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Review

Telecommunication Technologies for Smart Grid Projects with Focus on Smart Metering Applications

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Academic Editor: Neville Watson
Received: 10 February 2016; Accepted: 29 April 2016; Published: 17 May 2016

Abstract: This paper provides a study of the smart grid projects realised in Europe and presents their technological solutions with a focus on smart metering Low Voltage (LV) applications. Special attention is given to the telecommunications technologies used. For this purpose, we present the telecommunication technologies chosen by several European utilities for the accomplishment of their smart meter national roll-outs. Further on, a study is performed based on the European Smart Grid Projects, highlighting their technological options. The range of the projects analysed covers the ones including smart metering implementation as well as those in which smart metering applications play a significant role in the overall project success. The survey reveals that various topics are directly or indirectly linked to smart metering applications, like smart home/building, energy management, grid monitoring and integration of Renewable Energy Sources (RES). Therefore, the technological options that lie behind such projects are pointed out. For reasons of completeness, we also present the main characteristics of the telecommunication technologies that are found to be used in practice for the LV grid.

Keywords: smart grid; smart grid projects; telecommunication technologies; smart metering solutions

1. Introduction

The current power grid needs to constantly evolve to adapt to the increasing technological demands. Particularly, the development and growth of Renewable Energy Sources (RES) has implied a transformation in the way the energy is produced and stored. In addition, the need to reduce the total CO_2 emissions calls for a better and more efficient energy usage. Modern power grids are adapting to cope with this new scenario, evolving to accommodate the integration of renewable energy sources and to enable a more efficient energy management through automated control and modern telecommunication technologies [1].

A smart grid implies that a vast amount of information will need to be handled. The integration of renewable energy sources requires a constant monitoring and control of the power grid. As a consequence, the operation of the whole grid requires an efficient management of energy generation, transmission and distribution. For this reason, the role of the telecommunication technologies used in the smart grid is of vital importance. In general, there are three main domains of applications for the smart grid network: the High Voltage (HV) network used for the electricity transmission, the Medium Voltage (MV) network used for the electricity distribution and the Low Voltage (LV) network used to provide electricity at end-users [2]. Specifically for the LV network, special attention is given to neighborhood and building area networks. In [3] the technological solutions for this type of networks are listed. Smart metering is an important part of the LV network, because it contributes in transmitting energy consumption/generation data towards the utilities and information data towards the smart meters. Therefore, they play a key role in energy management and saving.

There are several telecommunication technologies utilised by smart metering applications and they are mainly distinguished according to the transmission medium used for the signals, thus being divided into wired and wireless. A popular wired technology is Power Line Communications (PLC), which refers to the use of the existing power lines for the signal transmission. A benefit of this technology is that there is no need for new infrastructure. PLC technologies can be classified into two categories: Broadband PLC (BB-PLC) and Narrowband PLC (NB-PLC) [4]. Many wireless techniques can be used depending on the type of signal transmission examined, like the ZigBee or cellular wireless technologies. In general, there are two links for transmitting data from the smart meter to the control center: the first link carries data from the smart meter to a data concentrator whereas the second link connects this data concentrator to the data center [5]. In the rest of the paper, we refer to these links for smart meter data communication as "first" and "second" link. Figure 1 shows this concept of smart meters communication to the utility center through data concentrators. In Figure 1, it is shown that various technological solutions can be used for both links.

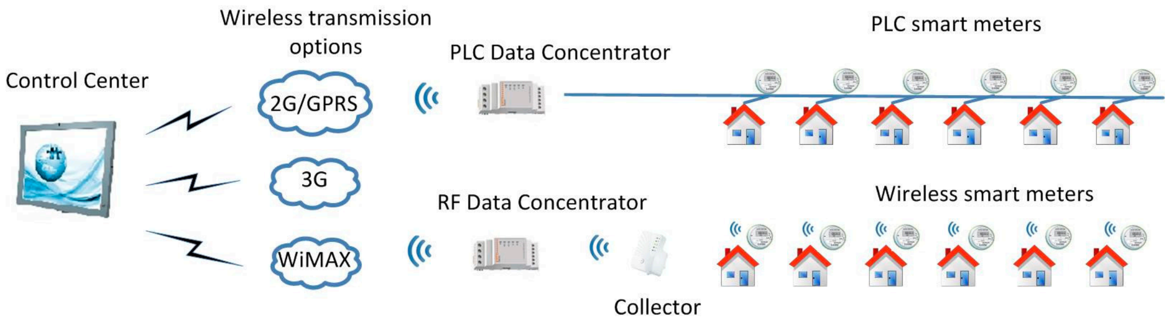

Figure 1. AMI—Communication from the smart meters to the utility system with several technological solutions.

In this paper, we aim at identifying the telecommunication technologies selected in reality for smart grids with emphasis on smart metering applications. For this purpose, a survey is performed based on the smart grid projects realised in Europe, as presented in [6], and the technological solutions applied in them. In general there are/have been more than 450 smart grid projects examining different issues; however, we select the projects directly or indirectly involving LV smart metering applications and special focus is given to the telecommunication technologies selected for them. The scope is to give a clear picture of the trends in the field and to provide readers with valuable information about what has been used in practice. To complete the picture, we present the technological solutions chosen by several European countries with respect to their national smart meter roll-out. In addition, an insight is provided about the technological trends in topics like smart home/smart building, integration of RES and grid management, since they are found to be directly or indirectly related to smart metering applications. A small feedback is given about the telecommunication technologies used in the MV grid through projects that combine research on LV smart metering applications with research on the MV grid. However, a thorough analysis of the aspects of the MV smart grid network would be out of the scope of this work. For reasons of completeness we also give the main characteristics of the telecommunication technologies that are mostly found to be used in practice through our survey in order to help the reader understand their usage and the main concepts behind them.

The rest of the paper is organised as follows: Section 2 lists the wired and wireless telecommunication technologies respectively, which are available for the LV smart grid, as they are found in the literature. Particular emphasis is given to the technologies that are found to be used in reality at a great extent as smart metering solutions. In Section 3 the technologies selected for smart metering applications mainly in Europe are presented. In Section 4 some of the main smart grid projects are presented with special focus on the role of smart meters and the technologies used. Section 5 concludes the paper.

2. Technologies for LV Smart Metering—Background Information

2.1. Wired Technologies

2.1.1. Narrowband PLC (NB-PLC)

Narrowband PLC (NB-PLC) technology implies that data is transmitted through a narrow frequency band at a low bit rate. NB-PLC technologies aim at offering indoor (home automation) and outdoor (smart grid) command and control services. One application of NB-PLC is the control and telemetry of electrical equipment such as meters, switches and heaters. NB-PLC is usually applied for the telecommunication link between the smart meter and data concentrator. [7,8].

In Europe the NB-PLC band goes roughly from 3 kHz to 150 kHz and is further divided into four sub-bands. More specifically, the CENELEC A band (3–95 kHz) is mostly used by power utilities for applications like monitoring or controlling the low-voltage and distribution network. CENELEC B-band (95–125 kHz) can be used for any kind of applications, the C-band (125–140 kHz) for home networking systems while the CENELEC D-band (140–148.5 kHz) is specified for alarm-and security systems. In Japan, ARIB has specified the 10–450 kHz frequency band for PLC applications, whereas in USA FCC has defined the 10–490 kHz frequency band for this purpose [9].

Two Orthogonal Frequency Division Multiplexing (OFDM)-based NB-PLC solutions that can offer high data rates, and which have been introduced to the market prior to high data rate standards, are namely PRIME and G3-PLC: Both PRIME [10] and G3-PLC [11] use the (OFDM) transmission method and the DBPSK/DQPSK modulation technique. The difference is that in PRIME the DPSK concept is used in the frequency domain, whereas in G3-PLC in the time domain. Another difference lies in the encoding procedure of the two specifications [12]. Some of the available standards for NB-PLC are as follows:

- IEEE 1901.2—It is a high data rate standard and it defines NB-PLC both via alternating and direct current. Smart Grid applications are included. Other PLC technologies operating below 500 kHz can also coexist. It is noteworthy that the standard includes three physical and MAC layer specifications, the G3-PLC (10–500 kHz), the G3-PLC for CENELEC A and the PRIME for CENELEC A [8].
- ITU-T G.hnem—This standard can be used for a variety of Smart Grid applications such as smart metering, demand response, *etc.* It is a high data rate standard and uses the OFDM technology that refers to in-home energy management and home automation. It should be noted, that in this standard, the recommendations ITU-T G.9902, ITU-T G.9903, ITU-T G.9904 are included, which contain the physical and data link layer specifications for ITU-T G.9902, G3-PLC and PRIME NB-PLC OFDM transceivers respectively [13].
- IEC 61334—Part 5 of this standard defines NB-PLC systems, whereas part 5-1 defines in particular an S-FSK scheme (G1 specification). Single carrier technologies are used, meaning that the data rate is low. The data concentrator in such a system acts as a "local relay" for a management centre [14].
- IEC 62056 is a set of standards for electricity metering data exchange and they are the standard versions of the DLMS/COSEM specification. Part 21 defines how data transmission of electricity meters takes place, while mode E indicates that the use of DLMS/COSEM through High-Level Data Link Control (HDLC) is supported. Single carrier techniques are used also in this case, thus leading to low data rates transmitted [14].
- ISO/IEC 14908-1 (Lonworks)—Lonworks technology has been created by Echelon. For electric utility applications, the CENELEC A band is used. CENELEC C band is used for in-home applications. The resulting data rate is kept at low levels (few kbps) [8].

