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Towards Efficient Energy Management: Defining HEMS and Smart Grid Objectives

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***Abstract*—Energy consumption has increased considerably in the last years. The way to reduce and make energy consumption more efficient has become of great interest for researchers. One of the research areas is the reduction of energy consumption in users' residences. In order to reduce energy consumption in home environments, researches have been designing Home Energy Management Systems (HEMS). Efficiently managing and distributing electricity in the grid will also help to reduce the increase of energy consumption in the future. The power grid is evolving into the Smart Grid, which is being developed to distribute and produce electricity more efficiently. This paper presents the high level goals and requirements of HEMS and the Smart Grid. Additionally, it provides an overview on how Information and Communication Technologies (ICT) is involved in the Smart Grid and how they help to achieve the emerging functionalities that the Smart Grid can provide.**

***Keywords*-Home Gateway, Home Energy Management System (HEMS), Smart Grid, power grid, Advanced Metering Infrastructure (AMI), Demand-Response (DR), Information and Communication Technologies (ICT)**

I. Introduction

Despite the fact that home appliances have become more energy efficient [1], electricity consumption in households has increased 30% over the last 30 years [2]. This is due to the fact that the number of appliances that can be found in households is also increasing. According to the International Energy Agency (IEA), European electricity consumption is going to increase 1.4% per year up to 2030, unless countermeasures are taken [3].

Residential buildings can reduce their energy consumption by becoming more energy efficient. This paper tries to identify the objectives that need to be fulfilled in order to deploy an energy efficient infrastructure. This infrastructure will help reduce the electricity consumption in users' residencies and make the electric grid more efficient by having more control over the electricity flow.

The research areas of efficient energy management can be divided into three more specific research areas: energy management in-home environments with Information and Communication Technologies (ICT), energy management in the power grid with ICT and ICT linking the Smart Grid and customers.

In this paper, 'utilities' are referred as the parties involved in the production and distribution of electricity, through the power grid. In addition, we use the term 'distribution' to refer to the process of electricity transport from the generation plants to the users' residences.

As shown in Table I, energy consumption in home environments can be reduced by installing Home Energy Management System (HEMS) [1] in users' residences. A HEMS will provide the users the necessary tools to manage and reduce their consumption. ICT will enable two way communication among the customers-location and utilities. ICT will benefit the users, as it will enable the provision of real time rates and billing status. If users take into consideration the price of electricity while consuming and reduce their consumption when the price is high, consumption will be optimized, as the utilities will be able to shift and shape demand. In addition, providing this exchange of information is one of the first steps towards optimization of energy distribution and production. This will provide the utilities with statistical data that will help predict energy consumption. In order to reduce losses and optimize energy distribution and production, the power grid elements need to be upgraded. Upgrading and introducing ICT in the power grid will lead to the so called Smart Grid. The Smart Grid will include new components and functionalities to efficiently manage the electricity distribution and production.

In this paper, the different goals that should be achieved in these areas in order to reduce energy consumption in home environment and make distribution and production of electricity more efficient are presented. When designing HEMS and Smart Grid systems, researchers usually focus on one of the existing goals such as the integration of the electrical vehicles or renewable energy sources. However, it is important that these systems are designed in the framework they are going to be deployed in and with all the goals they should achieve to maximize the benefits. This paper summarizes the different objectives of these research areas which can be used as a guideline.

The remainder of this paper is organized as follows: Section II introduces the concept of Home Energy Management System (HEMS) and describes the high level goals and requirements to deploy it successfully. Section III provides an overview of the actual power grid and introduces the Smart Grid concept. The Smart Grid objectives and functional areas are also introduced in this section. An overview of ICT in the Smart Grid is provided in Section IV, where the communication requirements for the functional areas of

Table I
IMPROVING ENERGY MANAGEMENT

Issues \ Research areas	**Home environments**	**ICT**	**Power Grid**
Energy Goals	Reduce energy consumption	Provide grid's status information for efficient consumption and distribution	Reduce losses and integrate DER and EV
Who benefits?	Users	Users and utilities	Utilities
How?	HEMS	Information exchange	Smart Grid

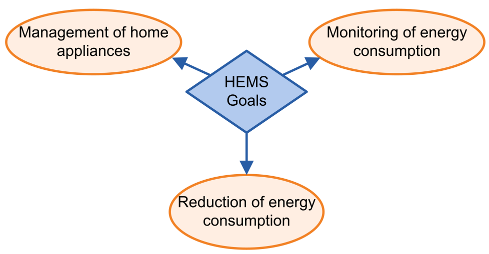

Figure 1. Home Energy Management System Goals

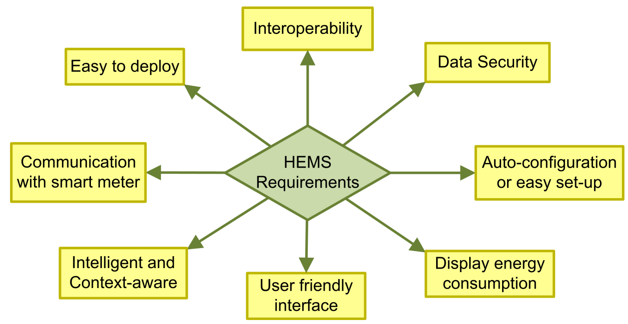

Figure 2. Home Energy Management System Requirements

the Smart Grid and issues are presented together with the ongoing ICT European projects. Finally, in Section V the conclusions are presented.

II. ENERGY MANAGEMENT IN HOME ENVIRONMENTS

Introducing Information and Communication Technologies (ICT) into home environments can help to reduce energy consumption of users. A HEMS is a system that includes all the necessary elements to achieve this reduction of electricity consumption in home environments. One of its main elements is the so called home gateway or residential gateway which is able to communicate and manage the rest of the home appliances and offers the users tools to reduce their consumption. Using context-aware information in HEMS will provide knowledge, which can be used to further decrease energy consumption.

Section II-A presents the goals HEMS should achieve and the high-level requirements it should fulfil. Section II-B will present the major challenges when designing HEMS.

A. HEMS High-Level Objectives and Requirements

The main objectives of a HEMS are shown in Figure 1. HEMS main goal is to reduce the energy consumption. However, to achieve this, monitoring energy consumption and managing appliances are needed. In order to reduce energy consumption, it is first necessary to know how energy is consumed. Therefore, consumption monitoring is needed. Secondly, it is necessary to manage the appliances in order to apply energy reduction strategies.

