctuations while allowing the energy provider to shift loads such that energy from renewable sources, or in more general at times of a surplus of electricity generation, is preferably and efficiently used. Also, it is expected that this also will reduce balancing energy for deviation of customer consumption from the predicted demand and to reduce peak power in the distribution grid area considered, which again yields economical benefit for grid operator and energy supplier. Finally a more balanced grid with reduced peak consumption will reduce 'stress' in the grid, and allowing for a reduced assumption for maximum power needed in a grid. Hence, there are physical limits for load shifting which stem from restrictions of the load's parameters on one side and the willingness of customers to cooperate on the other. It is yet to learn more about such limits for load shifting given a system of ISET-***BEMI+*** operating in an urban grid area.

The field test is designed to provide data in order to be able to research these questions. Further more, the field test will first of all test the developed equipment under real customer conditions (and not any research laboratory or pilot) and then provide information and experience in order to identify architecture and technological, economic and regulatory needs for a mass-rollout of energy management systems in the future.

However, it should be noted that the proper implementation of such a field test will also show the problems and limits that need to be considered if dealing with real customers. Not only does the acceptance of such systems by customers need to be explored, but also their degree of understanding and willingness to study and use any data provided. Not all data available is appropriate to present to an 'average' customer without overstressing his cooperation possibilities and willingness. Finally, through unbundling and many competing energy and service providers in Germany, there are many stakeholders to be included in the process. This is a very important question to be stressed in the field test. Although there is only one grid operator and electricity provider (MVV) involved, there are also other stakeholders that have to collaborate in order to make the field trial work properly; these are (i) non-MVV company and service providers, e.g. PPC-AG, Powerline Corporation for price, metering and other signal transfer via powerline, or the billing of costumers done by 24/7 United Billing GmbH, and (ii) MVV-internal departments or affiliates, such as the departments for electricity grid planning, sales, tariffs, purchasing of electricity, which are all operated as profit centres and all are nearly as difficult to involve as separate companies.

3.1.3. Solution Approach

In order to technically enable this demonstration, a new hardware and software design for the **ISET-*BEMI*+** is used. The hardware shall provide an energy efficient, stable and remotely manageable solution for automatic energy management and in-house as well as wide-area ICT interconnection.

The hardware was decided to be upgraded as the existing hardware platform did not offer many resources for future improvements (this was only possible by using synergies with other R&D projects as detailed below). Part of the hardware will be also newly developed, e.g. switching boxes to remotely switch on/of electric appliances. Here the secure wireless communication is the challenge. The software design shall provide a modular and open environment for energy management and energy-related information processing. A reference implementation of the software framework to be implemented in the field test is currently under development. Details of both the new hardware as well as the software will be presented in the Deliverable 3.2.

In order to be able to carry out this development, the relation of SH/SG to ongoing projects has to be considered very carefully. In order for SH/SG field test B to be successful, synergies between those projects, namely the national projects Modellstadt Mannheim (MoMa) and Smart Meters (SM) have to be used most efficiently. This is possible since field tests for all three projects are scheduled to start in fall 2010. Synergies apply both to hardware and software development and installation as well as data usage for further theoretical studies.

In order to evaluate the reduction of energy cost by load-shifting, reference customers are required that are not included into the smart grid strategy. For the reference load data, temporal resolution of 15 minutes is considered as sufficient. Unfortunately, there are no historic long-time measurements available due to data privacy reasons. Therefore, the following options are being considered:

1. Usage of load curves for the customers of field trial B based on measurements taken after installation of smart meters, but before introduction of variable tariffs and activation of automatic energy management

2. Using the standard load curves for residential customers as normally used by electricity providers as a basis for their internal load prediction (only valid for aggregated customers)

3. Comparing the behaviour of customers known as ecologically oriented with other ones that are not sensitised, 'average' customers.

4. Usage of load curves gathered within other R&D projects, in particular the project SM. Customers will be equipped with smart meters allowing in principle to follow a load curve with time (a standard

electricity meter is integrating over the time). Customers will be able to follow their consumption which is assumed to influence their energy consumption to some, but possibly limited, extent. This project will however NOT include automated switching of devices

In the best case there will be more than one reference group available to get an indication on a hierarchy of customer behaviour change: 'business as usual', with smart meter and visualisation without and with variable tariffs. Note that such, possibly extended, interpretation is possible only by harmonising and combining otherwise independent project-field tests. The partial coupling of resources not only allows for a field test implementation at very low costs, but additionally allows an extended interpretation or quality of data gathered.

Since field test B involves real grid end customers and takes place in a grid area within a strong urban network, security of supply is most vital. Variable tariffs will be transmitted to customers actually influencing their energy cost according to their behaviour. There will be the same variable tariff given to all field test customers on a day-ahead basis. Depending on the extent of load shift, there is a chance to observe the impact of synchronous automated load switching and to conclude if and which steps have to be taken in order to avoid negative effects on supply stability caused by synchronous load switching.

3.1.4. Enterprise Integration Architecture

A prerequisite for the introduction of variable tariffs is that households are equipped with electronic meters. This requires a complete reorganization of the process chain from installation to operation and maintenance for the new metering technology as compared to the mechanical Ferraris meters. Furthermore, a new system landscape is required for the metering data to be processed, in order to ensure a completely automated data process chain of the involved IT systems (for metering data collection, billing etc.). In the field trial B, which was the only trial in SmartHouse/SmartGrid that involved real billing of variable tariffs, the architecture was split into the mere electricity meters and the concentrator. The latter is also called MUC – multi-utility controller – or gateway and is also installed at the household.

The metering data is transmitted via the concentrator. Through this, the actual communication intelligence does not lie in the meter. The biggest part of the intelligence needed for billing is located centrally at a newly designed software platform. For the trial, this platform has been developed mainly in the framework of the partner trial in the Modellstadt Mannheim project (moma) together with IBM, involving the SAP for Utilities environment that MVV is running.

A central flexible system for calculating variable tariffs is tested in the field trial, together with the continuous monitoring of whether the automated processes function well and whether the generated metering data is processed correctly. For the calculation of the variable tariff, a new software feature has been developed which enables mapping the meter readings to the price profile (= rating).

The software features developed by IBM has the following functionality:

- Storing of individual price profiles from a distribution grid cell server located at Fraunhofer IWES
- Storing of individual price profiles in a central database
- Storing of the meter readings relevant for billing in a central meter reading management module
- Rating of meter reading: mapping of meter readings with according tariff of the virtual tariff registry

The virtual tariff registries are then made available to the SAP IS-U system. Tariff definition and calculation is done in an additional tool in the form of a two-step tariff. In the field trial, the two steps have been defined as follows:

- High tariff: electricity (work) price of 24.99 EURct/kWh
- High tariff: electricity (work) price of 14.99 EURct/kWh

The metering data is transmitted on a monthly basis. The aggregate consumption per meter is sent over the SAP X-I interface at the last day of each month.

In the field trial, all customers receive a best price bill. In this case, the monthly electricity costs are calculated both for the variable tariff and for the standard tariff for the actual consumption of the specific customer in the high and low tariff periods. Only the lower price of the two option is actually billed to the customer. The cost saving is detailed in the bill in order to provide an actual incentive for load shifting. There were two reasons for introducing the best price billing:

- **Contradictory legal requirements**: The German Verfication Act requires that an end customer can always verify his bill at the electricity meter. Therefore, the incremental meter readings must be visible at a display for all applicable tariffs at all times. In the field trial, however, the tariffing is done in a central software and made visible to the customer via the MVV metering portal (in his web browser) and not at the meter itself.
- **Cost risk:** The trial participants don't have any cost risk through participating in the trial, which increases acceptance especially for cases in which the technology does not function as properly as it could be expected for a mass-scale roll-out.

3.1.5. Research Questions

Field test B is expected to contribute answers to the following research questions:

- *Potentials:* How do end users react to variable pricing? Which incentives have to be given to customers to reach a designated load shifting reaction? How much technical potential of load shifting can be activated using the BEMI approach with variable tariffs? How much of this potential is attributed to devices that are:
  - managed automatically without user interaction (SOC), e.g. fridges
  - managed automatically requiring some user interaction (FPS), e.g. washing machines
  - not managed automatically at all, but eventually used differently by the customer due to variable tariffs ("user-controlled") ?
- *Savings:*
  - What is the approximate cost saving to be achieved by the management strategy when considering a specific variable tariff compared to a fixed tariff calculated as average from the variable tariff?
  - Which part of the savings is obtained from SOC, FPS and customer-controlled devices?
- *Applicability and architectural needs*
  - Which practical problems arise when installing energy management gateways at customer's premises? How can the modular software environment be enhanced to provide an appropriate basis? Which problems are to be expected in mass-roll out and how can they be solved?
  - How can the customers' needs be fulfilled while allowing optimal operation for the overall system? Which needs exist for the design of the user interface? Which options do customers need for influencing the system's behaviour?
  - What are problems faced with all different stakeholders involved by setting up a system of 'active customers'? This is also thought to give insight in a competitive market with different stakeholders involved (possibly also different service providers).
  - Any limits faced or to be expected if many active customers are included at the same time

The field test is also expected to provide some data regarding the following questions:

- *Prediction:*
  - Can overall customer load related to 1 hour or 15 minute load profiles be predicted? If yes, what can be said about the incurred prediction error?
  - Can the prediction also be done for customers where automatic load shifting is applied using variable tariffs? What can be said about the incurred prediction error?

- *Impact on grid operation (cf also WP4):*
  - To which extent can load shifting be used to limit demand peaks in the distribution grid? How much contribution to this is obtained in average / maximum / minimum from SOC, FPS and customer-controlled devices?