To complete the picture, there is another technology that is also popular for smart meter applications when it comes to the data transmission from the smart meter to the data concentrator, namely Meters and More. According to it the physical layer is designed by using the Binary Phase-Shift Keying (BPSK) modulation, while the LLC layer is based on IEC 61334-4-3. This technology is optimum for the transmission of very short messages, especially for PLC and wireless IP communications [15].

2.1.2. Broadband PLC (BB-PLC)

The concept of BB-PLC was initiated with the scope of providing Internet access applications. In general, the idea was to use BB-PLC for the so-called last-mile communications and for home networking. BB-PLC devices offer bit rate in the order of hundreds of Mbit/s and they do not need new infrastructure. Their frequency band of operation is between 2 and 30 MHz [16]. The Open PLC European Research Alliance (OPERA) project aimed at offering broadband access service by exploiting the BB-PLC technology. Among the project objectives were: to improve both the LV and the MV PLC system in terms of bandwidth, distances reached and network management [17]. Three types of devices are defined, namely the Head-End (HE), the Repeaters and the Customer Premises Equipment (CPE). These devices form a multi-hop system [18]. The project outcomes have been used, among others, for research in the MV BB-PLC field; an example is the work in [19] where a channel estimation algorithm for MV-PLC systems is produced.

Although the broadband scenario has been widely used for in-home applications and Internet access, it has not experienced major deployment when it comes to smart metering applications [20]. However, there are some examples where the BB-PLC is used for smart metering and in general for smart grid applications. For instance, in [21] BB-PLC has been chosen for realising the communication link between the home controller and the utility control center. In [22] its usage at the MV substation level has been examined and in general its implementation in the MV distribution network field.

As a first step, industrial specifications were made available for BB-PLC. The most popular ones are the HomePlug 1.0 allowing data rates of 14 Mbps and the HomePlug Turbo allowing for data rates of 85 Mbps. Higher data rates at the scale of 200 Mbps were defined by the HomePlug AV, the UPA and the HD-PLC specifications [8]. The equivalent industry alliances are the HomePlug Powerline Alliance, the Universal Powerline Association (UPA) and the High Definition Power Line Communication (HD-PLC). Afterwards, some standards followed, namely:

- TIA-1113—It is based on HomePlug 1.0 specification and defines a data rate of 14 Mbps. The Physical layer is based on OFDM while the MAC is based on the CSMA/CA (Carrier Sense Multiple Access with Collission Avoidance) scheme [23].
- IEEE 1901—It defines a speed at the rate of 100 Mbps and is based on the HomePlug and the HD-PLC alliance specifications. The Physical and MAC layer are defined by two technologies, the FFT-based OFDM and the wavelet-based OFDM. By this way, compatibility is assured for devices using the two different aforementioned specifications (HomePlug and HD-PLC) [8].
- ITU-T G.hn—This standard gives a high data transfer rate reaching up to 1 Gbps and it refers to Home Networking [24].

2.1.3. Digital Subscriber Line (DSL)

DSL is another technology that can be used for smart metering applications. DSL makes use of the traditional telephone line for the data transmission. It provides a backhaul for the smart grid data from homes to the utilities. DSL is a reliable and also a low-cost solution, since the infrastructure exists in most cases. A disadvantage of the DSL technology is that its throughput depends on the distance of the subscriber from the serving company [6]. Another issue that arises with DSL when applied in Smart Grids is the possibility that the end-users get to be involved in smart grid access. This could give rise to the installation cost or create functional problems [25].

2.1.4. Fiber Optic Communications

Fiber optics provide a high-capacity, high-speed data exchange transmission media that is widely used in backbone transmission networks. At present time the high installation costs associated to its deployment makes it only a suitable solution *in situ* ations where high data transmission rates are required [26].

2.2. Wireless Technologies

2.2.1. ZigBee

A wireless technology that is widely used in smart meter applications is ZigBee, which has its physical and MAC layers based on the IEEE 802.15.4 standard. Similarly to the NB-PLC, when it comes to smart meters, it is usually preferred for the telecommunication link between the smart meter and the data concentrator rather than the link between the data concentrator and the control centre. It operates in the 2.4 GHz band (worldwide) and its range is between 10 and 100 m, depending on the output power and the environmental conditions [27,28].

It is suitable for applications with low data rates and low power consumption and it is appropriate for wireless control and monitoring applications. Some typical applications include building automation, home automation, wireless sensor networks, smart lighting, Advanced Meter Reading (AMR), *etc*. ZigBee entails a low cost of deployment as well as low complexity. Regarding the AMR applications, one of the advantages of Smart meters, into which the ZigBee protocol is embedded, is that they can easily communicate with smart in-home devices, like smart appliances and home displays. On the other hand, ZigBee experiences a high interference ratio from other applications that use the same bandwidth, which could cause system degradation [6,27].

The ZigBee protocol can be also chosen for building a wireless mesh. This is a communication network made up of radio nodes in a mesh topology. The nodes can be all connected to each other, leading to a fully meshed topology or partially connected, leading to a partially meshed topology. The concept of a meshed network indicates that when a node fails, then the information data can be forwarded through an alternative path to the destination. Every smart meter in a mesh network is considered as a node and data is routed through them [6,29]. Figure 2 depicts a mesh network that consists of smart meters. It is shown that in the case of a fault, an alternative route is found for the information to be transmitted.

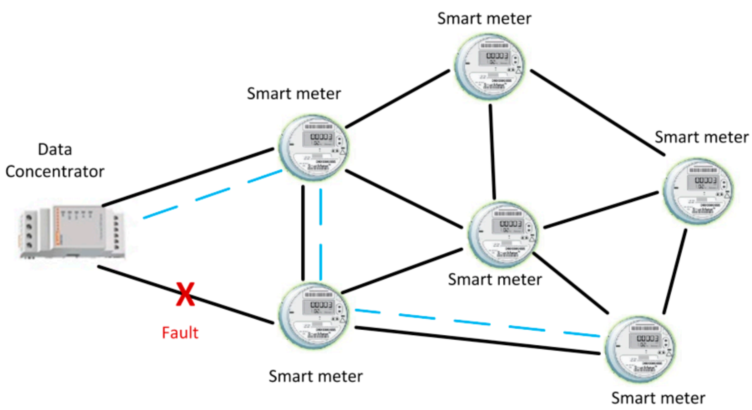

Figure 2. Smart meters forming a mesh network for data transmission.

2.2.2. Cellular Technologies—GSM/GPRS-3G-LTE

Usually, cellular technologies on smart metering applications are preferred for the telecommunication link between the data concentrator and the utility data center. One of these cellular technologies can be the GSM or GPRS. The frequency bands used in Europe are the 900 and the 1800 MHz bands. GSM has also been considered for implementation for smart grid monitoring and controlling. The main advantage of GSM is that the network already exists, thus making it the simplest solution for utilities [6,26]. On the other hand, the GSM network was not originally designed to carry smart metering data, but voice data, so the handling of the increased data traffic from smart meters along with existing voice data services could become an issue. In addition, the GSM/GPRS bands have been mostly allocated for existing mobile services; therefore, it is hard to get the available spectrum for developing a dedicated network for smart metering applications [26].

The 3G is the third generation of the mobile telecommunications technology. The data rate provided should be at least 0.2 Mbps. The two main standards considered to belong to the 3G category are the UMTS and the CDMA2000. Two more standards are the EV-DO and the EDGE. The frequency band occupied is between 800 MHZ and 1900 MHz for CDMA and EVDO. In addition, the 450 MHz band can be used for CDMA applications [26,30]. Referring to the smart metering applications, the 3G can be used as the communication link between the data concentrator and the utility data center. The advantage of this technology is that it is already deployed in a large scale, so it can be considered as mature and stable [30].