We consider that HEMS has to fulfil the requirements summarized in Figure 2 to achieve these goals satisfactorily:

- Easy to deploy: It has to be taken into consideration that HEMS should be easy to deploy into users' houses because deploying new cables or infrastructure is sometimes not a feasible nor cost efficient solution. Using already installed communication systems, such as wireless communication or power line communication which will minimize the costs and gain users' acceptance.
- Interoperability: in order to monitor and manage users' appliances efficiently, a home network has to be introduced, where devices can exchange information and commands, without interoperability conflicts. The appliances found in users' premises are usually manufactured by different producers and may use different communication technologies can lead to interoperability issues among devices.
- Data security: Security has to be incorporated into HEMS in terms of data encryption and authentication to protect the system against external threats. However, security issues will not be analyzed as they are out of scope of this paper.
- Auto-configuration or easy set-up: HEMS is going to be used by users without enough knowledge to perform network configuration tasks. Taking into consideration that users may add or change their home appliances, HEMS should provide easy to use configuration tools or in the best case the network should be auto-configurable.
- Display energy consumption: One of HEMS goals is to monitor energy consumption. This information should be available to users through the user interface. Furthermore, the displayed information could be shared with the utilities, to create statistical data of energy usage in home environments, or with third parties. Current consumption and also previous con-

sumptions, providing daily, monthly and even annual reports should be provided. Additionally, the possibility to compare the electricity consumption between months or even compare it to other sources, such as average neighborhood consumption or other users' consumption is an interesting feature.

- User friendly interface: The user interface should display information about the current consumption and also previous consumptions as stated above. Additionally, this interface should also provide management options, where the users may modify their preferences and control their appliances. User preferences are related to the strategy used to reduce users' energy consumption and may vary from system to system. It is also important to provide the possibility of controlling devices, as the system may apply undesired configurations and the user has to be able to correct them.
- Context-aware and intelligent: HEMS should have some intelligence to facilitate efficient energy management. This can be achieved by creating a context-aware system. A context-aware system is capable of collecting information from the environment, or context, and react accordingly. It is considered that a context-aware system can significantly improve the reduction of energy consumption. There are different ways in which context-aware systems can be implemented in HEMS: by defining energy polices or rules or by creating intelligent system.
  A HEMS that uses energy policies is a context-aware system which collects information from the environment and then uses this information together with the policies or rules to reduce energy consumption. This type of system is a static system and contains predefined policies or rules. However this policies and rules may be modified at any time by the user, by deleting, creating or modifying them.
  An intelligent HEMS requires a more complex system. In the context of this paper the intelligent HEMS is defined as a system that reduces energy consumption by using context-aware information to predict users' behavior and then applies the energy management strategy without compromising the users' comfort. Before being able to predict users' behavior and apply the energy management strategy, there has to be a learning process. This learning process includes (1) collecting context-aware information, which can include location-aware information, and (2) analyzing and processing this information to extract the users' routines and patterns. Once the learning process is completed, the system can extract the settings needed to reduce energy consumption. Unlike a rule based HEMS, this system is dynamic, adapts to user and also self-evolving.
- Communication with smart meter: As it will be explained in Section IV-B, the smart meter is found in costumers premises to measure the electricity consumption and communicate this information to the utility. Enabling this communication will provide the user with real-time price and billing status, energy consumption information, as well as possible services that may arise. HEMS should communicate with the smart meter to obtain this information. An example of a new service HEMS could obtain from the smart meter could be comparing the household energy consumption to other users' consumption. However, some of these new services could be offered through the Internet and not through the smart meter.

In the next section, the challenges found designing HEMS, when trying to comply with the above requirements, are presented.

B. Issues and Challenges

The main challenge to provide an efficient HEMS is interoperability. HEMS should provide seamless interaction between devices. However, there are a number of different home appliance manufacturers and communication technologies available for the user, which makes device interoperability problematic. In addition, devices of the same type, such as washing machines, can have different functionalities depending on the model. Technical incompatibility has limited market possibilities. Users are looking for a 'one size fits all' solution without having to worry about compatibility requirements. Therefore, one of the main challenge in HEMS is the variety of technologies, providing different communication methods, as well as the diversity of producers, providing different types of devices and services. This seamless interaction between devices could be provided by creating a central element, the home gateway, which would be able to communicate with all the devices. An example of how to solve this problem can be found in [4], [5].

Additionally, other challenging expectations from users have to be fulfilled, related to the following requirements: auto-configuration or easy set-up, user friendly interface and easy deployment:

- Easy to use and control: there is diversity in users' preferences and expectations when interacting with HEMS. Some users would like an interface that will give them advanced options while others would just like a simple system but without losing control of their devices [6]. Furthermore, users have different user interface preferences, some users would like to use their mobile phone or PDA, while others would rather use their computer or a controller. An example of how to deal with this can be found in [7].
- Easy to configure: complex configuration or professional help to configure the network is a drawback. HEMS should be easy to configure or even be auto-configurable. However this can be a challenge due

to the heterogeneity of home appliances and home technologies. Strategies and mechanism for software configuration and updates for devices installed in home environments can be found in [8], [9].

- Easy software upgrade: home appliances can have software installed, which in some occasions has to be updated. Software update should be easy for users to perform. The authors in [8], [9] present how to deal with software upgrades in home devices.

Moreover, designing HEMS as an intelligent and context-aware system is not an easy task and presents these following challenges:

- Design of context-aware systems, data collection and interpretation: HEMS may use sensors to collect information about the users' behavior. The system may have to work with different types of sensors and from different brands. This will force the system to be designed to deal with different sensor details which sets a barrier to interoperability. Dey et al. [10] proposes an infrastructure to support software design and execution of context-aware applications using sensors to collect data.
  Another issue is coping with the amount of data transmitted from home appliances and likely sensors. An example of how to deal with this can be found in [11].
- Policies and rules: There are two main challenges when using policies to implement energy management: coordination and contradiction. As the number of appliances in the house increases so does the number of policies, which can lead to coordination problems and contradictory rules. Tools to identify interactions and detect conflict resolution between policies should be incorporated into HEMS to manage rules and policies more efficiently. An example of this can be found in [12], [13].
- Intelligent HEMS: This type of HEMS should include an algorithm which after processing the collected data will be able to learn and predict the users' behavior. Examples of such algorithms can be found in [14], [15].
- Multiple-inhabitants: Prediction of users' behavior when there is more than one user in the home environment adds complexity to the predicting algorithm as each user has his/her own routines, practices and policies/rules, which may be different for each user.
- Not compromising users' comfort: HEMS should not have undesirable outcomes, it should be an intelligent system that can adapt to different situations and user behavior.