3.2. Functional Description

3.2.1. Summaries of Business Cases

The SmartHouse/SmartGrid business cases have been defined in deliverable D1.1 of this project. A short description of the business cases addressed in field test B is provided in the following.

Aggregation of Houses as Intelligently Networked Collaborations

SmartHouse/SmartGrid concepts will exploit the potential that is created when homes, offices and commercial buildings are treated 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.

The joint management of a collection of houses and commercial sites can be done in two ways. The aggregator might directly control one or several participating devices (e.g. deep freezers, air conditioning); this would require the end-users to allow direct access to the control of these appliances. Another way is that an aggregator can only provide incentives to the participating devices, so that they will behave in the desired way with a high probability, but not with certainty. The second option leaves the power of control to the end-user, i.e. the owner of the appliances, and might thus be more acceptable, and also easier to implement from a legal perspective.

One important concern in the aggregation of smart houses as intelligently networked collaborations is to avoid tipping effects in a mass application scenario: if all customers are controlled in a uniform way or all customers are given the same incentive at the same time, the overall system might destabilize by the sum of all reactions. This would compromise the objective behind the coordinated control, i.e. a more efficient operation of the energy system. Therefore, solutions for aggregating and jointly controlling smart houses have to deal with the implications of a mass use scenario and avoid tipping effects.

Variable Tariff-Based Load and Generation Shifting

The overall load patterns of electricity consumption are quite well predictable. Characteristic peaks occur at some time intervals (e.g. at noon or at 19:00 in mid-European winter days) and other time intervals are characterized by low consumption, especially during night-time. Also, the availability of renewable energy resources can be predicted with certain accuracy, giving an indication of probable situations in the electricity system for the next day. 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, e.g. on the EEX or APX. If these wholesale prices are passed over to the end-users (directly or in a modified way), the end-users have incentives to shift loads from high-price times to times of lower prices, which would be beneficial for the retailer and for the overall system.

The key idea of the business case is, thus, to provide the customer with a variable price profile on the day before power delivery. This profile, calculated by the retailer, should be fixed once it has been communicated to the customer, so that the latter can rely on it for his further planning of generation and consumption. The price profile can look different for each day, however, to reflect market conditions that also vary from day to day. These variations will likely increase with increasing generation from fluctuating sources like wind and solar energy.

The price profiles could be based on the wholesale prices that the retailer faces when procuring the energy amounts he sells to the customer. The exact relation between the spot market prices and the variable tariff profiles sent to the smart customer can be determined flexibly. The possibilities range from a direct adoption of the spot-prices (plus grid costs, taxes etc.) to more complex contractual relations specifying maximum price and average price levels of the customer. Moreover, in order to make the flexible tariff model more acceptable for the end-user, a "maximum average cost per kWh" could be guaranteed by the retailer, protecting the customer from unintended very high energy bills. It has to be noted, however, that each guarantee for prices decreases the customer's financial incentive to shift his consumption and generation in the desired way, thus weakening the demand response.

At the customer's premise, an energy management system should receive the price signal and determine the optimal timing for the energy consumption of those appliances that can be shifted in time (e.g. washing machines or dishwashers) or that have a storage characteristic (such as fridges or deep-freezers). The same applies for generation units, such as μ-CHP plants – these are scheduled to run at those time intervals when prices are highest. The automated energy management frees the customer from the burden to monitor prices every day in order to save money, and it guarantees that possible load and generation shifts occur in an optimal way.

It may be part of the business model that the retailer receives feedback from the customers after the publication of the price curve and during the day of delivery on their automatically planned / predicted load and generation profiles. So the retailer can optimize his portfolio by trading on intraday electricity markets. It is also possible, however, to rely solely on a prediction model of customer behavior. As a further option, it would be possible that in exchange for an additional financial incentive, customers might be willing to accept adaptations of the price profile during the day of delivery reflecting changes in the retailer portfolio that come up during the day and also to reduce imbalance in his portfolio.

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 attract new customers and reduce his costs when buying from wholesale power markets.

Energy Usage Monitoring and Optimization Services for End-Consumers

In her „Action Plan for Energy Efficiency", the European Commission estimates the EU-wide energy savings potential of households at around 27% (European Commission 2006). As one important measure for realizing this potential, the action plan states that awareness must be increased in order to stimulate behavioral changes. A study for the German Ministry of Economic Affairs[7] estimates the potential for energy savings through a timely display of energy consumption at a minimum of 9.5 TWh per year (this corresponds to 1.5% of the total energy consumption in Germany in 2006). Personalized and well targeted advice on how to save energy can help further exploit the savings potential.

When detailed metering data is collected on a large scale, valuable information can be extracted from the data pool, which can help end-consumers to achieve the desired reduction in energy consumption. For example, through comparing one's own consumption pattern with average load profiles of comparable households, an end-consumer can become better aware of his energy usage. Or, if the place of energy consumption is made visible in a comprehensible manner, the end-consumer is able to find out how much energy is spent by which appliances, and can identify the greatest potential for a reduction of energy consumption. A portal or display that combines information about present and past consumption, comparisons to average consumption patterns, and precise suggestions how to further lower consumption which are tailored personally to the customer is probably the most effective way of realizing the possible

[7] BMWi (2006): E-Energy – Potenziale der Informations- und Kommunikations-Technologien zur Optimierung der Energieversorgung und des Energieverbrauchs (eEnergy), Federal Ministry for Economic Affairs and Technology.

increase in households' energy efficiency. It should therefore be tested within the SmartHouse/SmartGrid project.

The business concept of services that comprise average consumption patterns could rely on the principle of reciprocity: those customers who contribute to the data set by allowing metering data to be read by the service provider can also access average data. This concept gives an incentive for the end-users to reveal their data, under the condition that it is not accessible by unauthorized parties.

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. If neither positive impacts from increased customer loyalty, nor a customer's willingness to pay for the information service are given, this business case risks being not viable. A retailer usually makes more profit if he sells more products, and if the energy consumption feedback leads to lower energy consumption, sales volumes would decrease for the retailer. Either the energy feedback has a value in itself for the customer (this valuation could also be exploited through higher average tariffs or through advertisement), or other measures, for example through subsidies or tax relief, have to compensate for the losses in sales volumes to make this a viable business case.

3.2.2. Context

Very similar to field test A, the two sub-systems smart retailer and smart house must be connected by the smart grid to implement the according business case. The smart retailer hereby principally has the task of calculating day-ahead variable tariffs for individual smart house customer groups, while the smart houses control devices according to that tariff.

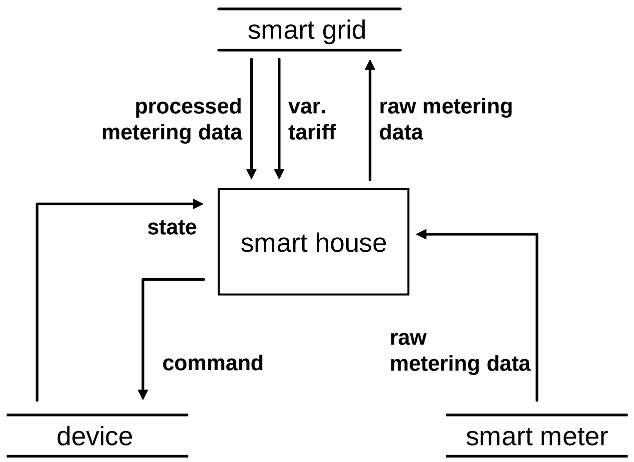

Figure 18: Context of the smart house system in field test B

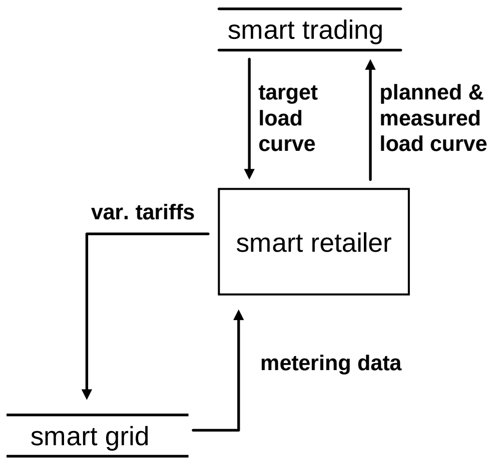

Figure 19: Context of the smart retailer (aggregator) system in field test B

Figure 18 shows the smart house's context. The smart house energy management receives an individual tariff from the smart grid at a given day x which is valid for day x+1. Based on this indirect incentive, the energy management plans optimal device operation schedules for day x+1. For this, it estimates the device behaviour based on historic data about the device's state (e.g. the average program runtime of a washing machine). On day x, it automatically controls the device and supervises the state in order to carry out unplanned switching actions (e.g. switch-on of a cooling device in case of unplanned temperature rise). The overall load of the smart house on day x is measured and transmitted as raw metering data to the smart grid. The metering & billing system of the smart retailer accordingly processes the metering data, e.g. calculating average consumption values for months or weeks, and delivers this data to the smart house for evaluation by the user via a centralized web portal.

In Figure 19, the context of the smart retailer is shown. Its main two functions are the processing of metering data as explained in the previous paragraph and the generation of tariff profiles at day x for the day x+1. It should be noted that there may be different tariff profiles for different smart house groups. This technique is typically used to prevent all smart houses from switching on all devices at the same time, which could lead to electric network instability. The variable tariff generation is based on one hand on historic metering data which reflect the reaction of the different smart house groups on previous tariff incentives and on the other hand on load curve targets for the day x+1. These targets are assumed to be given by the smart trading and are typically calculated such as to allow optimal energy procurement considering available sources, e.g. renewables or imports. Since not all data needed for this is known at day x, appropriate prognosis algorithms must be in place, e.g. for prognosis of the energy cost at the EEX (European Energy Exchange) or the expected wind-power in-feed. Also, the smart trading has to respect the fact that the aggregated smart houses cannot accomplish an arbitrary load curve since devices are not controllable without constraints and not all devices can be controlled. Hence, the smart trading must exploit planned and measured load curves to learn which load curves can be expected to be feasible.