The Long Term Evolution (LTE) technology is a standard for high speed mobile communications. It is the evolution of the GSM/UMTS standards. With regard to the 3G architecture, it shows reduced latency. However, its wireless interface is incompatible with 2G and 3G networks. In addition, different bands are used in different countries meaning that devices compatible with one country's regulations can be incompatible with another one's [31]. Referring to smart grid applications it can be used, like the other cellular technologies, for supporting the Advanced Metering Infrastructure backhaul network and in particular the communication link between the data concentrator and the utility control center. The main advantages of LTE technology is the low latency it offers, its high capacity and its low power consumption. On the contrary, the main problem is that the equipment cost remains high [30].

2.2.3. WiMAX

WiMAX is a wireless communication standard that can provide with a data rate up to 75 Mbps. It can be considered as an alternative technology for delivering fixed wireless broadband access [4]. It refers to the family of IEEE 802.16 standards for wireless-networks and it can be used as a backup technology for cellular phone technologies like GSM and CDMA [32]. With respect to the smart grid applications, it can be a suitable candidate for connecting the data concentrator with the utility's control center. This technology can be a suitable solution for utilities, since it implies low implementation costs, a lower degree of complexity and with an effective control over possible applications [33]. In [6] some smart metering projects are listed, where WiMAX is used for connecting the back-haul utility system with data concentrators. Despite the advantages that it has to offer, the fact that the bandwidth of WiMAX needs to be shared among users remains an issue [30].

2.2.4. Low Power Wide Area Network (LPWAN)

Apart from the wireless solutions described above, nowadays there are emerging technologies which would be suitable for the realization of the Internet of Things (IoT). Such technologies are suitable for the Low Power WAN (LPWAN), where transmissions of a few kb over large distances at low speeds in the most power-efficient way are required. Therefore, such a network could be suitable for smart metering applications. Three technologies designed for this scope are namely:

- SigFox—Its concept is similar to cellular networks; however it is designed to offer services to devices. The transmission is Ultra Narrowband (UNB), while the 868 MHz band is used. There are 400 channels of 100 Hz. Due to the ultra-narrow bandwidth, the noise effect is very low, thus the system is able to recuperate a very low power received signal [34].
- LoRaWAN—It is a specification for Low Power Wide Area Networks and it operates in the 433, 868, 915 MHz band. The channel bandwidth is 125 kHz; the modulation used is either FSK or a chip spread spectrum modulation; the data rates that can be supported are from 0.3 kbps to 50 kbps [34].

- NB-IoT—It is a narrowband radio technology designed for the IoT, which has been standardized by the Third-Generation Partnership Project (3GPP) body. It can be deployed in the GSM spectrum and it can support a big number of low throughput devices [35,36].

Table 1 gives an overview of the wired and wireless technologies for LV smart metering applications analysed in Section 2.

Table 1. Smart grid Communication Technologies.

Technology	Applications	Frequency Band	Data Rate	Specifications/Standards
NB-PLC	Indoor/Outdoor command & Control services, AMI	3–490 kHz	~200 kbps	PRIME, G3-PLC/IEEE 1901.2, ITU-T G.hnem (Higher Data Rates) IEC 61334-5-1, IEC 62056-21, ISO/IEC 14908-1, Meters & More (Lower Data Rates)
BB-PLC	In-home applications, Home Networking	2–30 MHz	~100 Mbps (IEEE 1901) ~200 Mbps (HomePlug AV) ~1 Gbps (ITU-T)	HomePlug 1.0 (14Mbps), HomePlug Turbo (85Mbps), HomePlug AV (200Mbps) TIA-1113, IEEE 1901, ITU-T G.hn
DSL	Data Transmission over telephone lines	ADSL: 25–1104 kHz VDSL: 25 kHz–12 MHz	256 kbps–100 Mbps	ITU G.991.1, ITU G.991.2 (SDSL) ITU G.992.1, ITU G.992.2 (ADSL) ITU G.993.1, ITU G.993.2 (VDSL)
ZigBee	AMI	2.4 GHz (worldwide)	250 kbps	ZigBee Home Automation
Wireless Mesh	For communication networks made up of radio nodes	900 MHz, 2.4 GHz	54, 48, 36, 24, 18, 12, 9, 6, 4, 5, 1.5 up to 300 Mbps for outdoor	IEEE 802.11, IEEE 802.15, IEEE 802.16
GSM/GPRS	Mobile functionality—voice, data transfer	900 MHZ, 1.8 GHz	14.4 kbps (GSM) 56–114 kbps (GPRS)	EN 301349, EN 301347, EN 301344
3G	Mobile functionality—voice fast data transfer	450 MHz, 800 MHz, 1.9 GHz	over 0.2 Mbps up to 14.7 Mbps (CDMA, EVDO)	UMTS, CDMA 2000, EV-DO, EDGE
LTE	High speed data for mobile phones and data terminals	700–2500 MHz	100 Mbps (requirement) up to ~320 Mbps	
WiMAX	Mobile Broadband or at-home broadband connectivity, Alternative to DSL	2–11 GHz	up to 75 Mbps (IEEE 802.16d) up to 15 Mbps (IEEE 802.16e)	IEEE 802.16, IEEE 802.16d, IEEE 802.16e
LPWAN	IoT, Smart metering applications	868 MHz (SigFox), 433, 868, 915 MHz (LoRaWAN), 700, 800, 900 MHz (NB-IoT)	lower than 100 kbps	SigFox, LoRaWAN, NB-IoT

3. Smart Meter Technological Solutions in Europe and Projects for Their Implementation

Smart metering contributes to the EU 2020 strategy for the reduction of 20% of the 1990's carbon emission levels by 2020. Most of the EU countries planned or already deployed nation- wide or selective smart-metering roll-outs, whereas only four countries reached the conclusion that a smart-metering deployment will not have a positive effect in a national level. Only Sweden and Italy accomplished their national rollout. Overall, it is expected that until 2020 around 200 million smart meters will be deployed with an estimated investment of 35 billion € [6]. In this work, we are interested in the technological solutions used for this scope. In general, different technologies have been preferred depending on the country and the application environment. In the following we present some of the smart metering technological solutions selected by different countries in Europe.

3.1. Italy

The energy provider ENEL uses power line communications technologies to transmit data from the smart meters to the concentration hub. In particular, the technology chosen for this scope is Meters and More. The concentrator is located usually in the MV/LV transformer and further on the data is transmitted through the wireless public area network to the central system. The whole initiative has been realised through the "Telegestore" project that started in 2001. Since then, over 32 million devices have been installed. Apart from the smart meters, the completion of the project entailed the deployment of the concentrators installed in medium to low voltage substations, used to gather the data recorded by the connected meters as well as the central system for meters remote management, billing information processing and for monitoring the quality of service [37,38].

3.2. Spain

In Spain, the energy provider Iberdrola has chosen to use smart meters based on PRIME technology. By the end of 2014, circa 4.2 million smart meters had been installed, as part of the Sistemas de Telegestión y Automatización de la Red (STAR) or 'Network Remote Management and Automation Systems' project [39]. By 2018 the company intends to update the whole distribution grid by installing 10.3 million smart meters and updating 80,000 transformer units, which will cost around 2000 million € [40]. Smart meters used by another Spanish energy provider, Gas Natural Fenosa, are also based on the PRIME technology. By 2014 the company had already installed 1.26 million smart meters [39]. On the other hand, Endesa, which belongs to the ENEL group, has already installed 7 million smart meters. This number represents 60% of the company's current fleet. The company has also announced that will complete the massive replacement procedure within 2017, one year ahead of the deadline. So far, data of more than 6.4 million smart meters are being managed, whereas a total of 600 million euros will be invested for the implementation of the new remote management system between 2015 and 2017. The Meters and More technology is used, meaning that NB-PLC is the key technology for the first transmission link, whereas wireless solutions, like GPRS are preferred for the second transmission link [41].

3.3. France

In France, the energy provider ERDF has initiated the smart metering employment with respect to the overall upgrade of the traditional network to an intelligent one. The initial project, called "Linky", involved the installation of over 250,000 smart meters in homes in the greater Lyon area and was completed in 2011 [42]. After the success of the pilot program, the company decided to proceed with a massive smart meter roll-out. It is expected that by the end of 2020, 35 million smart meters will be installed, with a cost of around €5 and €6 billion [43,44]. The smart meters to be used are/will be based on G1 and G3-PLC technology, with percentages of 20% and 80% respectively, whereas the technology for transmitting data from the concentrator to the control center is mainly GPRS [43,45].

3.4. United Kingdom

In the UK, the Department of Energy and Climate Change has given great importance to interoperability issues with respect to smart meters. By this way, smart meters will be compatible with every energy provider in case the customer wishes to switch from one to another. For this reason, the Smart Metering Implementation Program has been issued, defining Smart Metering Equipment Technical Specifications (version 1 and 2)—SMETS1 and SMETS2. Both versions define the physical specifications a smart metering system should have and its functional requirements.