III. Energy Management in the Power Grid

As stated before, energy consumption in home environments is increasing and consumption patterns have considerably changed in the last years. The National Academy of Engineering acknowledges the power grid as the supreme engineering achievement of the 20th century, due to its ingenious engineering, its support for other technologies and the impact in improving quality life style for society [16]. However, the power grid has not changed significantly during the last century (the average substation transformer age is over 40 years old [17]). The power grid was designed to provide one-way flow of electricity and centralized generation. Furthermore, the actual power grid has limited automation and situational awareness and there is a lack of customer-side data. Therefore, an upgrade is needed to achieve efficient energy distribution and production and to fulfil the new power grid functionalities, which will be explained in Section III-D. The integration of these functionalities into the power grid will lead to the so called Smart Grid. Smart Grids will incorporate ICT to fulfil the new requirements and functionalities.

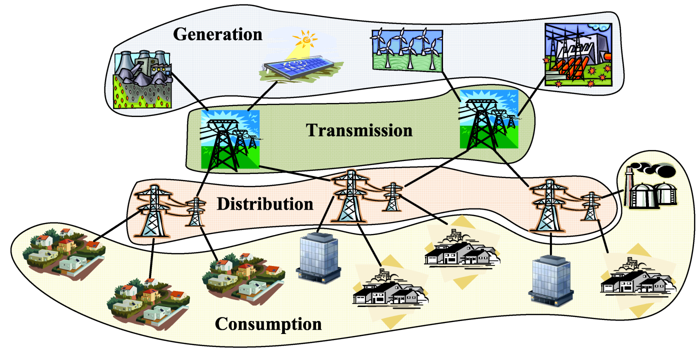

Figure 3. Power Grid Architecture Overview

The next section provides an overview of the power grid and Section III-B presents the Smart Grid concept and NIST and ETP Smart Grid view. In Section II-A, the high-level objectives of the Smart Grid are explained. Finally, in Subsection III-D the functional areas of the Smart Grid are presented.

A. Power Grid Architecture Overview

The power grid is an interconnected electricity network, which includes infrastructure of power generation, power transmission, power distribution and control. A typical power grid system is illustrated in Figure 3. A brief description of the different sections of the power grid is given below.

- Generation: it is composed of different types of power generators, such as coal, fossil fuels, natural gas, nuclear, wind turbines and hydraulic power plants among other. The main part of the electricity generated comes from large power plants located in strategic locations. For instance a coal power plant could be found near a coal mine. This section of the power grid is responsible to generate enough power to supply the demand.
- Transmission system: it carries electric power in an efficient way from the power plants to the distribution

system, where the power will be later consumed. Transmission system may span hundred of kilometers and line voltage are above 100 kV in Europe. The electricity is transmitted at very high and high voltages to reduce the energy losses in long distance transmission. The power plants are connected to the transmission system by a substation or transformer. A substation contains circuit breakers, switches and transformers, which step-up or step-down the voltages in the lines. Furthermore, substations can be found through the transmission system to change the voltages in the lines.

- Distribution system: it is similar to transmission system as their function is to carry electricity. However, the distribution system carries the electricity from the transmission system to the to consumers. This system includes medium and low voltages and also contains substations to interconnect it with the transmission system. The substations are also found thought the distribution system. The voltage in the transmission system lies between 69 kV and 240 V in Europe.
- Consumption system: composed by residential/home consumers, commercial and industrial consumers. The consumers are equipped with an electricity meter that register the consumers electricity consumption. Consumers may be found in rural, suburban or urban areas. Moreover, industrial consumers may be connected to the distribution grid at power levels higher than 240 V.
- Control Centers: In the traditional power grid the system operation and maintenance is done through centralized control and monitoring, Supervisory Control and Data Acquisition (SCADA). The control centers, communicate with the substations found around the power grid through private microwave radio, private fiber and public communication network [18].

As it will be explained in the following sections, the power grid architecture is changing into a more distributed and decentralized grid which will introduce new functionalities and ICT requirements.

B. Smart Grid Definitions

The Smart Grid concept is used by the different players involved in the power grid, not only utilities but also governmental entities. However, there is no standard definition. Different definitions exist, some functional, some technological, and some benefits-oriented:

- European Technology Platform (ETP): ETP defines the Smart Grid as "an electricity network that can intelligently integrate the actions of all users connected to it generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies" [19].
- European Commission: European Commission defines the Smart Grid is "an electricity network that can efficiently integrate the behavior and actions of all users connected to it generators, consumers and those that do both in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety" [20].
- Electric Power Research Institute (EPRI): "The term Smart Grid refers to a modernization of the electricity delivery system so it monitors, protects and automatically optimizes the operation of its interconnected elements from the central and distributed generator through the high-voltage network and distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances and other household devices" (EPRI) [21].
- US Department of Energy (DOE): "An automated, widely distributed energy delivery network, the Smart Grid will be characterized by a two-way flow of electricity and information and will be capable of monitoring everything from power plants to customer preferences to individual appliances. It incorporates into the grid the benefits of distributed computing and communications to deliver real-time information and enable the near-instantaneous balance of supply and demand at the device level" [22].

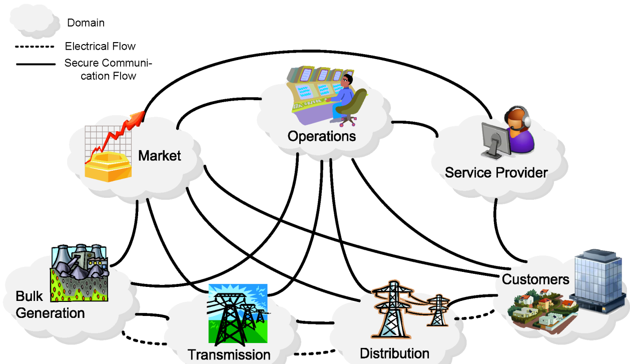

Figure 4. NIST Smart Grid Reference Model [24]

The Smart Grid is still an open concept. However, from these definitions it can be seen that the Smart Grid will enable a more dynamic, resilient, sustainable, efficient and adaptable grid with new capabilities and will involve the participation of different players, from customers to utilities. The Smart Grid will not only supply power but also information and intelligence. As the European Technology Platform (ETP) states "the smartness is manifested in making better use of technologies and solutions to better plan and run existing electricity grids, to intelligently control generation and to enable new energy services and energy efficiency improvements" [23].

Furthermore, NIST has developed a *Framework and Roadmap for Smart Grid Interoperability Standards* which "presents the first steps of a Smart Grid interoperability framework based upon initial standards and priorities to achieve interoperability of Smart Grid devices and systems" [24]. Additionally, it provides a conceptual architectural reference model shown in Figure 4. This model divides the power grid into domains, actors and applications. There are seven domains, which are further divided into sub-domains. Each domain is a high-level grouping of actors, organizations, individuals, systems or devices which have similar objectives and may have overlapping functionality. NIST defines actors as devices, systems, or programs which are capable to make decisions, exchange information and interact with actors from the same or other domains. The tasks performed by one or more actors are defined as applications. In the following, there is a brief description of each domain and also some of the identified interfaces by NIST for which interoperability standards are needed.