The central role of the smart grid for data processing and transfer is shown in the according context in Figure 20. Concerning field test B, it should be noted that the field test focuses on the smart houses context. The smart retailer and smart trading functions are partly bundled into the Pool-BEMI, which calculates tariffs based on EEX price and solar power prognosis.

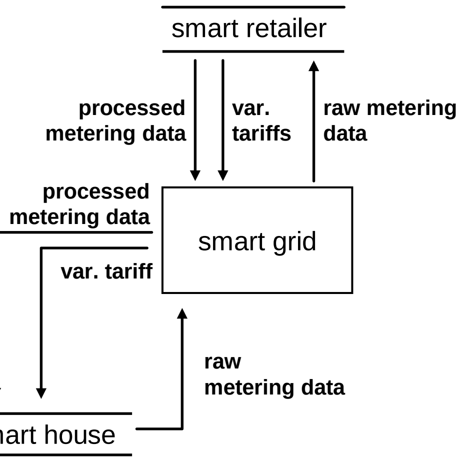

Figure 20: Context diagram for the smart grid in field test B

3.2.3. Entities and Actors

The entities actors in the combined business case are summarized inTable 5.

	Actor	Description
Variable tariffs	Energy supplier	The energy supplier (in his role as a retailer, an energy trader and the balancing responsible party) aims to minimize imbalance risks and purchasing costs.
	End user	The end user (consumer) wants to reduce energy costs and agrees with the installation of technical load / generation shifting devices.

Energy monitoring	Energy service provider or supplier	Collects consumption data of his customers and aggregates them to form valuable information; makes the information available to the customer in a web portal or an in-house display.
	End user	Allows the service provider / supplier to access detailed meter data; requests information services from the service provider in order to reduce his private energy consumption and costs.

Table 5: Actors and entities for variable tariffs and consumption monitoring in a smart house

3.3. Application Architecture

3.3.1. ICT Hardware and Software

The following ICT systems will be used in the field test:

- At customers' sites: ISET-***BEMI+*** gateway system comprising:
  - Computing core connected to Internet, e.g. by powerline or DSL, providing web-based visualization and user interface.
  - Switch boxes for automated load switching and single load measurement/supervision, connected to computing core via Z-Wave radio frequency network
  - Smart meters for calibrated household load data acquisition with temporal resolution of at least 15 minutes.
- At several central points, a back office system will be needed which provides following functions:
  - Creation of variable day-ahead tariffs and distribution of those tariffs amongst the field test gateways on day-ahead basis ("Pool-BEMI")
  - Gateway remote software update, supervision, diagnosis maintenance. Data processing and recording of supervision data from individual gateways.
  - Data processing and recording of metering data from individual customers.

  The back office will be implemented using servers situated at project partner's sites involved in the MVV field trials (Power Plus Communications AG, Fraunhofer IWES (formerly ISET), Papendorf Software Engineering GmbH). Gateways will be equipped with the software framework described in D2.1 based on Java/OSGi. The outcome of the field test is also expected to contribute to a further development of the framework considering stability, refinement of basic applications and validation of the modular and open design approach.
- Back office hardware and ICT is to be situated and configured such that all gateways can be reached by means of bidirectional communication links.

3.3.2. Tools to be Used

Standard software development tools that mainly rely on open source will be used for framework development. This includes:

- Eclipse integrated development environment
- Java SDK
- Equinox open OSGi implementation
- Open source database (currently used: H2[8])
- Open source web server (currently used: Jetty)

[8] Final decision will be made during software/hardware integration tests

- Visual C++ compiler suite

For hardware and firmware development of the switching box based on Z-Wave, the development kit from Zensys and PK51 compiler suite from Keil is used.

3.3.3. Standards to be Used

Web services as defined in D2.2 will be used for communication between back office and gateways. Transmission of metering data will be done according to common standards. The gateway's software framework will be based on the open specification currently prepared by the Open Gateway for Energy Management Alliance (OGEMA).

3.3.4. Developmental Stages

The developmental stages for preparation of the field test comprise:

- Development and test of a basic software framework version for the following applications:
    - Tariff-based energy management of SOC- and FPS-Devices
    - Automatic switching of SOC- and FPS-devices by Z-Wave switching boxes
    - Reception of variable tariffs
    - Data visualization of tariffs and device schedules for the customer
    - Recording load measurement data for SOC- and FPS-Devices
- Development, test and stabilization of gateway hardware (computing core and Z-Wave based switching box), development and stabilization of pre-prototypes
- Integration, test and documentation of complete ISET-BEMI+ system using pre-prototypes
- Preparation of manual with instructions for on-site system installation, operation start and test
- Pool-BEMI: Definition of algorithms for generation of day-ahead tariff profiles, implementation of tariff generation and tariff forwarding to the gateways
- Production of some ten system prototypes to be installed at first field test customers
- Installation and back office integration of up to ten first systems

  Operation start:
    - Software installation and start of operation of gateways
    - Start of operation of central metering data recording
    - Implementation and test of ICT interconnections between BEMIs and Pool-BEMI
    - Software installation and start of operation of Pool-BEMI
- Stabilization of operation. Production of remaining systems
- Installation and back office integration of the remaining systems
- Data acquisition and evaluation
    - Acquisition of metering and measurement data from unmanaged and managed grid regions and individual households
    - Data evaluation for variable tariffs considering research questions defined above

3.3.5. Deployment Schemes

Hardware and Software roll-out for field test B will be closely matched with project Modellstadt Mannheim (MoMa) and Smart Meters (SM) in order to use synergies as outlined in 3.1.3. The following table lists the hardware nodes that will be used.

Component	Location	Function
ISET-*BEMI*+ computing core	Households	Running gateway framework
Household electric loads	Households	Applications to be managed automatically or user-controlled
Switching Boxes	Households	Automated load switching and supervision, power measurement
Remote readable Energy Meter	Households	Quarter hourly energy metering for billing and customer information
Powerline Modem	Households	WAN interconnection of Energy Meter and computing core
PC Server for Pool-BEMI	Electric Network Substation	Tariff generation
PC Server	Electric Network Substation	Meter Data aggregation, Tariff data transmission to customers
Metering data central PC server	PPC	Meter data storage, preparation for billing, provision of consumption data for customers
Terminals for update and remote diagnosis	PSE, IWES	Software update and remote management of ISET-*BEMI*+
Evaluation Server (Database)	IWES	Collection of logging and device operation data (single managed devices) from the field for evaluation

Table 6: Hardware nodes for field test B

At the back office level, standard PC technology will be used. At the Smart House level, embedded systems will be used with hardware specifically optimized for low energy consumption, ease of installation and high reliability.

3.4. Design of Experiments

3.4.1. Test Scenarios & Verification Scheme

Verification of the system operation will be possible by two mechanisms:

1. Supervision of single ISET-***BEMI+*** behaviour, namely:
    a. Is the gateway in operation? Can a bidirectional data link between back office components and gateway be established?
    b. Does the gateway receive tariff information?
    c. Is the in-house connection to the switch boxes stable? Does the supervision of the loads by the gateway yield plausible data (e.g. freezer temperature)?
    d. Is the optimization for controllable load switching plausible regarding the tariff?
    e. Do controllable loads get switched according to schedules computed by the gateway?
    f. Is metering data being recorded and transmitted to the back office? Is the metering data plausible?
2. Supervision of overall system behaviour. Is the reaction of the overall customer load on the variable tariff given plausible regarding the reference group? Is the overall customer energy consumption plausible regarding the reference group?

3.4.2. Final Objective Verification Procedures

The final objective can be considered as verified if:

- The verification of the system's operation is successful according to 3.3.2
- A load shift of field test customer's load can be observed when compared to the reference load. The load shift can be ascribed to automated (or manual) load switching by variable tariffs and can be made plausible.
- It can be observed that the load shift, especially the time of the overall customer's peak demand, can be adjusted by giving a variable tariff.
- It is possible to derive contributions to answering research questions defined in 3.1.4.