In SMETS 1, the Electricity Smart Metering System (ESMS) should comprise of: a Clock; a Data Store; an Electricity Meter; a Home Area Network (HAN) Interface; a Load Switch; a User Interface; a Wide Area Network (WAN) Interface. An In-home Display is used so that the client gets direct information regarding electrical consumptions. The clock is used for synchronization purposes; the smart meter's data is stored in the data storage unit in case they are needed to be retrieved; the load switch is useful in cases of overload; the user interface is used for customer interaction purposes. The HAN and WAN interfaces are very important for enabling communication of the smart meter itself with the in-home consumer devices, the in-home display and the energy provider control center (Head End System—HES). Among the functional requirements defined, the ESMS should be able to establish a communication link with at least one consumer device and the In-home Display via its HAN interface and with a HES via its WAN interface [46,47].

There are some differences between SMETS 1 and SMETS 2. In the specifications' second version the electricity smart metering equipment (ESME) is divided in three categories. For the Single Element

Electricity Metering Equipment category, the equipment should comprise of: a Clock; a Data Store; an Electricity Meter; a HAN Interface; a Load Switch; a User Interface, including a Keypad. The main difference is that here there is no WAN interface. The HAN interface should be able to communicate with the In-home Display or a similar device that provides consumer access to consumption data provided by the electricity meter as well as with a device that can give access to the meter's data to the energy provider. For this reason, the HAN interface should be able to support a ZigBee network at the 2400–2483.5 MHz band and to establish communication via the DLMS COSEM technology. The first option is useful for fulfilling communication between the meter and the In-home Display/Consumer devices, whereas the second option is used for communication between the meter and the energy provider's data collection system [48,49].

Several projects have taken place for the replacement of traditional meters with smart meters. It should be mentioned that some of them have taken place/ started before the release of the SMETS 1/SMETS2 specifications. For example, the Scottish Power energy provider has installed around 5000 smart meters in isolated areas. The initial scope was to use the system in order to test the appropriateness of a radio based communications network for handling with the information from smart meters [50]. The energy supplier SSE has fulfilled the North Leigh project during which around 800 smart meters have been installed in the village of North Leigh. This project has been part of an Energy Demand Research Project (EDRP) supported by the Department of Energy and Climate Change and the industry regulator, the Office of the Gas and Electricity Markets (OFGEM) [51]. The energy provider Edf has been the leader of the project "Low-Carbon London", installing 5000 smart meters for the consumers living in London. This project has also been supported by OFGEM [52]. Finally, the energy provider British Gas also started the smart meter roll out, installing so far 1 million smart meters [53]. Figure 3 shows an example of the usage of smart meters along with an in-home display for the end-customer.

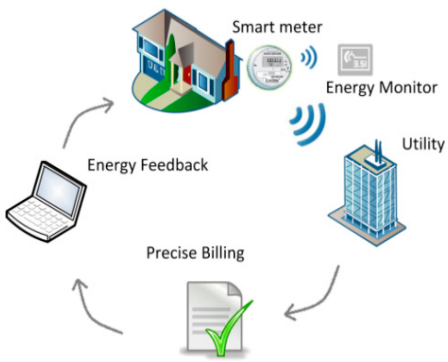

Figure 3. Example of the usage of a smart meter and an in-home display.

Although the situation is more or less clear as to the telecommunications technologies used in the above countries, this is not the case everywhere, either because there is vague information about the utilized technologies or because many countries are at the primary stage of smart meters deployment.

3.5. Germany

In Germany, several pilot projects have been carried out by the utilities, according to which thousands of smart meters have been deployed. Apart from this, every new construction since 2010 is required by law to have a smart meter installed [54]. In the following we list some of these pilot projects and we present the main technological solutions selected for them. For example, the energy supplier E.on launched a pilot project during which 10,000 smart meters have been installed in the region of Bayern and especially in the city of Bad Staffelstein. The technologies of PLC and GPRS have been applied on smart meters. The end client had also an important role, by providing a feedback for the whole project via a questionnaire [55].

Another pilot project, named "Mülheim Zählt", has been carried out by the energy provider RWE. During this project 100.000 smart meters have been installed in the city of Mülheim involving an investment of more than 30 million euros. The project's completion has been achieved at the end of 2012 and as a result, Mülheim was the first mid-size German city to be close to fully equipped with smart meters. Apart from the smart meter itself, an information/communication module was provided to the customer. The project results showed that there was a slight improvement in energy savings for customers using a smart meter with respect to clients not using one [56].

One of the developments made by the energy provider EnBW has been a smart meter with an integrated module that allowed all smart meters within a building to be connected, thus leading to successful in-home/building communication. Transmission of data to the energy provider could be achieved via the power line technology. The end-client has the possibility to obtain information about energy consumption even through his/her own computer thanks to an adapter, when connected to the Internet. These first smart meters have been installed in the region of Baden-Württemberg [57].

EnBW has a subsidiary, YelloStrom, having as business scope the distribution of energy and energy-related services to residential and commercial customers. A solution developed by YelloStrom is based on using the customer's broadband connection to transfer the smart meter data back to the energy provider. Through the project "Yello sparzähler online", smart meters have been implemented with the scope of creating an energy system that would allow the customers to measure and control the power consumption of their electrical appliances [58]. The smart meter communicates through the power line with the router, which in turn sends the data to the energy supplier through Internet [59].

Finally, the energy provider Vattenfall has initiated its activities in Sweden and afterwards expanded in several countries, like Germany, Finland, Denmark, The Netherlands and the UK. In Germany it has carried out a pilot project in 2010 in which around 10,000 smart meters have been installed in Berlin, mainly in the district of Reinickendorf [60]. The company has also successfully tested G3-PLC modems manufactured by Devolo, a company providing PLC hardware solutions [61].

3.6. Sweden

Sweden is the second European country that has completed the smart meter roll-out beside Italy. According to [62] the techniques for data transmission from the smart meter to the energy provider can vary. The most common one is power line communications combined either with radio (40%) or GSM/GPRS (13%) or as a stand-alone technology (27%). Wireless solutions are also chosen, like radio (13%) or radio combined with GSM/GPRS (7%). Vattenfall has completed the smart meter roll-out in 3 phases. The first one (Actaris project) aimed at deploying 110,000 smart meters (June 2003–June 2006). During the second phase (Iskraemeco project) 150,000 smart meters have been applied (July 2004–September 2006). The final phase was the realisation of the Telvent/Echelon project (June 2006–June 2008), in which 600,000 smart meters have been installed [63]. During the third phase the smart meters are used along with IP connected data concentrators. Communications are realised through PLC GSM and GPRS [64]. It should be noted at this point, that some of the smart meters provided by Echelon support the IEC 62056-21 and the ISO/IEC 14908 standard [65,66].

Vattenfall has also participated in several research work activities, like the Smart Grid Gotland project, which targets at integrating large quantities of renewable energy sources in the grid by the use of modern technology [67]. E.on Sverige has installed so far 1 million smart meters in the country. The main technologies used for smart meter data transmission has been power line communications and GPRS [68]. Another energy provider, Mälarenergi, has deployed around 100,000 smart meters which are functional since 2009. The data transmission from the smart meter to the data concentrator can be realised with power line communications or with radio technologies. For the second telecommunication link GPRS is used. The company has mainly chosen radio solutions between meters (75%) and secondarily power line communications (25%) with usage mostly in zones where radio technologies cannot be used [69]. In accordance to the country's regulations for the smart meter roll-out, another energy provider, Fortum, has deployed 860,000 smart meters [70]. Svenska Kraftnät has participated in the smart grid project "Stockholm Royal Seaport", which indicates a sustainable city with a smart grid as the enabler [71]. Finally, Eskilstuna Energy and Environment has been appointed leader of "Planning for Energy Efficient Cities" (PLEEC), which is an FP7 project funded by the European Commission and which targets at making European cities more energy efficient [72].

Even though in the aforementioned countries there are several pilot projects for smart meters that have been carried out, this is not the case for all EU countries. In many countries the roll-out or even the pilot efforts have just started or are planned to take place in the future.

3.7. Greece

In Greece the first pilot project has been accomplished by the year 2015 and was led by Hellenic Electricity Distribution Network Operator (HEDNO). According to this program, around 160,000 smart meters are placed in selected geographical areas throughout the country, like Athens, Thessaloniki and the island of Lesvos. The main technologies that have been/will be used for the smart meters implementation are/will be the power line communications and wireless technologies like GPRS, GSM, and 3G. The selection of the equivalent technology depends on the geographical and population characteristics of each area [73].