- Bulk Generation: More renewable energy resources will be deployed into the Smart Grid. The main actors in this domain are big power plants such as renewable variable sources (solar and wind), renewable non-variable (hydro, biomass and geothermal) and non-renewable (nuclear, coal and gas). This domain may also include energy storage for later distribution of electricity.
- Transmission: Similar to the electricity transmission system today, this domain carries electricity over long distances. However, a two-way communication system will be deployed in substations and other intelligent devices found inside this domain, which will it make it substantially different from the current one.
- Distribution: The main changes to the distribution is the two-way communication system for monitoring and controlling. It may also include storage of energy and connection with alternative distributed energy resources (DER), such as wind farms and solar panels systems.
- Customers: In the Smart Grid, customers will be capable of generating, storing and managing the use of energy as well as the connectivity with their plug-in vehicles into the power grid. In this conceptual model the smart meters, besides being able to control and manage the flow of electricity to and from the customers, will provide information about energy usage and consumption patterns. Consumers will have a two-way communication with utilities and other third parties.
- Markets: Markets domain includes the operators and participants in electricity markets, such as market management, DER aggregation, retailing, wholesaling and trading among others. This domain is in charge of coordinating all the participants in the electricity market and ensuring a competitive market, in addition to exchanging information with third-party providers. For instance, roaming billing information for inter-utility plug-in-vehicles could be an example of a third-party service.
- Service Providers: This domain handles all third-party operations between domains. Examples of actors in this domain are installation and maintenance, billing, customer management and emerging services among other. Through this domain customers and utilities can exchange data regarding energy management.
- Operations: Operations domain is in charge of managing and operating the flow of energy through the power grid. It is connected to customers, substations and other intelligent devices through a two-way communication. Actors included in this domain are metering reading, maintenance and construction, security management and network operations among others. This domain provides monitoring, reporting, controlling and supervision status, which is an important to obtain a reliable and resilient power grid.

The European Technology Platform (ETP) network vision of the Smart Grid is shown in Figure 5 [3]. ETP does not define domains, however, it identifies the stakeholders involved, which may include governmental entities, consumers, traders, transmission and distribution companies, ICT providers and power equipment manufactures among others. Their vision on for the Smart Grid includes a two-way communication among these stakeholders which will provide coordination at regional, national and European level. ETP expects deployment of intelligent devices and distributed energy resources along the power grid. Furthermore, the European Commission identifies the following challenges for enabling Smart Grid deployment in Europe that have to be addressed [25]:

- Developing common European Smart Grids standards.
- Addressing data privacy and security issues.
- Regulatory incentives for Smart Grids deployment.
- Smart Grids in a competitive retail market in the interest of consumers.
- Continuous support for innovation and its rapid application.

C. *Smart Grid Objectives*

One of the main objectives of the Smart Grid is to make the power grid more efficient and to incorporate renewable energies. These objectives can help to reach the targets set by the European Commission.

Figure 6 summarizes the main high-level objectives the Smart Grid should fulfil. When designing the Smart Grid these goals should be taken into consideration and be integrated together in order to maximize the benefits.

- Enable the active participation of consumers: In the Smart Grid, customers will become active participants and will play a role in optimizing the operation of the system. The grid can ask the users to reduce their consumption to avoid shortages and reward them with

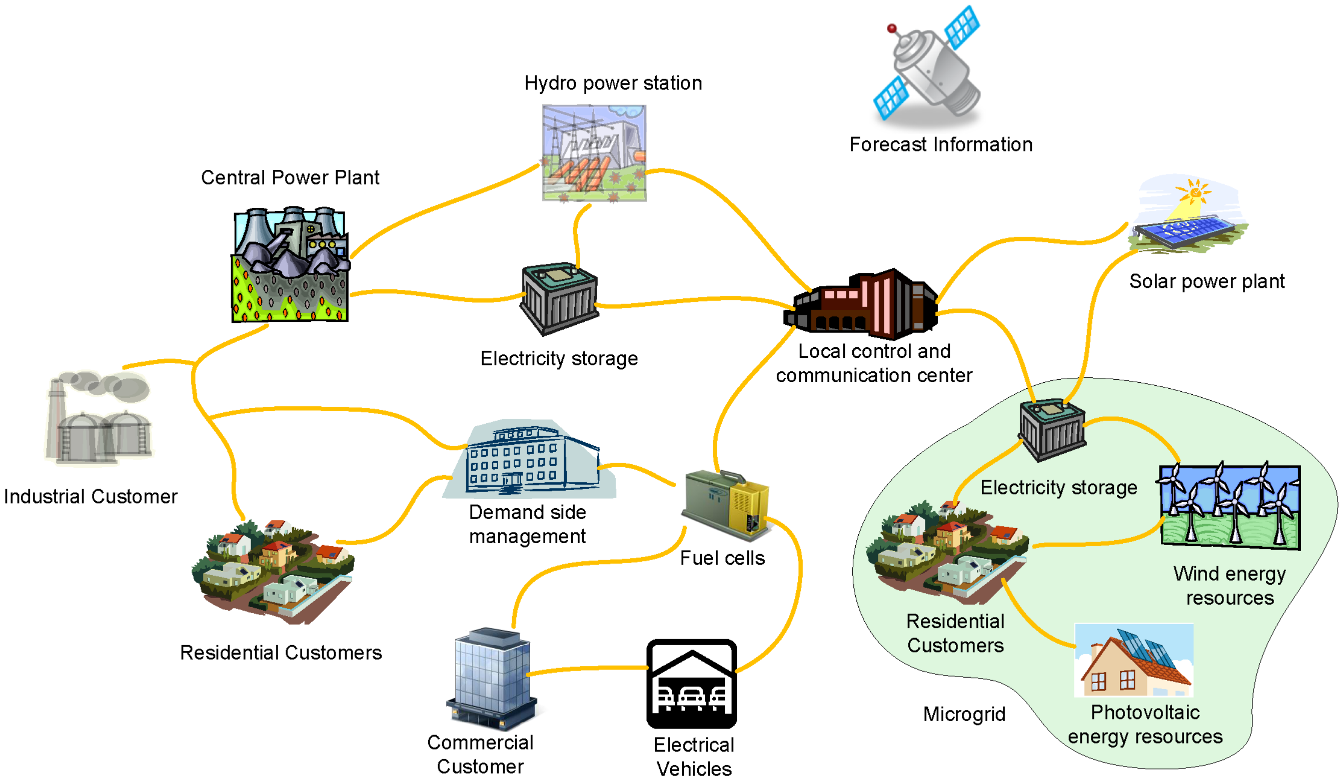

Figure 5. European Technology Platform Network Vision [3]