4. Field Test C: Micro-Grid Operation Meltemi

4.1. Overview

- **Partners:** PPC (lead) & ICCS
- **Focus:**
  Reaction to critical situations of a cluster of Smart Houses to enhance the security of supply.
- **Main Objectives:**
  - Demonstrate ability of a decentralized system for transition into electrical isolation
  - Demonstrate decentralized provision of ancillary services:
    load shedding support to alleviate network congestions.
- **Location:**
  - Meltemi, Greece

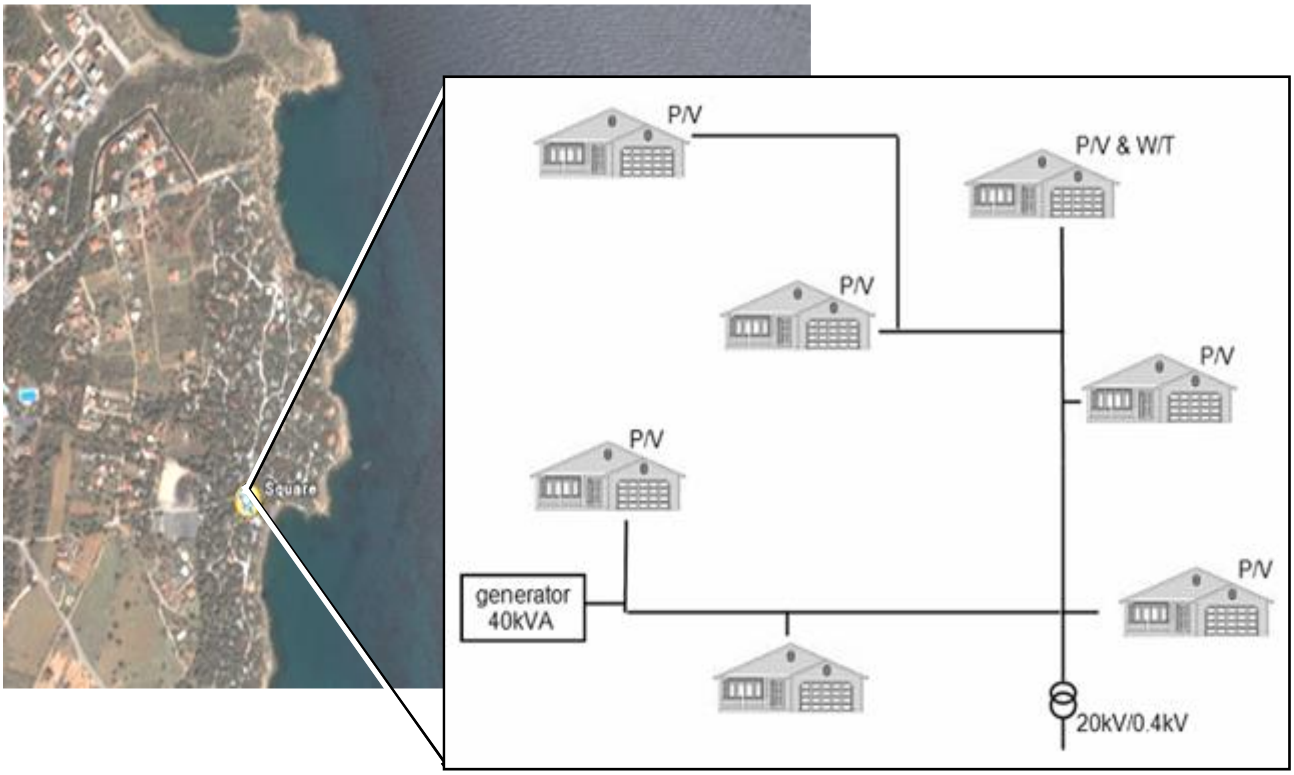

Figure 21: Meltemi recreational site

4.1.1. High-Level Description

The test of field trial C will be hosted in Meltemi, which is a seaside camping located 15 km north-east to Athens. Meltemi consists of 170 cottages used as a camping resort mostly during summer. Meltemi has an interesting load curve which varies a lot between summer and winter. Due to the small size of each cottage, the electrical consumption of each house is lower than 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 PV panels can form the Meltemi camping into a potential interesting micro-grid. The primary target is the optimal use of the power sources. In order to optimize the use as well as the production of energy, the special characteristics of the installation should be identified. The primary characteristic is that the camping site is inhabited mostly during the summer. This fact creates big changes in the total load curve between the two seasons.

The Meltemi camping is a perfect test field to validate methods of increasing the use of Renewable Energy Sources (RES) as well the overall performance of the system in a liberalized environment. However within this proposal ICCS-NTUA and PPC will carry out tests that focus in two main aspects:

- Taking into account the topology of the network and system the ability of a decentralized system for transition into electrical isolation will be studied.
- A second very interesting scenario in a decentralized is to provide ancillary services and more specific load shedding support during peak load especially in summer season, in order to alleviate network congestions. For this scenario not only the technical requirements should be considered but also the market environment.

The test assumes the existence of an energy market and a retail company that provides incentives to LV customers in order to allow the control of their devices. The retail company will use this ability in order to sell ancillary services (including black start and fast system restoration) to the main grid and to settle imbalances.

The actual problem is whether a multi agent system or service-oriented architecture may be capable to support efficiently such operations. Furthermore another critical issue is the system organisation that is suitable for this kind of operations. More specifically, should the agents be highly cognitive in a cooperative environment? In this site the system tries to cope with the problem by adopting a more sophisticated architecture. The agents are trying to take the correct decisions through cooperation.

4.1.2. Problem Statement

In field test C the following business cases will be combined:

- Distribution Grid Cell Islanding in Case of Higher-System Instability
- Black-Start Support from Smart Houses
- Integration of Forecasting Techniques and Tools for Convenient Participation in a Common Energy Market Platform
- Aggregation of Houses as Intelligently Networked Collaborations
- Distribution system congestion management

The problem statement for field test C can be described as follows:

How can the Smart House support the grid in case of emergency in an energy market environment?

The Smart House should include some functionalities in order to deal with emergency and critical situations. This operation includes two phases: the first phase is before the unexpected event and during that phase the team of houses should make some preparation actions as described in the next section. In the team of houses belong all the consumers that are equipped with the load controller. The second phase is during the event where the system should decide the actions for fast restoration.

This scenario suggests that the aggregator and the DNO interact with the Smart Houses. They should provide to the system the proper information in order to react correctly during the emergency case. However the critical part is that the network of Smart Houses should have a level of autonomy and decide by itself the overall system management. Furthermore since the system assumes the existence of an energy market it is obvious that the energy consumed/shedded during any operation should be monitored.

4.1.3. Solution Approach

The solution approach is presented in the next figure:

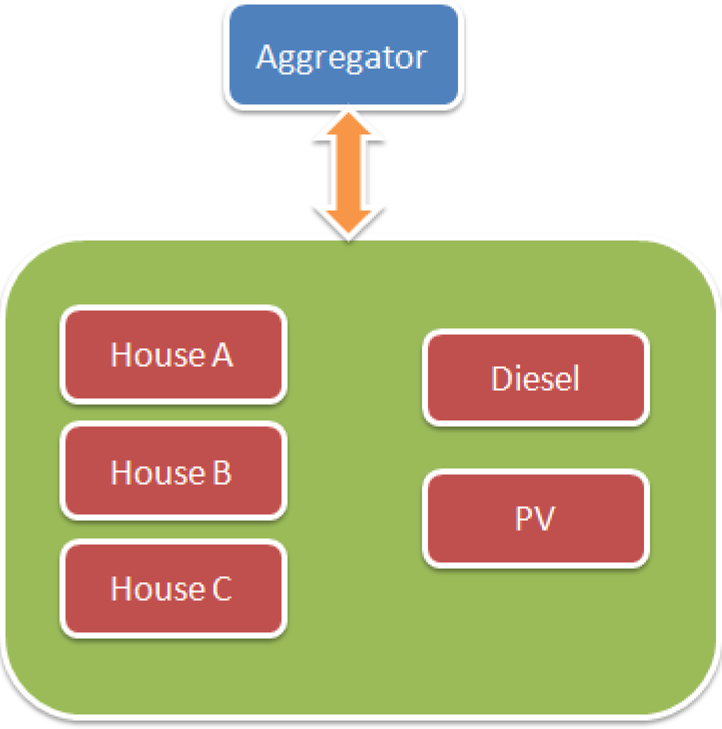

Figure 22: General MAGIC system overview

Figure 23: Sequence of steps

As stated in the previous section, there are two phases in the system. In the first phase, the agents monitor the system and provide to the other agents as well the aggregator with information regarding the status of the system: Fuel Level, Current 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.

Load shedding, in our case is often motivated by grid stabilization (security to prevent blackouts) and is interfering with customer interests. Indeed, load reduction in critical grid situation is not considering the user process functionalities. It is often applied in emergency situation. For the long term planning, loads may be sorted by priority levels. Afterwards, zones or types of load which have the lower priority level will be shed first.

Thus, a load classification (during the first phase) is required to determine what the most appropriate loads for a specific control type are. Based on the controllability, there are "critical loads" which cannot be controlled and "controllable loads" which can be interrupted fully or partially for a determined or undetermined duration.

The second phase includes the actions 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 MV system is unable to restore operation in a specified time, a first step in system recovery will be a local black start. Two steps will follow next

1. Local black start of the micro-grid;
2. Grid reconnection.

The strategy to be followed is a matter for investigation and involves the cooperation of the various system controllers, both central and local, using predefined rules and exploiting autonomous agent concepts. The restoration process for any power system is a very complicated process. The related restoration tasks are usually carried out manually, according to predefined guidelines. They have to be completed fast in a real time basis under extreme stressed conditions. In a micro-grid, the whole procedure is much more simple because there are not many loads, switches and large, difficult to control, generation units. In addition, the power electronic interfaces of the distributed resources and loads offer considerable flexibility. Thus, the idea of creating a totally automatic system for restoration seems quite realistic.

4.1.4. Enterprise Integration Architecture

The goal of the field trial C is focusing on critical situations although some billing process/monitoring is also included based on the communication with the SAP portal, implemented through custom web services. The enterprise integration for field C focused mainly in the interaction with the metering infrastructure and the DMS systems.

The Common Information Model (CIM - IEC 61970) is an abstract model that represents all the major objects in an electric utility enterprise typically involved in utility operations. By providing a standard way of representing power system resources as object classes and attributes, along with their relationships, the CIM facilitates the integration of Energy Management System (EMS) applications developed independently by different vendors, between entire EMS systems developed independently, or between an EMS system and other systems concerned with different aspects of power system operations, such as generation or distribution management. This is accomplished by defining a common language (i.e., semantics and syntax) based on the CIM to enable these applications or systems to access public data and exchange information independent of how such information is represented internally.