3.8. Concluding Remarks

As it can be concluded, many energy providers have started to replace their traditional meters with smart ones, whereas many relevant projects have taken place. The situation is not homogeneous throughout Europe. Some countries have made significant progress towards their smart meter roll-out, whereas in others pilot programs are planned to be realized in the future. It is also noteworthy that some countries apply different smart metering technologies, whereas in others there is a dominant technology chosen. Power Line Communications play an important role when it comes to smart metering applications. However, there is a variety of standards/specifications that can be selected. Table 2 summarizes the information provided in Section 3, with respect to the main technologies applied for smart meters in several countries. It should be highlighted at this point that the list of technologies and the standards/specifications that are mentioned to be used throughout Section 3 is not exhaustive. The technologies that are pointed out represent some cases of applications or in some occasions, the main technologies selected for a large-scale smart meter roll-out, like the case in Italy. The fact that other technologies can also be used or that have already been selected for specific applications is not excluded. Furthermore, in this Section, some information is also provided about rough estimations on investments and the quantity of smart meters installed, which refer to a specific project/actions taken by a specific energy provider. Other projects are likely to have taken place, involving other investment and smart meter scenarios.

It is also worth noticing that in some cases, emphasis is also given to the communication between the smart meter and a device for customer information purposes, like the In-home Display. In the UK, the technology specified for this scope is wireless (second version of Smart Metering Equipment Technical Specifications) and in particular, the ZigBee specification should be supported within the band of 2400–2483.5 MHz. In Germany, one of the energy providers has enabled customer information regarding electrical consumptions through the Internet.

Table 2. Some of the technologies used by country for smart metering data transmission.

Country	Technology	Standard(s)/Specifications (If Available)
Italy	NB-PLC	Meters & More
Spain	NB-PLC	Meters & More, PRIME
France	NB-PLC	G3-PLC, IEC 61334-5-1
UK	NB-PLC, WAN	IEC 62056-21, Communication based on open standards (some cases)
Germany	PLC, GPRS	
Sweden	NB-PLC, GSM/GPRS	IEC 62056-21, IEC 14908 (some cases)
Greece	NB-PLC, GSM/GPRS	

4. Smart Metering Applications—Smart Grid Projects

There have been numerous projects realised in the area of smart grid applications throughout Europe. In this survey we have focused on projects, in which smart metering has been/is a part of their investigation, with the aim of arriving to conclusions about the technologies selected for them. In addition, other projects involving simultaneously many smart grid areas have been included in this survey, such as smart network management, integration of RES and smart home. The purpose has been to make derivations for the role of smart meters and to identify the topics of research that the smart grid scientific community tends to focus. In general, it is noteworthy that the number of smart grid projects is very high, indicating the increased interest in the area. Out of the 50 projects analysed in this paper, 28 and four of them involve collaboration of participants from more than three and more than 10 countries respectively. With respect to the projects' duration, 39 of them have/had duration of more than 2 years, whereas six of them lasted/last for 5 years and more. In the following, we briefly describe the aforementioned projects and refer to their selected technologies, where applicable. The project categorisation is indicative, since many of them have/had multiple topics of investigation.

4.1. Smart Metering Application Projects

4.1.1. InovGrid

A project that involves the implementation of smart meters is the InovGrid, realised in Portugal, during which, 50,000 smart meters have been installed in Evora and other 100,000 in seven other regions. The majority of the smart meters work with the PLC technology; in particular the PLC DCSK is used. At a minor extent, the PLC PRIME and the RF mesh are used, as well as the GPRS technology. The project aims at providing with equipment that will contribute to the control and management of the distribution grid at any instant [74].

4.1.2. MeRegio

Another project involving smart metering has been the MeRegio project, led by the German energy supplier EnBW. According to it, the smart meter communicates its data to the customer's router and further on the data is sent to the control center via broadband Internet. It aims at adjusting the electrical appliances so as to be switched on and off when the charging rate is low [75].

4.1.3. Hook Norton

Smart meters have been applied also during the realisation of the Hook Norton (UK) project targeting overall an examination of energy consumption in a rural area and monitoring the distribution substations. For the data transmission from the homes to a concentration hub within the substations, the NB-PLC technology has been used, whereas wireless solutions have been employed for further transmission of data to the control center. A feedback to the end users related to the total electricity consumption has been provided from the utility center via an Internet interface [76].

4.1.4. EDRP

Another project in UK is the EDRP project, which involved four energy suppliers and aimed at examining if reduced energy consumption can be achieved when end users receive a better feedback about their energy usage. For this purpose, smart meters and real-time displays have been installed. The smart meters normally communicated with the energy supplier via GSM. In some cases, smart meters and real-time displays were hard-wired to a GSM modem transmitting data to the energy supplier or were integrated with a GSM modem. The PLC option has been also examined, at a minor extent within two communities for data transmission from the smart meters to the concentration hub, while GSM has been employed for further connection of the concentrator and the control center [77].

4.1.5. Remarks on Smart Metering Application Projects

The four projects examined in Subsection 4.1 deal with smart meters implementation. Two of them include a customer feedback in order to achieve energy consumption reduction (Hook Norton, EDRP). A similar concept is followed by the project MeRegio, where the appliances are switched on and off according to charging rates. Table 3 summarizes the characteristics of the projects mentioned in this Subsection.

Table 3. Summary of Smart Metering Application projects and their main characteristics.

Project	Aim	Characteristics	SM Technologies Used
InvoGrid	Control and Management of the grid	Provide with equipment for grid control	PLC DCSK, PLC PRIME, GPRS
MeRegio	Smart Metering installation	Sending SM data through customer's Internet	
Hook Norton	Examine energy consumption and monitor the distribution substations	Examine Customer involvement to energy reduction	NB-PLC (first link) Wireless (second link)
EDRP	Impact of customer feedback on reduction of consumptions	Smart Meter and In-home display installation	GSM (both links) PLC at small extent (first link)

4.2. Grid Monitoring and Control through Smart Metering

4.2.1. E2SG

Another project, where smart meters play an important role has been the E2SG project, in which organizations or institutions from nine countries participate. Its scope has been to design mechanisms for an efficient smart grid monitoring and control. The project addressed issues of grid sensing, smart metering and communication, including network monitoring by using phasor measurement units (PMUs), smart meters application and implementation of an architecture for data collection, storage and management. The smart meters that have normally been used, worked with a low power wireless transceiver. Another topic of the project has been smart conversion, like optimum power transfer to the grid and best possible interfacing of energy generating nodes with the AC grid and efficient interfaces from the end user to the grid for energy reduction. Advanced grid control methods have been examined as well as the topology of the grid [78].

4.2.2. NOBEL

In the "NOBEL" project, in which participants from four countries took place, the usage of smart meters has been examined for grid monitoring purposes. In particular, it has been examined the case where the smart meters communicate with each other over low power radio, thus forming a wireless sensor network, whereas wireless standards have also been implemented [79].

4.2.3. Mirubee

Grid monitoring through smart metering applications have also been examined in the "Mirubee" project, realised in Spain. In this project an electricity metering system has been proposed, which has been able to identify the electricity consumption of each device connected to the grid, through a so-called signature the device entailed. Once the consumption was logged, it was forwarded to a cloud server through Wi-Fi technology [80].

4.2.4. Remarks on projects for Grid Monitoring and Control through Smart Metering

In these three projects, smart metering has been used for grid monitoring purposes. Wireless solutions are used for different telecommunication purposes in all of them. In the project E2SG the smart meters worked with a low power wireless transceiver, in the project NOBEL the smart meters form a wireless network, whereas in the project Mirubee, WiFi technology has been used for transmitting device consumption to a cloud server. Table 4 summarizes the characteristics of the projects mentioned in this Subsection.

Table 4. Summary of projects for Grid Monitoring and Control through Smart Metering and their main characteristics.

Project	Aim	Characteristics	SM Technologies Used	Other Technologies
E2SG	Smart Grid Monitoring and Control	PMUs used for network monitoring, Smart Meters application, optimum power transfer to the grid	Smart Meters with wireless transceiver (some cases)	
NOBEL	Grid Monitoring	Smart Meters form a wireless sensor network	Wireless for communication among smart meters	
Mirubee	Grid Monitoring through smart meters	Identifying electricity consumption of each device connected to grid	PLC (first link)	Wi-Fi for transmitting device consumption to a cloud server

4.3. ICT for in-Home and Building Energy Management

4.3.1. ICE-WISH

The ICE-WISH project, which involved participants from 11 countries, aimed at motivating households in developing energy conservation practices and managing energy usage in the best possible way. The project objectives included the construction of a platform in order to collect sensor data and the definition of ICT and communication infrastructure. A system for the user to observe the energy results has also been part of the project. Wireless techniques have been used for the data transmission to the control center from the data concentrator hub [81].