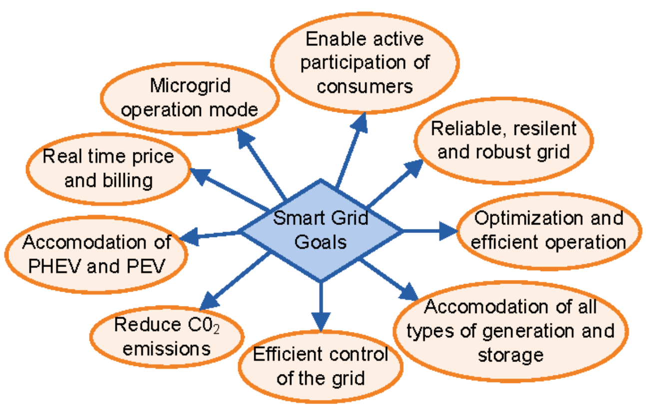

Figure 6. Smart Grid Objectives

economical benefits. This process is referred as Demand Response (DR), discussed in more detail in III-D. DR will help utilities shape the demand according to the available production. Enabling this interactive service network in the power grid will improve the efficiency, safety ad reliability of the electricity transmission and distribution [22].

Customers are installing renewable energies in their premises and the Smart Grid should be capable of accepting these injections into the grid. Consumers in the Smart Grid that consume and generate energy will be called prosumers (**pro**-duces and con-**sumers**).

- Reliable, resilient and robust grid: the Smart Grid should improve security and quality of supply and reduce the number of blackouts and shortages to increase system reliability. In order to achieve a more resilient, reliable and robust grid than the actual power grid, Smart Grids should be easily reconfigurable and dynamic, in other words they should be self-healing system.
- Optimization and efficient operation: optimization and efficient operation of the grid implies a reduction of energy losses in power grid. Moreover, the Smart Grid should significantly reduce the environmental impact of the whole electricity supply system and improve the grid infrastructure operation. This can be achieved by upgrading the grid components and by using consumption statistics to foresee the electricity usage. It should also embody efficient and reliable alarm and fault management for self-healing procedures.
- Accommodation of all types of generation and storage: the Smart Grid has to accommodate from large centralized power plants to renewable energies installed in the users' premises or distribution systems. In addition, it is foreseen that new storage systems, such as community storages, may be included in the Smart Grid. To properly manage and control these new components, the

Smart Grid should be designed as a decentralized and distributed grid to better facilitate the connection and operation of generators of all sizes and technologies.

- Efficient control of the grid: introducing ICT into the power grid can help collect real-time data if the consumption, production and grid status. This information can be used to achieve efficient control of the power grid to balance loads and avoid blackouts and electricity shortages.
- Reduce carbon emissions: The European Commission Climate Action set three energy targets to be met by 2020, known as the “20-20-20” targets which are [26]:
  - A reduction in EU greenhouse gas emissions of at least 20% below 1990 levels
  - 20% of EU energy consumption to come from renewable resources
  - A 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency.

  The carbon emissions can be reduced by incorporating some of the already mentioned objectives:
  - Reduce network losses by using more efficient components
  - Facilitate penetration of renewable energies, such as wind turbines and photovoltaic cells installed in the distribution grid or in users’ premises.
  - Improve operational decisions in the power grid by using weather forecast to estimate the production of solar and wind farms. Also load forecast will make the power grid more efficient.
  - Use DR to reduce or even avoid demand peaks. [27] presents a system where the house consumption is kept under certain limit to avoid demand peaks.
- Accommodation of PHEV and PEV: Even though Plug-in Hybrid Electric Vehicles (PHEVs) and Plug-in Electric Vehicles (PEVs) are not yet wide-scale adopted, they should be taken into consideration when designing the Smart Grid. It is foreseen that the amount of PHEV and PEV will increase which will lead to a considerable increase of electricity demand which cannot be supported by the current power grid.
- Real time price and billing: ICT will provide the means to transmit real time price and billing information to the user. Furthermore, the consumers will be provided with greater information and options for choice of supply. The Smart Grid should incorporate the necessary elements to make this information available. The price of electricity is determined on the basis of supply and demand.
- Microgrid operation mode: Microgrids are generally defined as low voltage grids, which can range between few hundred kilowatts to a couple of megawatts, and include distributed generation sources, storage devices and consumer side. The ETP defines a microgrid “a controlled entity which can be operated as a single aggregated load or generator and, given attractive remuneration, as a small source of power or as ancillary services supporting the network” [3]. Although microgrids mainly operate connected to the rest of the power grid, they can automatically switch to islanded mode when faults occur, which could cause shortages or blackouts in the microgrid area. Microgrids should later on re-synchronize with the rest of the power grid with minimal service disruption, when the fault is stabilized. During islanded mode, the microgrid main functionality is to balance the distributed resources with local energy loads. Therefore, microgrids are capable of taking decision locally, while operating in islanded mode, but also when connected to the rest of the grid. However, coordination with the rest of the power grid and actors is necessary when the microgrid is connected to the power grid. Microgrids provide a new level of flexibility in configuring and operating the power grid, which may makes the grid more efficient, reliable, resilient and dynamic.

D. Smart Grid Functional Areas

The high level objectives described in the previous subsection can be classified into the six functional areas defined by DOE [28] in which most Smart Grid applications fall:

- Advanced Metering Infrastructure (AMI): refers to the infrastructure capable of measuring and collection consumption and generation at the consumer side and communicating it, in a two-way communication flow, to management system which makes this information available to the service provider. Additionally, AMI can provide real-time price information to the consumers. The consumers data can be collected and transmitted by using the smart meter installed in the consumer premises. The energy consumption data can be then be used by the service provider and utilities for grid management, outage notification, and billing purposes.
- Demand-Response (DR): is a reduction of consumption by the consumers, residential users, commercial or industrial as a response to high electricity prices or a request from the utilities in order to reduce heavy loads in the system. By using DR systems demand can be shaped to follow the production and therefore shortages and blackouts can be avoided. Furthermore, renewable energies, such as wind energy, have very variable power output depending on weather conditions. DR can help balance such loads providing a more flexible and dynamic power grid. However, accepting power reduction request is voluntary and can create some operational complexities.