The MAGIC system has an ontology that has partial compatibility with the CIM and this way can have a common description of the electrical system with any DMS / EMS system. More specifically, the compatibility was tested with the MORE CARE [D3.3C] Database which is designed to share a common vision of the electrical system. Please note that CIM is an object oriented model not a database model however is far beyond the scope of this document to provide such details. Figure 24 presents the structure of the central database (assuming DMS in our case) and how the information is stored.

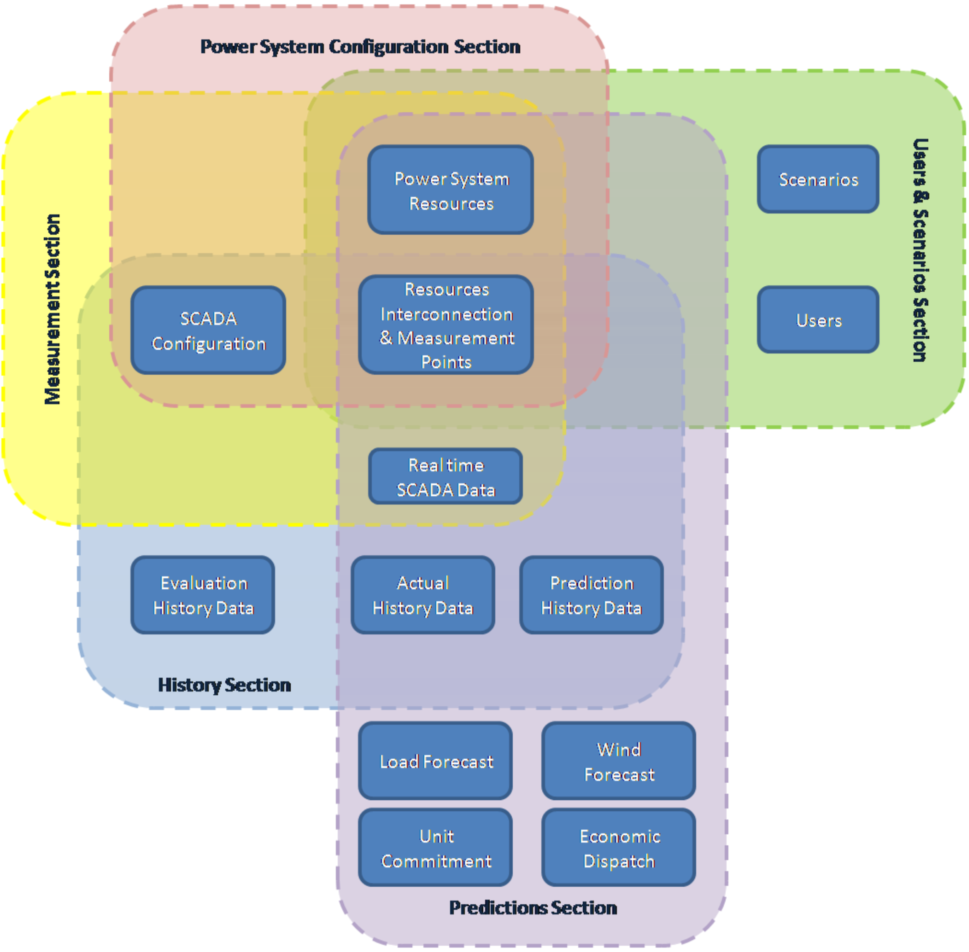

Figure 24: High level logical representation of the MORE CARE database

Power System Configuration Section

The Power System Configuration section is the core part of the MORE CARE system database. It provides information on the resources of each power system, their interconnection, measurement points and their mapping to available SCADA values. Due to the diverse nature of the equipment and their properties in a power system a more general approach was chosen. Every part that makes up a power system is considered a Power System Resource that is of a certain type. The type of the resource can span from entire power systems, power stations to simple circuit breakers. Each Power System Resource may include other Power System Resources thus enabling the database to maintain a hierarchy of objects essential for grouping of resources ,system topology (e.g. a Power Station contains multiple generators; a wind farm contains multiple wind turbines) and for CIM object model conversion.

The properties of a Power System Resource are derived by the type of the resource. The properties that are considered essential for a certain Power System type are flagged to ensure that all needed information of the resource is in place before it can be used by the system. Each property can be mapped to the corresponding CIM object property in order to provide the capability of using the CIM object model.

Interconnection between Power System Resources is achieved using the CIM's Terminal – Connectivity Node model, which further aids in the conversion to a CIM object model and the exchange of configuration setups between systems. Each Terminal can belong only to one Power System Resource and can be connected only to one Connectivity Node. Furthermore, spatial information for the connection points and resources are kept in order to provide a graphical representation of the system on a map.

The generalization approach has a clear advantage in that new types of resources (even not presently known ones) can be easily created and integrated into the system by defining the required properties and any needed extended property without the need for database schema alterations.

Measurements Section

The Measurements section the structures necessary to store current information received from each Power System Resource's SCADA. The information is used to get the current view of each Power System Resource. The real-time data is stored for a specified period of time for each Power System. When the period elapses the data is aggregated and transferred to the History section.

Predictions Section

This Section provides the structures needed for the various modules which are used for prediction to store their data. The modules produce data using the information about the Power System Resources properties given by the Configuration Section and the historical data provided by the History section. The predictions for each power system are then stored in the corresponding structure defined by their type. Predictions include but are not limited to Wind and Load forecasts, Unit Commitment and Economic Dispatch.

History Section

In this section all of the historical data collected by the SCADA of each power system resource is stored. The MORE CARE system's aggregated real-time SCADA data are stored in a different structure to facilitate later evaluation of the aggregation methods used against actual values provided by the power system. Furthermore, prediction history data are preserved in order to evaluate the models against actual values. Due to the massive amount of data kept, parts of the historic data are exported in a predefined XML format. This enhances performance of the database without actually losing information as it can be imported when needed.

User Configuration & Scenario Section

In order to facilitate access control to the system and its information the database uses a user access schema based on group and individual rights. Each user can have a personal view of the systems and a set of privileges allowing him to interact with individual power systems. The access rights and view of the system are defined by a system administrator. Users with necessary access rights can create scenarios by adding, editing and deleting power system resources, altering resources properties and interconnections without hindering the system's operation. These scenarios and their results can be then shared across users and groups to enhance collaboration.

4.1.5. Research Questions

Field test C is expected to contribute answers for the following research questions:

- Saving:
  - How much energy is required for each business case?
  - Is there a methodology to calculate this amount of energy or is it based on measurements?
  - How will the aggregator calculate this energy in a real system?
- Technical:
  - Is it feasible to provide such services?
  - What were the technical problems during the experiments?
  - Can these problems affect a real application?
  - Is it possible to estimate the impact on the network operation using the results of the experiment?
- Economical:
  - Are these realistic business cases?
  - Is it possible to evaluate the benefits for the aggregator and the consumers?

4.2. Functional Description

4.2.1. Summaries of Business Cases

Aggregation of Houses as Intelligently Networked Collaborations

SmartHouse/SmartGrid concepts will exploit the potential that is created when homes, offices and commercial buildings are treated 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.

The joint management of a collection of houses and commercial sites can be done in two ways. The aggregator might directly control one or several participating devices (e.g. deep freezers, air conditioning); this would require the end-users to allow direct access to the control of these appliances. Another way is that an aggregator can only provide incentives to the participating devices, so that they will behave in the desired way with a high probability, but not with certainty. The second option leaves the power of control to the end-user, i.e. the owner of the appliances, and might thus be more acceptable, and also easier to implement from a legal perspective.

One important concern in the aggregation of smart houses as intelligently networked collaborations is to avoid tipping effects in a mass application scenario: if all customers are controlled in a uniform way or all customers are given the same incentive at the same time, the overall system might destabilize by the sum of all reactions. This would compromise the objective behind the coordinated control, i.e. a more efficient operation of the energy system. Therefore, solutions for aggregating and jointly controlling smart houses have to deal with the implications of a mass use scenario and avoid tipping effects.

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 cases considers that the islanding procedure is performed automatically. The scenario has 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 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.

As mentioned before, the transition to the island mode is automatic and neither 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.

Grid cell islanding is of value to the DSO. If instabilities occur in the distribution grid, it is the DSO's task to restore stability as quickly as possible and with the lowest possible number of affected customers. Through islanding, the DSO can reduce the number of connected customers that are negatively affected by the higher-system instability. Islanding also helps the DSO to quickly restore system stability within his grid area. The service of grid-cell islanding can be provided by a commercial aggregator who installs the necessary control equipment in contracted households and then performs the islanding upon request by the DSO in case of a higher-system instability.

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.

The scenario has four main steps: the first step is before the event that may occur, the second step is just after the event, the third step is the steady islanded operation and the final step is the reconnection to the main grid.

The first two steps of the black-start support resemble the operation as described for the grid cell islanding case (see Section 0). When the system is in a safe state, it will try to reconnect in order to provide power to the grid; the goal is to provide as much energy and power as possible.

Black-start support is of value both to the DSO and the consumer. If a black-out occurs in the DSO's grid area, it is his responsibility to restore system stability as quickly as possible. Flexible demand helps him to perform this task. Black-start support could be provided by a commercial aggregator who installs the necessary control equipment in contracted households and then performs black-start support upon request by the DSO in case of a black-out. This service could be coupled with the grid cell islanding service, and could be provided by the same aggregator. Similarly to the previous business case depends on the market structure and the benefit depends on who is responsible to pay for the possible load shedding and how much the customers are willing to pay for quick power restoration.