4.3.2. E2SoHo

In the E2SoHo project the energy consumption reduction in social housing has been examined by implementing an ICT solution for energy management. In addition, the project dealt with interoperability issues between smart meters from different vendors. The ICT system has been composed of a communications and data processing platform, a user interface for tenants and a user interface for building managers. This solution can be integrated with smart metering systems that are used throughout Europe. From the technological point of view, the communication between the sensors and the data loggers is done through wired (RS485) or wireless (Zigbee) solutions. Afterwards, the data logger has been connected wired or wirelessly to a router, which communicated the data to a server through TCP/IP [82].

4.3.3. EnergyTIC

ICT tools have also been examined for in-home energy management, as indicates the project "EnergyTIC". Some 1700 houses participated in the project. The end users have been informed through useful messages for their consumptions from water and energy companies, thus being able to monitor and adapt their energy usage [83].

4.3.4. eSESH

The eSESH project, which involved participants from six countries, offered mainly energy awareness and energy management services to 5000 tenants through ICT solutions. For this purpose, energy awareness and management systems have been created in 10 sites in order to provide with a feedback on the energy consumption and reduce consumption peaks respectively. In addition, load management has also been implemented, so as the energy distribution system operator could remotely adjust the customers' load. The project offered the possibility to have data visualization for electricity, gas, heating, cold and hot water. Regarding the telecommunication technologies used, they vary depending on the site. So, NB-PLC communications are chosen for some cases for the data transmission from the meter to data concentrator or wireless solutions for other cases (ZigBee). For data transmission to the control center, wireless solutions like GPRS can be found [84].

4.3.5. Smart Build

Energy management in buildings through an ICT system has been the topic of investigation in the "Smart Build" project, which contains participants from five countries. The project's scope is to initially collect data from the buildings under test using sensors and meters and then forward this data to the control center through a hub. Further on, analysis of data for energy efficiency issues is performed, thus accomplishing energy monitoring and control in smart buildings. For achieving communication among sensors, several communication protocols have been used and wireless connections have been employed [85].

4.3.6. SportE2

Similarly, energy management consumption in buildings for sport facilities through ICT solutions has been examined in the "SportE2" project. This project has been run by participants in four countries. Initially, the project aimed at studying how energy is used in sport facilities through smart metering and then to provide with the necessary interfaces that would enable control of heating, cooling and lighting. For this purpose, a sensor network was deployed along with various communication solutions. The smart meter communication technologies varied among the different sites and included PLC and wireless smart metering solutions, like ZigBee and GSM. For the realisation of the sensor network, standard communication protocols have been used, including Ethernet and ZigBee [86].

4.3.7. VERYSchool

Another example of energy management in buildings through ICT solutions has been the "VERYSchool" project involving participants from nine countries. It has been about providing with ICT hardware and software solutions so as to optimize energy consumption in school buildings. Firstly, energy consumption has been examined through smart metering options and further on, data has been saved on a database—the so-called Navigator—regarding energy efficiency. The data is utilized through energy management programs by the system coordinator. The database has been fed with all necessary data by Building Energy Management System (BEMS) devices [87].

4.3.8. FINSENY

Another project dealing with energy management for buildings through ICT solutions has been the "FINSENY" project, in which participants from 12 countries took part. The project addresses ICT solutions for the operation of smart distribution networks as well as issues related to monitoring and control of microgrids and their interconnection to the overall grid. Regarding the distribution networks, the project intended to design an ICT solution for distribution system automation in order to enhance the grade of integration of Distributed Energy Resources. For this purpose, access to electrical data of the MV network has been planned by the control center. With respect to the energy management in buildings, smart metering solutions have been used. In general, the PLC technology has been preferred for smart meter communication with the data concentrator. In cases, PRIME technology has been also used for smart meters. Normally, substations are considered as the sensors and smart metering aggregation points in the LV or MV network. From that point, data is communicated with the central operation center through GPRS technology. For the Home Network and communication between devices inside the house, the ZigBee protocol is used [88].

4.3.9. Smartspaces

The project "Smartspaces", which involved participants from nine countries, also referred to energy saving issues in Europe's public buildings through ICT solutions. The scope has been to utilise ICT in order to help the city councils to observe the energy consumption in public buildings. As a first step, energy consumption information has been provided and this has been used for analysis and alert systems in order to provide energy decision support and energy management services. The telecommunication technologies used for data transferring from the smart meter to the data collector vary from site to site and included ZigBee, GSM/GPRS or Ethernet [89].

4.3.10. Encourage

Energy management in buildings is an issue also addressed by the "Encourage" project, which included participants from five countries. Its scope has been to develop techniques that would contribute to optimum energy consumption in buildings and also to create mechanisms for communicating with external buildings or utilities. The communications technologies recommended within the building were the ZigBee protocol, the 802.11n protocol and the PLC Home Plug Green Phy technology. The Home energy Controller (HEM) could function with all these technologies, whereas the Home Energy Gateway (HEG) which served to transfer data from AMI meter to utility could operate with the wireless technology solutions, like GPRS, ZigBee, WLAN [90].

4.3.11. Sunshine

The "Sunshine" project, which involves participants from nine countries, deals with energy assessment of buildings and aims at providing building managers with all the necessary information so as to reduce energy waste by heating/cooling systems. Apart from this, it is also planned to control the public illumination system based on AMR [91].

4.3.12. Remarks on Projects Focused on ICT for in-Home and Building Energy Management

All of the projects examined in Subsection 4.3, deal with energy management, optimization of energy consumption in buildings. Two of them involve the construction of a platform for data collection (ICE-WISH, E2SoHo), whereas three of them refer to energy management in public buildings (SportE2, VERYSchool, Smartspaces). Smart meters play an important role for these projects, whereas information can be found in six of them about smart meter technologies. PLC technology is used for data transmission from the smart meter to the data concentrator in eSESH, SportE2, FINSENY projects. In these first two projects, wireless solutions have also been implemented for this transmission link, like ZigBee. Wireless technologies (ZigBee, GSM, GPRS) have been also used in the Smartspaces project. On the other hand, for the transmission link from the data concentrator to the control center, wireless solutions are used in five projects (ICE-WISH, eSESH, SportE2, FINSENY, Encourage). Furthermore, for the realization of an in-home/sensors network, ZigBee technology has been used in SportE2, FINSENY and Encourage projects. Other technologies for such networks have been also used, like wireless connections (Smart Build), RS485 (E2SoHo), Ethernet (SportE2) and PLC (Encourage). Table 5 summarizes the characteristics of the projects focused on ICT for in-home and building energy management. Figure 4 shows a smart building and the various options it offers in terms of energy management.

Table 5. Summary of projects focused on ICT for in-home and building energy management.

Project	Aim	Characteristics	SM Technologies Used	Other Technologies
ICE-WISH	Energy conservation in households	Platform construction for sensor data collection, consumer interaction with energy results	Wireless (second link)	
E2SoHo	Building Energy management	Construction of: a Communications and data processing platform; User interfaces		Wireless (ZigBee)/Wired (RS485) for sensors communication Data logger to router => wireless/wired Router to server => TCP/IP

Table 5. *Cont.*

Project	Aim	Characteristics	SM Technologies Used	Other Technologies
EnergyTIC	In-home energy management	Customer information about energy consumptions		
eSESH	Energy awareness and management	Remote adjustment of load by the DSO, Data visualization for electricity, gas, heating	NB-PLC, wireless (ZigBee)—first link, GPRS for second link	
Smart Build	Energy management in buildings	Collect data from sensors, meters and forward to control center via a hub		Wireless connections among sensors
SportE2	Energy management in Sport facilities buildings	Interfaces for control of cooling, heating, lighting, Deployment of Sensor network	PLC, wireless (ZigBee, GSM) for smart metering	Ethernet, ZigBee for sensor network
VERYSchool	Energy management in school buildings	Smart Metering to examine energy consumption, data forwarded to Database		
FINSENY	Energy management in buildings, monitoring and control of microgrids	Design ICT solution for integration of DER, Smart Metering for energy management	PLC (first link)—PRIME in some cases, GPRS (second link)	ZigBee for Home Network
Smartspaces	Energy saving in public buildings	ICT tools to observe and effectively manage energy consumption in public buildings	ZigBee, GSM/GPRS, Ethernet (first link—some cases)	
Encourage	Energy management in buildings	Optimise building energy consumption, communication with external buildings/utilities	Wireless: ZigBee, GPRS, WLAN	Within the building: ZigBee, 802.11n protocol, PLC HomePlugGreenPhy
Sunshine	Energy assessment of buildings	Reduce energy waste by heating/cooling, control public illumination based on AMR		

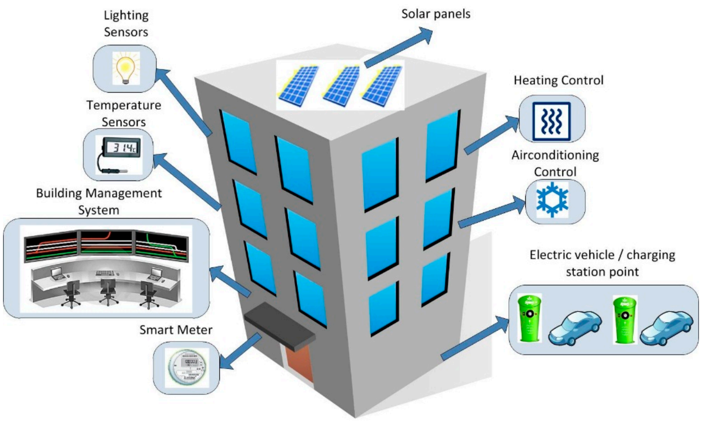

Figure 4. A smart building and its various energy management options.