- Wide-Area Situational Awareness (WASA): is a set of technologies that will enable improved reliability and prevention of power supply disruption by monitoring the grid status. WASA systems include sensors, which monitor the status of different elements in the power grid, intelligent devices, which can trigger an alarm in case of a critical situation, and two-way communication with the service providers. The main objective of WASA is to provide information about the grid status on real time. WASA will transform the power grid into a proactive systems, which will prevent critical situations instead of reacting to them.
- Distributed Energy Resources (DER): extends from distributed renewable energy sources to electric vehicle batteries, combined heat and power (CHP), uninterruptible power supplies (UPS), utility-scale energy storage (USES) and community energy storage (CES). It is expected that DER will be deployed along the power grid, specially on consumers and distribution system. Integrating DER into the power grid involves a major change as it implies decentralized generation and multi-directional flow of electricity, from utility-to-consumer, from prosumer-to-utility and even prosumer-to-consumer. DER applications require a more complex control situation and effective communication technologies to keep the balance in the power grid.
- Electric Transportation (ET): plug-in hybrid electric vehicle and plug-in electrical vehicles will drastically change the users consumption. This change of load has to be taken into consideration when designing the Smart Grid, which has to provide sufficient energy supply for electric vehicles and effectively manage the demand. This new kind of vehicles offer also the potential to function as storage devices, thus helping balancing the load in the Smart Grid by reducing the demand in energy shortage periods and absorbing the demand during excess supply periods.
- Distribution Grid Management (DGM): involves remotely control of the components found in the power grid. By using real time information about the power grid status and being able to remotely control the power grid, the Smart Grid becomes a more reliable power grid. Furthermore, Distribution and substation automation are part of the distribution Grid Management, which will provide more effective fault detection and power restoration. Supervisory Control and Data Acquisition (SCADA) and Distribution Management Systems (DMS), examples of DGM, require center-based control and monitoring systems in order to coordinate the power grid and keep balance.

Table II matches the presented objectives to be fulfilled by the Smart Grid in Section II-A and the above functional areas.

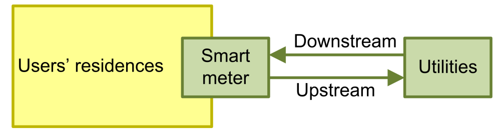

Figure 7. Communication between users' residences and utilities

E. *Towards Smart Grid*

The electrical grid has to undertake a transformation to reach the Smart Grids objectives. Introducing ICT into the grid will provide the communication tools to help reach some of the Smart Grids objectives. However, further changes in the Smart Grid components have to be done to successfully fulfil these goals. Advanced components, advanced control methods and improved decision support will be introduced in the power grid as it moves towards becoming a Smart Grid. In addition, sensing and measurements technologies should also be incorporated to evaluate the correct functionality of all elements in the grid and enable and efficient control.

IV. ICT IN THE SMART GRID

As it has been stated through this article ICT deployment in the power grid is an important step towards the Smart Grid. A reliable communication system that fulfills the Smart Grid's objectives, defined in III-C, and functionalities, defined in III-D, will determine the efficiency of the new power grid. The aim of ICT in the Smart Grid is provide more information about:

- Consumption: Knowledge about energy demand of the consumers will efficiency distribution. By providing this knowledge to the utilities, they can also foresee the energy needs of their consumers and avoid electricity shortages or blackouts. ICT can also be used to collect real-time consumption data to maintain the equilibrium between consumption and production.
- Production: Deployment of renewable energies, such as photovoltaic panels, is increasing in home environment and in the distribution system. Monitor and control is necessary for an efficient power grid.
- Status: Real-time monitoring the grid will help to detect critical situations. Remote control of the grid's component will help solve or even avoid this situations.

Deploying ICT in the power grid will start a cooperation between consumers and utilities. As shown in Figure 7, the upstream communication is defined as the transmission of data from the user to the provider and the downstream is defined as the one from provider to user. As stated before, the data transmitted in the upstream will include information about users' electricity patterns taking into consideration the likely installed renewable energies resources in their premises. The downstream communication is the transmission of electricity price and billing information from the utilities to the users. Having access to real time price

Table II
IMPROVING ENERGY MANAGEMENT

Objectives \ Functionalities	AMI	DR	WASA	DER	ET	DGM
Active participation of costumers	✓	✓	-	✓	✓	-
Reliable and secure supply	-	-	✓	-	-	✓
Self-healing	-	-	✓	-	-	✓
Optimization and efficient operation	-	-	✓	✓	✓	✓
Accommodation of all types of generation and storage	-	-	-	✓	-	✓
Efficient Control	-	✓	✓	-	✓	✓
Reduce Carbon Emissions	-	✓	-	✓	✓	✓
Accommodation of PHEV and PEV	-	-	-	✓	✓	-
Real-Time price and billing	✓	-	-	-	-	-
Microgird operation	-	-	✓	✓	✓	✓

and billing information will make the users become more conscious about their electricity consumption and they may try to reduce the associated costs, by avoiding peak hours, leading to a more distributed and efficient consumption. In addition, the utilities can use this downstream to ask their users to reduce their demand when demand peaks occur. This communication system will enable utilities to be proactive, acting before the problem occurs instead of reacting to it. Furthermore, utilities can offer new service that can be access by the user through this downstream.

Next section presents the communication requirements for the functional areas presented previously. Section IV-B explains how the smart meter and the home gateway collaborate with the smart meter. Finally, Section IV-C describes some of the issues raised by ICT in the Smart Grid.

A. ICT Requirements

Many communication and networking technologies can be used to support Smart Grid applications, which can vary around the power grid. S

Due to the different functionalities to be carried out by the Smart Grid, the ICT supporting them have different communication requirements. This will likely lead to a variety of communication technologies to be deployed in the Smart Grid. One of the technologies supporting ICT in the Smart Grid could be cable lines, fiber optic cable, cellular, satellite, microwave, WiMAX, power line communication, as well as short-range in-home technologies such as WiFi and ZigBee. Furthermore, different players in the Smart Grid have different views on what the communication requirements are for each of the functionalities presented in Section III-D as they are still under development. US Department of Energy (DOE) has written a technical report, *Communication Requirements of the Smart Grid* [28], which encloses the communication requirements based on the projections of future communications needs and the input of the different actors involved in ICT for the Smart Grid. Table III summarizes the Communication requirements found in this report and commented in the following subsections.

1) Advanced Metering Infrastructure (AMI):

- Bandwidth: It has been estimated that the bandwidth required for AMI will be between 10 to 100 kbps per node. However, communication among the aggregation point and the utility will likely have bandwidth requirements in the 500 kbps range.
- Latency: The delay between the consumption measurement and the moment at which the information is reported to the utility is not critical for AMI. However, demand response applications may be affected as they depend on this information.
- Reliability: AMI's level of reliability falls into the 99 percent to 99.99 percent range. The information provided by AMI has to reach the utilities. However, if some consumption measurement is lost it can be updated by the next measurement packet.
- Security: This network will carry consumption private information, therefore the it has to have a high security level.
- Backup Power: Backup power is not necessary as there is no consumption during blackouts.