4.2.2. Context

In field test C several sub-systems should be integrated in order to achieve the various business objectives. These are the Smart House, the Distributed Generators, the Substation (MGCC), the DNO and the Commercial Aggregator. The overall system architecture is presented in Figure 25. All actors closely cooperate in order to achieve the goals of the test field objectives.

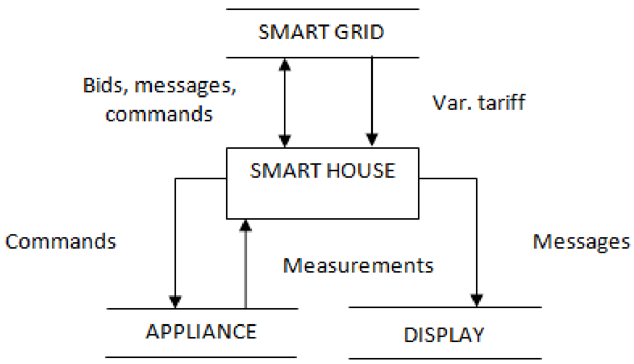

Figure 25: Context diagram for the smart house concept

Figure 25 presents the concept of the Smart House where the core is the embedded controller. The controller runs all the agent based software and is responsible to exchange messages with the other agents: MGCC and Aggregator. Furthermore the controller receives measurements from the appliances and sends commands to the corresponding relay. Finally the display is an important subsystem that presents messages to the consumer.

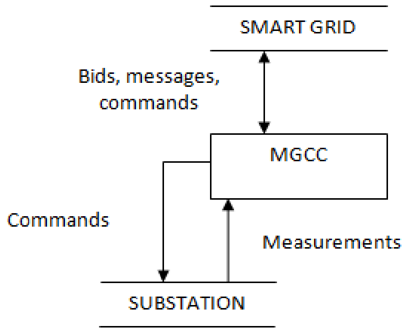

Figure 26: The MAGIC concept

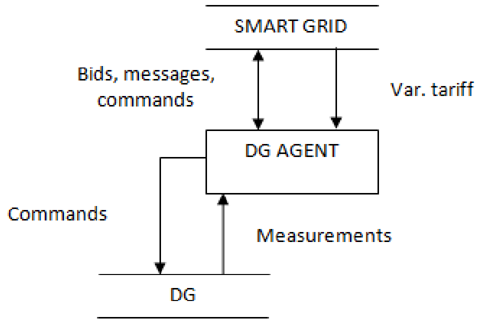

Figure 27: The DG agent concept

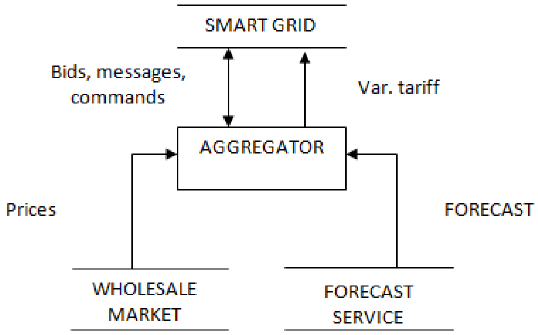

Figure 28: The aggregator concept

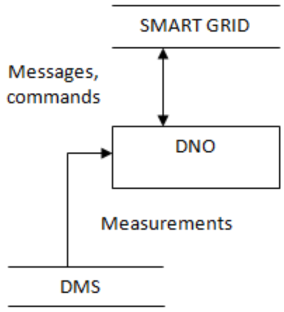

Figure 29: The DG agent concept

Figure 26 towards Figure 28 illustrate the role of the other main subsystems of the system. Please note that for the case of the Field C some concepts are simulated such as the whole sale market and the DNO. However in a real system the existence of such agents is mandatory since for critical situations such as a black out the involvement of the DNO is crucial.

Finally it should be noted that a list of functionalities are not presented here such as the messaging/ management system of the agents, the discovery services and the billing procedure. The first two functionalities are provided by the JADE platform. The last functionality is beyond the scope of this field test.

4.2.3. Entities and Actors

The entities actors in the combined business case are summarized in Table 7.

	Actor	Description
Grid cell islanding	Consumers	Provides control of their load as well as metering data about their consumption
	DSO	Manages the transition to island mode and allows the internal power management when it is considered as safe.
	Aggregator	Monitors the system before the event that may lead to island mode and manages the operation of a group of consumers as well DG owners in an efficient way during the island mode.

	DG owners	Provide information about their status and their production capabilities
Black start support	Consumers	Provides control of their load as well as metering data about their consumption
	DSO	Manages the transition to island mode and allows the internal power management when it is considered as safe.
	Aggregator	Monitors the system before the event that may lead to island mode and manages the operation of a group of consumers as well DG owners in an efficient way during the island mode.
	DG owners	Provide information about their status and their production capabilities

Table 7: Actors and entities for grid cell islanding and black start support

4.3. Application Architecture

The system is agent based and the basic agents are:

1. House Agent
2. PV Agent
3. Diesel Generator Agent
4. Aggregator Agent
5. Jade Platform Agents (DF & AMS)

Each one of these agents controls a part of the system; the negotiation between them is the actual scope of this demo. The application architecture is presented in the next figure:

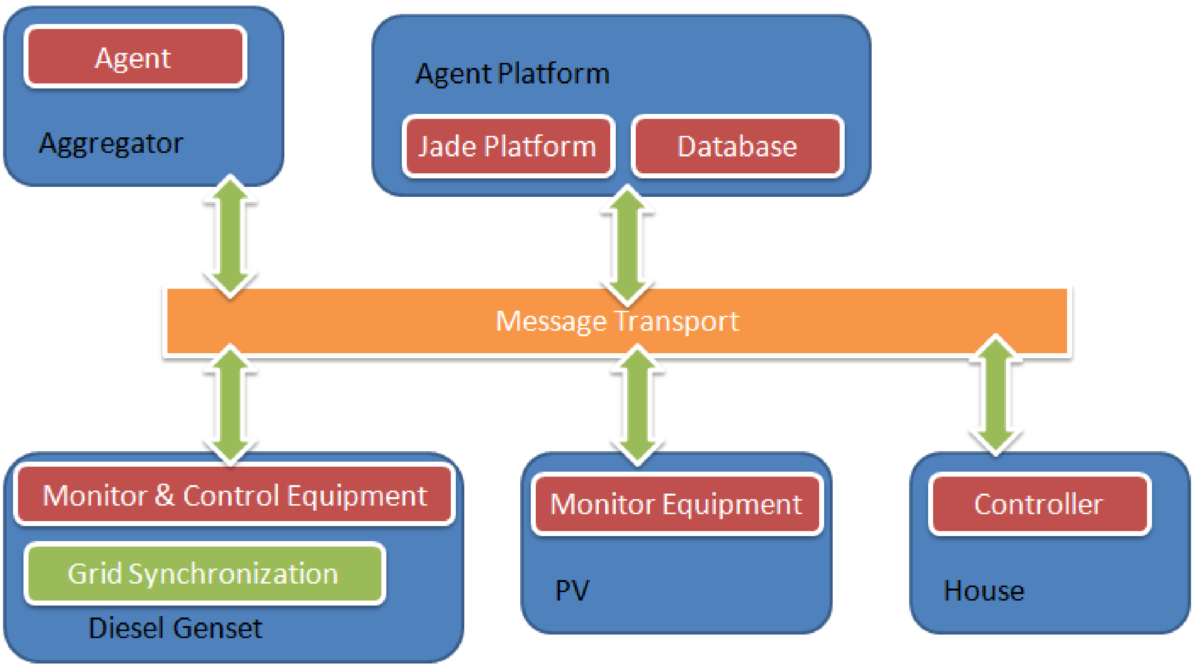

Figure 30: The application architecture

All the equipment as well the aggregator will be controlled (represented) by agents. The aggregator is responsible for the data collection and evaluation in order to define the system status. Furthermore it will coordinate the negotiations between the agents.

The main agent platform of Jade will run on a PC that will be placed in the RGW (Residential Gateway-map). The Generator will be equipped with the necessary infrastructure in order to be controllable and have the ability to synchronise with the grid. The agents for controlling and monitoring the diesel generator as well as for monitoring the PV panels may run in the same PC as the Jade platform, for simplicity. Finally, the controllers that will be installed in the houses will each host an agent.

The houses that will host the Load Controller have been selected and presented in the next map.

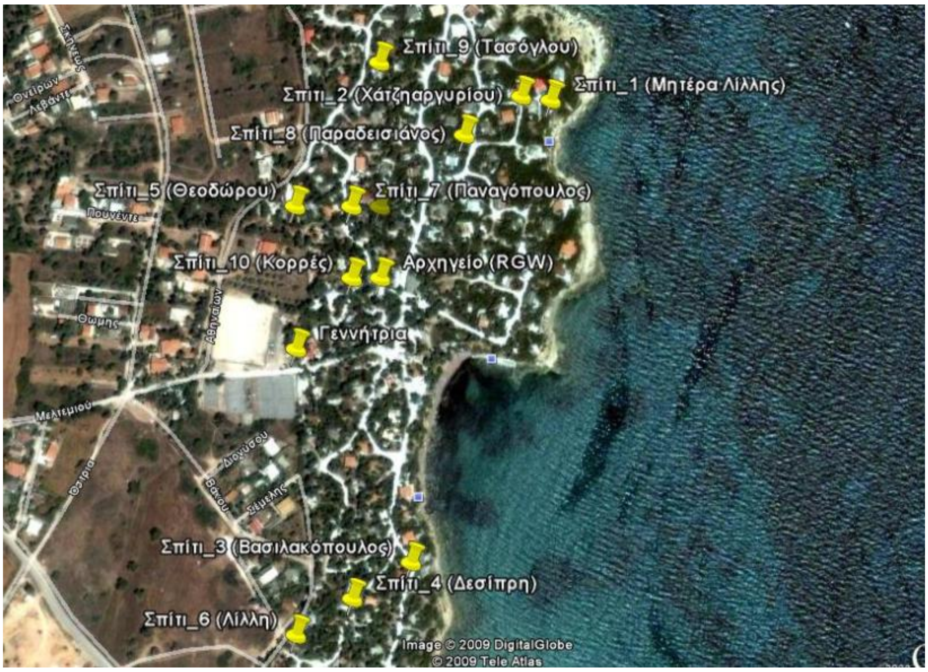

Figure 31: The selected houses that will host the load controller

4.3.1. ICT Hardware and Software

For the implementation of the field test C, two main components are critical. The first is the Jade platform which is a library suitable to implement the agents and the intelligent algorithms. The second component is the load controller which is the hardware platform that will host the agents.