4.4. *Other Projects for Energy Management through ICT Tools*

ICT tools and solutions have not only been examined in the concept of energy management of buildings/houses but also in terms of the energy performance optimisation in neighborhoods.

4.4.1. EEPOS

Such an example is the "EEPOS" project, which included participants from four countries. The project focused on energy management within the neighborhood and maximum utilisation of local distributed energy resources (DER) so as to have "energy positive" neighborhoods. The scope was to achieve energy management in a neighborhood level and to take advantage of the energy produced by RES, by load shifting to time peaks of their energy surplus. In general, when energy surplus was detected, it was intended to utilize this amount of energy wherever it was required within the neighborhood. The NEMS platform has been built to fulfill the project objectives. The information from houses/buildings has been transmitted to this platform, where data about weather conditions have also been registered. From the technological point of view, for the in-home network the ZigBee protocol was mainly used [92].

4.4.2. Cooperate

Another project that focused on energy positive neighborhoods is the "Cooperate", which included participants from four countries. The project dealt with neighborhood power and energy management through a platform. This cloud based service platform served for monitoring and control functions [93].

4.4.3. EPIC-HUB

The "EPIC-HUB" project, which involves participants from six countries, also deals with issues of improving the energy efficiency in neighborhoods through ICT tools. The port of Genoa, the airport of Belgrade and the exhibition center in Bilbao are the three main sites of the project. Monitoring of the energy produced and consumed and improving storage facilities as well as integrating RES are the main project objectives. The overall energy consumption monitoring is done through power meters located in the main substation through the GSM technology [94].

4.4.4. EDISON

ICT components and tools have been implemented in the "EDISON" project, in which a smart energy platform has been created that accommodates smart meters, sensors, actuators and power electronic devices. The project entails participants from five countries. Focus has been given on realising an efficient lighting system, in which sensors indicate when the lights should turn on and off in public buildings [95].

4.4.5. Smart City Kalundborg

The construction of a platform (hub) has been the subject of the "Smart City Kalundborg" project, which entailed participants of two countries. The platform entailed user friendly energy services to people and businesses. The goal was to have selected demonstration sites connected to this hub with the appropriate technical equipment. Specific software has been used to observe data on energy production and consumption. Among others, solar panels and electric vehicles have been tested and renewable energy production and integration has been monitored [96].

4.4.6. The Houat and Hoedic Islands

Energy control and monitoring has been the target of "The Houat and Hoedic islands" project, led by the ERDF French energy supplier. It mostly involved a field test during which an Energy-Box (EBox) was installed in the consumers' homes for energy control [97].

4.4.7. Remarks on Projects for Energy Management through ICT Tools

Summing up the projects described in Subsection 4.4, it can be observed that there are three projects that, among others, offer energy management services through a platform (Cooperate, EDISON, Smart City Kalundborg), like monitoring and controlling energy production and consumption. The project Cooperate, in particular, examines energy management and improving energy efficiency at a neighborhood level, which is also a topic for EEPOS and EPIC-HUB projects. On the other hand, the Houat and Hoedic islands project involves energy control at the consumer's side. Table 6 summarizes the characteristics of the projects described in this subsection.

Table 6. Summary of projects for energy management through ICT tools.

Project	Aim	Characteristics	SM Technologies Used	Other Technologies
EEPOS	Neighborhood energy management	Max utilization of DER for "energy positive" neighborhoods, construction of NEMS platform		In-home network: ZigBee
Cooperate	Neighborhood energy management	Construction of a platform for monitoring functions of neighborhood energy		
EPIC-HUB	Improve energy efficiency in neighborhoods	Monitor energy, improve storage facilities, integrate RES, Smart meters in the substation	GSM (smart meter to control center)	
EDISON	Energy management through ICT tools	Construction of Smart Energy platform with smart meters, sensors, power electronic devices		
Smart City Kalundborg	Energy services to businesses through a platform	Observe energy production/consumption, monitor RES integration		
The Houat and Hoedic islands	Energy control and monitoring	Energy control in consumers' homes through Energy-Box		

4.5. Grid Management

4.5.1. PowerMatching City

Management of the energy and the grid in overall has been addressed by the "PowerMatching City" project carried out in The Netherlands. Its objective has been to depict the grid of the future. Therefore, smart appliances, smart meters, renewable sources and storage volumes have been integrated in the system. The scope has been to examine how the system would perform and how people would react to this initiative. It has been noticed that the various technologies provide flexibility and give the possibility for the system to expand, whereas the system itself could adapt to fluctuating consumer demands. A VPN network has been used for the communication requirements between the households and the central servers. Local connections are realized by a separate ADSL connection. Such connections could also be provided by a broadband internet connection [98].

4.5.2. PRICE

Another project that dealt with energy management and grid monitoring has been the "PRICE" project led by the Spanish distribution system operator (DSO) Iberdrola. Among others, automation and monitoring of the grid have been issues of investigation as well as grid energy management. In addition, a monitoring system has been implemented that enables end-users to better manage their consumptions. Therefore, smart appliances communicated with the so-called Energy Box (E-box), which played the role of the household energy manager. The technologies used for this are ZigBee and PLC [99].

4.5.3. STAmi

The LV network management by utilising smart metering information has been the topic of investigation of some projects, like the "STAmi" project. Its goal was to create a web interface to collect real-time data stored in smart meters and it has been realised by the Italian energy provider ENEL [100].

4.5.4. ISOLVES: PSSA-M

Another project that deals with similar issues is the "ISOLVES: PSSA-M" project that has been realised in Austria and it aimed at obtaining an "image" of the network by utilising smart meter data.

For this purpose, real-time measurements have been taken regarding the voltage, current, active and reactive power with the objective to depict the LV network and facilitate the integration of distributed energy into the network [101].

4.5.5. NINES

Energy and grid management are issues also addressed by the "NINES" project, carried out in the UK. The project aims at improving and stabilizing the electricity grid in the island of Shetland. Through the so-called "Active Network Management" system, the HV network can be monitored. Storage devices, like storage heaters and water tanks are introduced, while the usage of renewable energy sources is also addressed [102].

4.5.6. ELECTRA

Smart network management issues are dealt by the project "ELECTRA", which involves participants from 12 countries. Among others, the project's objectives focus on control schemes for smart grids that would control the frequency and voltage while renewable sources of electricity are increasing. In addition, the functional layer of monitoring and control systems is elaborated and the functionality of the future control room is to be addressed [103].

4.5.7. Smart Grid Vendee

The project "Smart Grid Vendee", which is run by the French DSO ERDF, also addressed smart network management and aimed at the optimisation of local distribution grids and the development of the necessary tools needed for grid management and management of distributed resources. In particular, the project entails the integration of energy produced by wind parks and PV panels and therefore, management at the transmission level is required. The project includes six wind farms, 30 PV sites, 350 EV stations, whereas at the distribution side, six primary substations and some hundreds of secondary substations. Regarding smart metering solutions, "Linky" smart meters are chosen, with 500 smart meters being installed [104].

4.5.8. Model City Manheim

Grid management and control from power generation to power consumption has been studied in the project "Model City Manheim", in Germany. One of the objectives is to accommodate fluctuating energy generation from renewable energy sources. At the customer side, an intelligent controller is used, in order to assure that the generated energy is consumed. This device has information about energy consumption characteristics of several devices and it helps the end-user to decide about the moment of their functionality even when he/she is absent. For this purpose, communication through IP is used for the interaction of the devices in the distribution network, while data is transmitted via broadband powerline technology through the electricity grid [105].

4.5.9. Smart Grid Hyllie

The "Smart Grid Hyllie" project, which is realized in Sweden, examines an energy monitoring system that optimizes the energy utilization. In addition, the integration of renewable energy production is facilitated through monitoring and measuring the power output. Through this project, Hyllie will become an energy efficient town district via the construction and operation of a large scale smart grid [106].

4.5.10. Nice Grid

Grid management and integration of renewable energy sources are issues also examined in the "Nice Grid" project that entails participants from France and Belgium. The project indicates the insertion and utilisation of photovoltaic arrays, storage units along with smart meters and smart software components for advanced grid management. For this scope, the "Linky" smart meters are selected [107].