2) Demand-Response (DR):

- Bandwidth: There are different DR programs that can be implemented: incentive-based, rate-based DR, demand reduction bids. Therefore, communications requirements of DR program may vary depending on the sophistication of the system.
- Latency: The latency requirements start from as little as 500ms, to 2 seconds, up to several minutes. This wide range is likely due to the different DR programs. Some programs maybe considered time-critical as if the demand is not reduced, it would lead to a system overload situation. However, if not used for grid balancing, relatively lower latencies may be necessary.
- Reliability: DR is likely to be used as a grid management tool, reliability will be important, and experts have estimated reliability will range between 99% percent to 99.99% level.

Table III
COMMUNICATION REQUIREMENTS FOR SMART GRID FUNCTIONAL AREAS [28]

Functional Areas \ Communication Requirements	Bandwidth	Latency	Reliability	Security	Backup Power
Advanced Metering Infrastructure	10-100 kbps per node 500 kbps for backhaul	2-15 sec	99-99.99%	High	Not necessary
Demand-Response	14-100 kbps per node	500 ms-several minutes	99-99.99%	High	Not necessary
Wide-Area Situational Awareness	600-1500 kbps	20 ms-200 ms	99.999-99.9999%	High	24 hour supply
Distributed Energy Resources	9.6-56 kbps per node	20 ms-15 sec	99-99.99%	High	1 hour
Electric Transportation	9.6-100 kbps,	2 sec-5 min	99-99.99%	Relatively high	Not necessary
Distribution Grid Management	9.6-100 kbps	100 ms-2 sec	99-99.999%	High	24-72 hours

- Security: As DR messages can be used for load management, its is important to verify the integrity of the information exchanged.
- Backup Power: There is no need for backup power, as the load management functions and DR programs are not necessary if there is a blackout.

3) Wide-Area Situational Awareness (WASA):

- Bandwidth: Data transferred in WASA is continuous and periodical rather than variable, but its throughput is expected to be high. Furthermore, the increase of distributed generation resources deployed and the introduction of new applications for phasor data, the bandwidth requirements will increased.
- Latency: WASA is used for real-time monitoring, therefore, the latency requirements are low between 20 to 200 ms. However, if historical data is transmitted the latency requirements can be higher.
- Reliability: Due to WASA is used to avoid critical situations its reliability is higher than AMI and DR.
- Security: Due to the same reason as above security in WASA systems is expected to be high.
- Backup Power: Backup power is necessary as the information provided by WASA is used to find the why and where the failure occurred and repair it.

4) Distributed Energy Resources (DER):

- Bandwidth: DER are unpredictable energy sources as they depend on weather conditions. Therefore there generation measurements need to be transmitted. It is estimated that the bandwidth will range between 9,6 kbps to 56 kbps.
- Latency: DER will imply having multiple energy sources feeding the distribution grid at multiple locations, which will complicate service restoration. Although the estimated latency ranges from 20 ms to 15 s, during faults, a lower latency maybe needed.
- Reliability: It has been estimated that the reliability of DER should be similar to AMI and DR.
- Security: As this information is expected to be critical during failures, security should be high.
- Backup Power: Backup power is estimated to last 1 hour as DER information can be used to restore power.

5) Electric Transportation (ET):

- Bandwidth: Electrical vehicles (EV) will cause a considerable increase in demand, which needs to be coordinated to not overload the system. ICT are needed for this coordination and also for billing purposes as the ET will likely charge at a variety of locations, including customers premises, office parkings, and other public or private locations during long-distance travel. Bandwidth requirements have been estimated to be between 9,6 to 56 kbps. However if EV batteries are used in DR programs to reduce demand peaks or absorb excess of electricity the necessary bandwidth could be up to 100 kbps.
- Latency: Latency estimates depend on the communication's main purpose, if it is used only for billing or also used for DR programs.
- Reliability: Due to the fact that some of the functionalities are similar to AMI and DR the reliability is the same for ET communications.
- Security: Security is important as information about the vehicles location should be protected. In addition, the charge and discharge of the EV should be done by authorized parties.
- Backup Power: Charging will not occur during a blackout, and backup power will likely not be critical. In fact, EV batteries, if charged, may serve as backup power not only for likely ET communication but also other potentially critical applications on the Smart Grid.

6) Distribution Grid Management (DGM):

- Bandwidth: DGM will make possible to remotely monitor and control the grid through automated decision-making, providing more effective fault detection and power restoration. Therefore, bandwidth requirement varies depending on the task to be performed, it is expected that during faults and critical situations more bandwidth will be needed.
- Latency: DGM latency requirements vary, from less than 1 s for alarms and alerts to 100 ms for messaging between peer-to-peer nodes. However, the maximum

latency is expected not to exceed 2 s.

- Reliability: The reliability is expected to be similar to the rest of Smart Grid applications, between 99% to 99,99%.
- Security: Due to the management nature of this functionality high security is required.
- Backup Power: Backup power is necessary to effectively restore power in case of blackout.

B. Smart Meter and Home Gateway

The smart meter is found in costumers premises to measure the electricity consumption. The smart meter is equipped with communication capabilities to transfer the measured information to the utilities. Therefore, the smart meter is one of the main elements of AMI and the information collected can be used for WASA and DR. The smart meter is in charge of communicating this information to the utility as this element should ensure the validity of the data collected. Furthermore, the smart meter may also receive data from utilities, such as real time price. It can also be used to communicate with the components involved in DR, to transmit or receive information from/to the utilities.

The home gateway, besides being the main element of HEMS and being able to communicate with all the home appliances and the smart meter, can be involved in DR and AMI. The smart meter can communicate the real time price information to the home gateway which can display this information in a user graphical interface. Then, the HEMS or the user can react accordingly to the price. The request to reduce electricity consumption associated to DR can also be forwarded from the smart meter to the home gateway, or depending on the DR implementation, be send directly to the home gateway. The home gateway, can then, according to user preferences, accept or decline the utilities requests.

In order to reduce the the information flow through the smart meter, historical consumption and billing information can be directly transmitted to the home gateway.

C. Issues

As it has been presented in the previous sections the Smart Grid is a system of systems which involves different actors and has different functional areas that require ICT. Deploying ICT will require that these parties work together to obtain the maximum benefits. This may require data interfaces between the different parties that ensure interoperability. Integrating ICT into the grid may require (1) to deploy a new communication infrastructure in the grid, (2) to standardize the communication between parties, (3) to fulfill all the necessary requirements for the Smart Grid applications.