The core of the software development will be the Jade platform. JADE (Java Agent DEvelopment Framework) is a software framework fully implemented in Java language. It simplifies the implementation of multi-agent systems through a middle-ware that complies with the FIPA specifications and through a set of tools that supports the debugging and deployment phases. The agent platform can be distributed across machines (which not even need to share the same OS) and the configuration can be controlled via a remote GUI. The goal of JADE is to simplify the development of multi-agent systems while ensuring standard compliance through a comprehensive set of system services and agents in compliance with the FIPA specifications: naming service and yellow-page service, message transport and parsing service, and a library of FIPA interaction protocols ready to be used. The JADE Agent Platform complies with FIPA specifications and includes all those mandatory components that manage the platform that is the ACC, the AMS, and the DF. All agent communication is performed through message passing, where FIPA ACL is the language to represent messages.

The Intelligent Load Controller (ILC) that will be used in the Smart House / Smart Grid project is a system that can be used to monitor the status of a power line and take voltage, current and frequency measurements. In addition , it can control up to 4 relays and remotely control up to 256 PLC A10 devices (PLC load switches) connected to the power line. As far as the houses of the settlement are concerned, each ILC will control two relays. Only two controllers will have the PLC capability. Additionally, the ILC features a Wi-Fi/LAN interface that enables it to connect to a Local Area Network. The operating system supports the installation of a Java Virtual Machine. Therefore, an agent environment based on the JADE platform can be easily embedded in the controller. In Figure 32, a general schematic of the controller is presented.

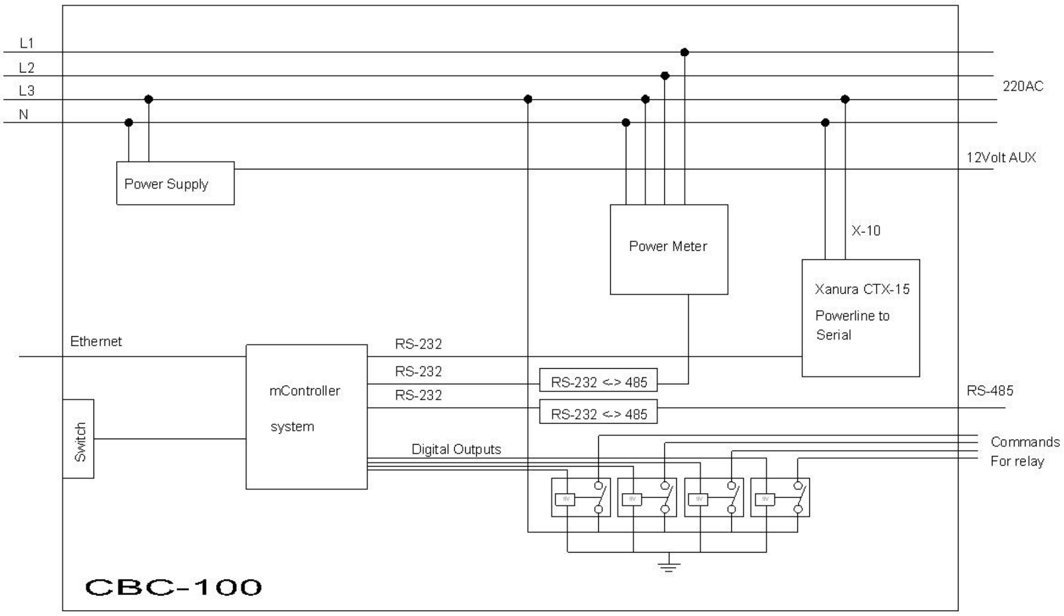

Figure 32: General schematic of the intelligent load controller

4.3.2. Tools to be Used

Standard software development tools will be used for framework development. This includes:

- Eclipse integrated development environment
- Java SDK
- Jade platform
- SQL Server Express

4.3.3. Standards to be Used

The systems will conform to the FIPA requirements and standards. Furthermore the Web services are a standard communication mechanism based on SOAP and WSDL. The communication with the metering devices will be done according to common standards.

4.3.4. Developmental Stages

The development of the test site has the following steps:

1. Definition of the experiments
2. Selection of the houses that will participate in the experiment
3. Selection of the main hardware
4. Selection of the auxiliary hardware
5. Laboratory testing of the hardware
6. Installation and commissioning of the hardware
7. Testing of the system
8. Experiments

4.3.5. Deployment Stages

The following tables describe the hardware nodes used in the experiments that took place in the Meltemi test site. The topological installation of these hardware systems is described in Figure 21.

The installation of the controlling equipment in the household level has three main parts. The first part is the load controller described in the previous section that is installed usually just before the main electrical boards inside the house. Next, metering and controlling equipment have been installed inside the electrical boards. Finally DSL routers have been installed (if not existed) in order to provide internet access to the controllers.

Monitoring equipment has been/is installed for monitoring of the PV, Diesel and the main substation (transformer) of Meltemi. Finally the Servers used, are commercial PCs since the computational needs for the size of the field test C are not very.

Component	Location	Function
MAGIC Load Controller	Households	The main controller
Relay & Control Equipment	Households	Equipment installed in the main electrical boards of the households
Remote readable Energy Meter	Households	Automated load switching and supervision, power measurement

Table 8: Hardware nodes for field test C

Component	Location	Function
PC Server for PV	Headquarters of Meltemi	Communication with the PV inverters
Advanced Energy Analyzer & Data Logger	Meltemi Main Substation	Monitor the whole consumption of the settlement
DSL router	Households	Equipment to provide internet access to the controllers.
PC Server for Jade	NTUA	Commercial PC that host the JADE platform
PC Database server	NTUA	Meter data storage, Message Storage
Laptop		A Laptop equipped with all the necessarily software in order to provide onsite access of the controllers. Used for maintenance and installation purposes.
Remote Multi Meter	Diesel	Equipment to monitor the diesel generator

Table 9: Hardware nodes not funded within SH/SG

4.4. Design of Experiments

The design of the experiment will consider that in Greece, there is not an energy market for LV consumer although the legal framework exists. More specifically, there is a fixed price for LV consumers and actually one aggregator. Thus, the experiments will be a simulation of this energy market.

Furthermore, the business cases that are related to field test C concern emergency and critical situations. However, we cannot deliberately create short circuit or any emergency situation, since this could be dangerous. Therefore, in certain moments the system will consider that there is an imbalance and therefore it should react accordingly. During the tests and experiments, the operators will warn the habitants.

4.4.1. Test Scenarios & Verification Scheme

As mentioned before, the field test C will be based on test scenarios in order to evaluate the system performance. Therefore the verification procedure will evaluate the actual performance of these scenarios. The evaluation will consider the following aspects of the system:

- Technical: is it feasible to control the equipment?
- Electrical: is the electrical behaviour of the system acceptable?
- Economical: does the system provide useful functionalities?

Finally, the questions in section 4.1.4 should be answered.

4.4.2. Final Objective Verification Procedures

The Description of Work mentions four key objectives that have to be addressed by the field tests.

Objective A: The developed ICT technical functionality works under real-life field conditions.

Field test C will provide input for the simulation process in order to prove the optimality of the real time control.

Objective B: The developed ICT technology is affordable.

The service oriented approach in the field test C will verify that the participation of the end users for the related business cases is limited and does not require any expertise. This is important since the critical situations are complex and require specialised knowledge as well online monitoring.

Objective C: The developed technology has significant potential for mass application across Europe.

Field test C will provide input for the simulation that will be carried out within the WP 4 .

Objective D: The developed technology is able to achieve aggregate energy efficiency gains > 20%.

Regarding the field test C this is not a specific goal and is not related to the critical situation management directly. However the decision is to equip the load controllers with displays in order to inform the consumers about the current consumption or energy cost. The behaviour and the comments of the consumers will be analysed.

5. SH/SG Objective Testing in the Field Trials

In this section, the contributions of each field trial to the measurements of the objectives formulated in the description of work are summarized, and comparative or site-specific measurements are pointed out.

5.1. Objective A: Applicability Under Real-Life Field Conditions

In deliverable D1.1, the general possibilities to analyze the measurable objective A have been described. In the following, the specific tests planned in the SmartHouse/SmartGrid project are described.

The sub-objectives of Objective A *"The developed ICT technical functionality works under real-life field conditions"* are recapitulated from the description of work in the following:

- *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 trial. It is furthermore verified by means of additional large-scale scenario simulations that will be carried out.
- *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 trial. 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.
- *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.

5.1.1. Contributions to Objective A

The field trials envisaged in the SmartHouse/SmartGrid project all contribute to testing in how far the measurable objectives defined in the Description of Work can be met by the technologies developed and deployed. In this section, it is specified which field trials will give answers related to which objectives. The detailed descriptions of how the objective can be measured are described in deliverable D1.1; the tests that can actually be carried out under the given trial conditions are named D3.2.

The contributions of the field trials for analyzing these sub-objectives are summarized in Table 10. Scalability will be tested in trial A, ease of use will be tested in trial B. The real-time control flexibility and optimality is relevant in all three trials and will be tested accordingly. The parentheses around the crosses in row A.3 symbolize that the optimality can only be proven theoretically or through simulations. From the trials, we can only get indications of whether the technology works properly in the field and whether it is accepted by the users. Besides, for the BEMI (trial B), the applied technology does not deliver *real-time* flexibility – however, flexibility and optimality is relevant here, too.

Objectives related to measurable objective A	Trial A	Trial B	Trial C	WP 4
A.1: Scalability	x			
A.2: Ease of use and responsiveness to end users		x		
A.3: Real-time control flexibility and optimality	(x)	(x)	(x)	x

Table 10: Contributions to measurable objective A

5.1.2. Comparative Objective Testing Measurements Planned Across Two or Three Trials

The only objective in group A that is addressed by all three trials is A.3. The difficulty in comparing the three technologies stems from the heterogeneous data sources that are available for comparison of the customer's behaviour with and without the SmartHouse/SmartGrid technology. Between trials A and C, the reaction time can be compared, i.e. the time span between an event (bid, setpoint setting, critical grid event notification) and the control signal within the house; the reaction (ramping-up/down) time of the device itself should not be taken into consideration here. Across all three trials, the load shifting potential is estimated. As different devices are connected in each trial, these results are, however, not fully comparable.

It should be noted that "optimality" is defined differently in each trial, depending on the functionality that should be demonstrated and tested. In trial C, for example, optimality is characterized by the time that the cluster stays in island mode until it can be reconnected to the grid. This is not relevant in the other trials. Only the deviations between ordinary operation and SmartHouse/SmartGrid operations can be compared across trials, not the "optimality as such".

5.1.3. Site Specific Objective Testing Measurement

Field trial A – As already stated the focus in this trial will be on scalability. It is, thus, the only trial that simulates a large number of houses / devices in order to answer the question whether the technology can also work in a large-scale application scenario.

Field trial B – Many of the field trial participants are more ecologically sensitive than the average customer, and thus have a specific motivation to participate in the trial. Other customers might be less ecologically oriented. The correlation between the attitude towards environmental concerns and the energy consumption behaviour with and without the BEMI will be specifically focused on in trial B. It must be noted that these studies will mainly be carried out in the framework of the Modellstadt Mannheim trial.

Field trial C – The customers in the trial C is typical consumers for the Meltemi camp but not for the rest of Greece. As mentioned in other deliverables, Meltemi is a holiday camp mostly inhabited during the summer. Furthermore, since the tests for trial C include mainly critical situations such us islanding and black start the selection was based on the topology of the network as well the willingness to participate in such tests. The focus on these critical grid situations is specific to trial C and will not be done in other trials.

5.2. Objective B: Affordability

In deliverable D1.1, the general possibilities to analyze the measurable objective B have been described. In the following, the specific tests planned in the SmartHouse/SmartGrid project are described.

The sub-objectives of Objective B *"The developed ICT technology is affordable"* are recapitulated from the description of work in the following:

- *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 trial.
- *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.

5.2.1. Contributions to Objective B

The contributions of the field trials for analyzing these sub-objectives are summarized in Table 11. All three trials contribute to the measurements of both objectives in the same way. Regarding costs (B.2), the trials can only give weak indications; this objective will be investigated further in work package 4.

Objectives related to measurable objective B	Trial A	Trial B	Trial C	WP4
B.1: The developed technology is affordable in terms of the knowledge and time resources required from end users.	x	x	x	
B.2: The developed technology is affordable in terms of financial investment and operational costs.	(x)	(x)	(x)	x

Table 11: Contributions to measurable objective B

5.2.2. Comparative Objective Testing Measurements Planned Across Two or Three Trials

For B.1, the common goal of the approaches applied in each trial is that the number and complexity of user interactions should be minimized. Also, the effort of installing the necessary hardware and software at home should require as few steps as possible. In order to come to an estimation of the time and knowledge necessary, the required steps and time / knowledge resources are surveyed for each energy management system considered. They will be listed in a way as it is exemplified in Table 1 of deliverable D1.1 Based on the gathered data, some conclusions on average total time investments and minimum skill levels can be derived. This also allows comparing the three approaches PowerMatcher, BEMI and Magic, giving additional insights about the future potential of each of the three technologies.

For B.2, only some indications of the cost of the energy management system hardware (BEMI, PowerMatcher or Magic) can be given. However, as the hardware for the project prototypes are not produced in large batches, it doesn't allow direct declarations about the hardware costs that would apply in a mass-scale scenario. The costs that occurred in each trial will be listed and analyzed in a uniform way. The conclusion towards the mass-scale scenario can only be done based on cost developments of comparable components and on discussions with the hardware suppliers and will be done within work package 4 of the SmartHouse/SmartGrid project.

5.2.3. Site Specific Objective Testing Measurements

In trial B, the analysis of the portal log files can give some additional indications about the time that each operation, like e.g. setting an operation preference in the BEMI portal, takes for the customers. They might also give hints on how users can cope with the functionalities delivered by the tools and whether they have the required skills. Besides, no site-specific measurements are foreseen in objectives of category B.

5.3. Objective C: Mass Application Potential

Objective C "*The developed technology has significant potential for mass application across Europe*" will be targeted by WP4. Some indication about the current availability of relevant enabling technologies are also provided in D5.3 "Market and Competition Analysis".

The sub-objectives of Objective C *"The developed technology has significant potential for mass application across Europe"* are recapitulated from the description of work in the following:

- *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.
- *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.

5.3.1. Contributions to Objective C

The contributions of the field trials for analyzing these sub-objectives are summarized in Table 11. No specific measurements are foreseen for this objective, but conclusions can be derived from other studies and measurements carried out in the project. A detailed description of simulations planned in WP 4 for analyzing objective C.2 will be provided in deliverable D4.1.

Objectives related to measurable objective B	Trial B	Market & Competition Analysis	WP4
C.1: Low entry barriers regarding adoption and diffusion of the technology	x	x	
C.2: There is a solid business case for energy utilities and energy service providers to step into ICT-enabled energy-efficiency technology.			x

Table 12: Contributions to measurable objective C

5.3.2. Measurements

There are no field trial measurements specifically carried out to estimate the measurable objectives in the category C. As it was pointed out in deliverable D1.1, the objective C.1 can be evaluated with a combination of the standardization analysis conducted in Deliverable D1.2, the availability analysis conducted in Deliverable D5.3, and through insights from the usability analysis done in trial B for tackling objective A.2 (and, to some extent, the experience gathered in all three trials within objective B.1). The objective C.2 can only be evaluated on a higher level of abstraction, taking into account the potential for mass-application. This is a question that can only be answered through scenario analyses, taking experience from the field trials as input values. Thus, objective C.2 will be tackled in work package 4.

5.4. Objective D: Energy Efficiency Gains

In deliverable D1.1, the general possibilities to analyze the measurable objective D have been described. In the following, the specific tests planned in the SmartHouse/SmartGrid project are described.

The sub-objectives of Objective D *"The developed technology is able to achieve aggregate energy efficiency gains > 20%"* are recapitulated from the description of work in the following:

- *D.1: Efficiency gains through interactive feedback to users on optimal energy* use (approx. 10%).
- *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).

- *D.3: Reduction of power grid losses* by increasing local sustainable demand and supply solutions (4-8%).
- *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%).

5.4.1. Contributions to Objective D

The contributions of the field trials for analyzing these sub-objectives are summarized in Table 11. Work package 4 will analyze all those aspects that cannot be answered based on the trial outcomes only.

Objectives related to measurable objective D	**Trial A**	**Trial B**	**Trial C**	**WP 4**
D.1: Efficiency gains through interactive feedback to users (about 10%)	Comment: this is no specific goal of the SH/SG technologies; besides, measurements that can set the basis for comparisons have not been carried out. This can only be answered quantitatively based on the literature. Qualitative outcomes come from trial B.			
D.2: Gains as a result of optimized energy management of devices (about 5%)				x
D.3: Reduction of power grid losses by increasing local sustainable demand and supply solutions (4-8%).				x
D.4: Gains through raising the accommodation ceiling of local networks for integration of local generation. (>10%)				x

Table 13: Contributions to measurable objective D

5.4.2. Comparative Objective Testing Measurements Planned Across Two or Three Trials

The calculation of energy efficiency gains due to the optimized energy management of devices (D.2) are measured through determining the generation efficiency for each time interval considered (i.e. 15 minutes intervals or at least hourly intervals), as described in deliverable D1.1. Estimations of the order of magnitude can only be done on the basis of simulations carried out in work package 4.

The load shifting potential is also the input needed for answering objective D.3. It is, again, taken as an indication for setting parameters in the scenario analyses and simulations to be carried out in the framework of work package 4.

5.4.3. Site Specific Objective Testing Measurements

The reaction of the customer to an energy feedback is analyzed in field trial B. The evaluation focuses on the analysis of log files from the two web portals offered to the customers. Besides, the customer’s reaction to the feedback is derived from the comparison of consumption data before and after the web portal was made available.

For trial C, the primary test objectives are related to the critical scenarios such as island mode and congestion management. However the load controller will be equipped with a display for an interactive feedback to the users. Furthermore, for the tests energy greedy devices will be controlled and the residence will be informed about environment friendly policies. Additionally, due to the small size of the samples (ten houses), the results may be significantly higher to the threshold and this may not reflect the real situation for Greece.