Some of the barriers the stakeholders have to overcome when developing ICT for the Smart Grid are:

- Diversity of available technologies: There are different available communication technologies that can implement the ICT in the Smart Grid. This leads to a diversity of possible architectures, which can cause division in the power grid.
- Different entities: There are different players involved in the development of the Smart Grid. It is important that these entities can communicate with each other and exchange information in order to achieve the objectives and functionalities of the Smart Grid. However, due to the fact that there is diversity of available technologies and different protocols for machine-to-machine communication, interoperability between the different entities involved in the Smart Grid is becoming a challenge.
- Different functional requirements: The different functionalities have different requirements and requires communication between different players which is a challenge to incorporate the ICT into Smart Grid as more than one communication network maybe needed.
- Security: As Smart Grid will enable remote control of the power grid elements, therefore security becomes an issue. The ICT incorporated into the Smart Grid should be resilient to cyberattacks. Furthermore, as the consumption data of consumers is transmitted through AMI, data authenticity should be ensured.
- Privacy: Detailed private information about the consumption in consumers premises will become available in the Smart Grid. This information may be of interest to different entities, which the user might not be interesting to share it with, as they can extract patterns of home activity from metering data. For example, which devices they own, when do they use them, and lifestyle routines can be deduced from the users' load profiles. Therefore, the data regarding consumption of users should be protected when transmitted through the Smart Grid and maybe restricted to only some entities.
- Data Ownership: Data ownership is closely related to privacy issues and is still a topic under discussion. One may think that the data should be owned by the consumers and they should agree to share it with third-parties or not. On the other hand, this data is crucial for utilities as it can be used to forecast consumption and improve the power grid efficiency. However, these two statements are not mutually excluding. A solution could be that load profiles of consumers are owned by the user but aggregated data of load profiles can be used by utilities for consumption forecasting.

D. Ongoing European Projects

The aim of this section is to provide an overview of some of the ongoing European Projects dealing with research and development on the Smart Grid and its ICT aspect. The projects described below belong to the 7th FWP (Seventh Framework Programme) and have been paired up with the functional areas described in Section III-D.

- BEAMS, Buildings Energy Advanced Management System [29], 2010-2013: The aim of this project is to develop an advanced and integrated management system to enable energy efficiency in buildings, indoors areas and public spaces. This project is takes into consideration the interaction of the overall system with the power grid and management of heterogenous loads, such as public lighting, heating, ventilation and air conditioning (HVAC), and sources, such as renewable energy sources (RES) and electric vehicles. The goal of the project is not to develop new technologies but to integrate and combine already existing technologies to reduce the CO2 emissions. This project objectives are similar to the herein presented HEMS, but aimed to buildings and public areas instead. Furthermore, it is related to the integration of ET and DER in the customers side.
- CASSANDRA, A multivariate platform for assessing the impact of strategic decisions in electrical power systems [30], 2011-2014: The goal of this project is to develop a platform for realistic modeling of the energy market stakeholder aimed to provide test and benchmark working scenarios. This project aims to provide an aggregation methodology and software platform, and find the key performance indicators. Due to the fact that it deals with energy markets, this project is a step forward towards DR.
- HIPERDNO, High Performance Computing Technologies for Smart Distribution Network Operation [31], 2010-2013: This projects mainly objective is to enable DGM functionality, and indirectly AMI. This project's goal is to develop and demonstrate high performance computing solutions for realistic distribution network data traffic and management scenarios. This solution is based in near to real time data traffic with built-in security and intelligent communications for smart distribution network operation and management.
- INTEGRIS, INTelligent Electrical Grid Sensor communications [32], 2010-2012: The aim of this project is to develop a novel and flexible ICT infrastructure for the new Smart applications such as as monitoring, operation, customer integration, demand side management, quality of service and voltage control, Distributed Energy Resources and power system operations management. Therefore this projects offers the ICT infrastructure necessary for WASA and DGM. The Smart Grid ICT infrastructure developed is based on a hybrid Power Line Communication (PLC)/ wireless integrated communications system, which will be able to fulfill the communications requirements foreseen for the Smart Grid.
- MIRABEL, Micro-Request-Based Aggregation, Forecasting and Scheduling of Energy Demand, Supply and Distribution [33], 2010-2012: This project is closely related to DR systems and supporting AMI. This is due to the fact that some of their main objectives are to: develop a concept of micro-requests to handle the energy demand and supply on a household level, design a decentralized scalable distributed system to handle the data load from customers, to forecast demand and supply based on historical and additional data (e.i. weather forecasts) and standardize the exchange of information between customers and utilities among others.
- OPENNODE, Open Architecture for Secondary Nodes of the Electricity SmartGrid [34], 2010-2012: This project has three main goals: 1- develop an open secondary substation node (SSN), 2- develop a Middleware to deal with the SSN and the utilities systems interaction for grid and utility operation, and 3- develop, based on standardized communication protocols, a modular and flexible communication architecture for the operation of the distribution grid. Therefore, this project is linked to DGM functionality.
- SMARTV2G, Smart Vehicle to Grid Interface [35], 2011-2014: The goal of this project is to create a safe, secure, energy efficient, controlled and convenient transfer of electricity and data to connect the electric vehicle to the Smart Grid. In this project, a new generation of technologies will be developed. This project aims to allow seamless and user-friendly energy load of electric vehicles in urban environments in the Smart Grid context. It is obvious that this project functionality is ET.

V. Conclusion

There is considerable literature on energy management and Smart Grid. This paper has tried to outline the main goals that have to be fulfilled by the Home Energy Management System and the Smart Grids. Additionally, an overview of the actual power grid and definitions for the term Smart Grid have been provided. Smart Grid models from NIST and ETP have also been presented and the functional areas of the Smart Grid have been explained. Furthermore, the role of ICT in the Smart Grid has been introduced and its benefits have been discussed. This article also presented some of the issues raised when introducing ICT in the Smart Grid. In the last section of this article some of the ongoing European Seventh Framework Programme have been presented. This projects have been related with the Smart Grid functionalities described in Section III-D.

When developing systems to reduce or make energy consumption more efficient, such systems usually focus on one specific capability. It is important that the overall framework and objectives are taken into consideration during the design of such systems to maximize their benefits. This paper can be used as a guideline of the objectives that should be fulfilled by HEMS and Smart Grid specially regarding ICT.

Furthermore, an interesting aspect of enabling communication between users and utilities is to use this bidirectional communication for Demand-Response systems. DR systems can be as simple as changes in electricity price or more complex such as the presented in [36]: Incentive-Based DR Programs, where utilities send a reduction requests to customers, and Demand Reduction Bids, where customer sends a demand reduction bid to the utility. An example of a DR system based on electricity price changes can be found in [37].

Finally, the authors of this article have developed a home gateway in JAVA using OSGi and ontologies and knowledge database. A detailed description of this home gateway can be found in [4], [38]. This home gateway has been specifically designed for HEMS and to help fulfill the requirements and objectives presented in Section II-A. It offers interoperability at the service level by using ontologies and incorporates a rule engine. Moreover, this home gateway can be used to exchange information with the utilities. The customer can define rules to automatically react to electricity price changes and reduction requests from the utility and generate Demand Reduction Bids.

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