4.5.11. e-GOTHAM

The project "e-GOTHAM", which involved participants from five countries, also addressed issues relating to grid management and integration of RES. The scope has been to divide the grid into micrograms with increased communication capabilities, which would enable collaboration between the different parts and with the overall power grid. Interoperability mechanisms have been addressed as well as algorithms for the coordination of the central and local controllers. The different elements under test, like prosumers, micro-grids, and hardware devices communicated through a middleware architecture, which has been constructed for the project's realization. The information exchanged has been formatted through the xml language. Semantic treatment of the information has taken place through a component of the middleware architecture, which has been specifically devoted for this scope. The project entailed also a Graphical User Interface through which the energy manager could configure energy sources and production plans in simulation algorithms, monitor and control maintenance plans, observe consumption data from smart meters installed in different locations [108,109].

4.5.12. Arrowhead

A project that deals with many smart grid topics and their interconnection is the "Arrowhead" project, which involves partners from 15 countries. In particular, it addresses issues relating to collaborative automation for five categories: production, smart buildings and infrastructures, electro-mobility, energy production and end-user services, virtual market of energy. Embedded devices play an important role in the whole project, while interoperability among services by almost any device is a topic of investigation [110]. With respect to smart buildings, Multi-resources smart meters (MSM) have been applied. These meters have not been installed at the consumers' homes, but in a lab environment. The consumption of the electrical devices has been monitored, whereas WiFi or Ethernet cables have been used for communication purposes [111].

4.5.13. Remarks on Projects for Grid Management

Grid management is a broad term and it can be a topic of investigation for many projects that perform different activities. In six of the projects analyzed in Subsection 4.5, grid management is examined, among others, in terms of energy monitoring and utilization of RES (ELECTRA, Smart Grid Vendee, Model City Manheim, Smart Grid Hyllie, Nice Grid, e-GOTHAM). The former project in particular examines control schemes for the smart grid, while RES increase. Projects PRICE and PowerMatching City deal among others with management of smart appliances, whereas the latter one has shown the system's ability to expand, while smart appliances, RES and storage units have been introduced. Grid stabilization in combination to storage units' introduction has been a topic of investigation for NINES project. Table 7 summarizes the projects discussed in this subsection.

Table 7. Summary of projects for Grid Management.

Project	Aim	Characteristics	SM Technologies Used	Other Technologies
PowerMatching City	Energy and grid management	Integration of Smart appliances, smart meters, RES, storage units		VPN network for communication between houses and central server, ADSL for local data connection
PRICE	Automation and monitoring of the grid	Smart appliances communicate with a user interface	PRIME (first link)	ZigBee, PLC for in-home communication
STAmi	LV network management	Creation of a web interface to collect smart meter data	Meters & More (first link)	
ISOLVES: PSSA-M	Network management through smart meter data	Real-time values of current, voltage and power are taken to depict the LV network		

Table 7. *Cont.*

Project	Aim	Characteristics	SM Technologies Used	Other Technologies
NINES	Improve and stabilize the electricity grid	HV network is monitored		
ELECTRA	Network management	Control schemes for smart grids that control frequency and voltage		
Smart Grid Vendee	Network management, integration of RES	6 wind farms, 30 PV sites, 350 EV, 6 primary substations, hundreds of secondary substations, 500 smart meters	G3-PLC technology (first link)	
Model City Manheim	Grid management, absorb energy from RES	Customer side: remote operation of electrical devices is managed through an intelligent controller		IP for remote command of the controller, BB-PLC for controller communication with devices
Smart Grid Hyllie	Optimising energy utilisation	Integration of RES via monitoring of power output		
Nice Grid	Integration of RES, Grid management	Utilisation of photovoltaic arrays, storage units, smart meters, smart software components	G3-PLC (first link)	
e-GOTHAM	Grid Management, Integration of RES	Dividing the grid into microgrids, algorithms for coordinating central and local controllers		Communication between
Arrowhead	Grid management	Collaborative Automation for: production, smart buildings, electromobility, end-user services, virtual market of energy	WiFi, Ethernet (Lab environment)	

4.6. Renewable Energy Sources—Integration and Monitoring

4.6.1. ECO-LIFE

The "ECO-LIFE" project, which involved participants from four countries, dealt with renewable energy production in houses and addresses the issue of balancing energy demand and supply at all times. For this purpose, low energy houses have been built and renewable energy sources have been inserted [112].

4.6.2. PV-NET

The "PV-NET" project targeted at promoting the use of RES and in particular the PV panels. It involves participants from six countries and it aimed at developing the most optimum PV net metering model, meaning that for each end user the net consumed electrical energy has been calculated by subtracting the energy produced by the photovoltaic systems. These net metering schemes have been optimized according to the area of application and to local pricing techniques [113].

4.6.3. i-EM

Monitoring of renewable energy plants and the smart grid in general, has been the topic of the project "i-EM" that took place in Italy. During this project, several products have been created for several purposes like: the smart grid management, the integration with renewable sources, monitoring of photovoltaic systems and the design and construction of renewable energy plants [114].

4.6.4. E-Harbours

Integration of renewable energy sources has also been the topic of the project "E-harbours", which aims at making energy systems more adaptable to renewables. It has focused especially on harbors and their wider industrial area. The goal has been to find flexibility in terms of energy in this environment, maximize the integration of renewable energy sources and exploit electric vehicles or other units for energy storage. Grid stability and exceed grid capacity are also issues, that have been examined [115].

4.6.5. Ashton Hayes Smart Village

The facilitation of the connection of micro-generation technologies, like photovoltaic panels and wind turbines on the LV network, along with network monitoring and analysis, has been the topic of investigation of the "Ashton Hayes Smart Village" project, which was carried out in the UK. The scope was to reduce the CO_2 emissions and increase the integration of renewable energy sources by power quality instruments in LV network and secondary substation power monitoring [116].

4.6.6. Stockholm Royal Seaport

A project that dealt with optimizing the resource consumption and the recycle solutions has been the "Stockholm royal Seaport", which took place in Sweden. Its goal was to turn the industrial port area into a "greener" place, where container and oil handling would be moved elsewhere. Recycle solutions, sustainable transport were some of the topics of investigation [117].

4.6.7. Remarks on Projects for RES—Integration and Monitoring

It can be observed that there are two projects that mainly focus on the integration of renewable energy sources for houses/end users (ECO-LIFE, PV-NET), whereas the Ashton Hayes Smart Village project mainly focuses on the integration of RES on the LV network. On the other hand, projects E-harbours and Stockholm royal Seaport aimed at the improvement of industrial areas, like harbors and how energy efficiency can be achieved. Figure 5 shows an example of renewable energy sources and their integration in the grid. Table 8 sums up the characteristics of the projects that focus on renewable energy sources, their integration and monitoring.

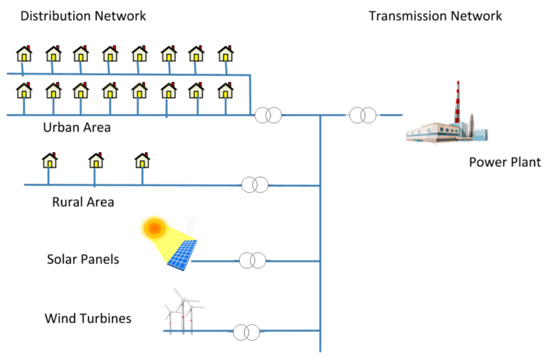

Figure 5. Integration of RES in the grid.

Table 8. Summary of projects for Renewable Energy Sources—Integration and Monitoring.

Project	Aim	Characteristics
ECO-LIFE	Balance energy demand and consumption—RES integration	Building of low-energy houses
PV-NET	RES usage	Installation of PV panels, Calculation of NET consumed energy
i-EM	Monitoring of RES	Design and construction of renewable energy plants, monitoring of PV systems
E-harbours	Integration of RES	Focus on harbors: maximize RES integration, EV as storage units
Ashton Hayes Smart Village	Integrate RES, reduce CO_2 emissions	PV panels and wind turbines inclusion in the LV network
Stockholm royal Seaport	Optimising resource consumption	Focus on industrial port area: recycle solutions, sustainable transport

4.7. LV and MV Monitoring and Management

4.7.1. Smartcity Malaga

A project that addresses issues like smart grid network management, smart metering and integration of RES is the "Smartcity Malaga" project that has been realised in Spain by the utility Endesa. The scope was to obtain a smart grid at all levels, both at the LV and the MV. Controlled meters have been installed in the LV and MV network for monitoring. In fact, an MV network of 40 km and 72 low/medium voltage centers have been monitored. The communication technology used for this MV network has been broadband PLC, while WiMax and 3G have been used as the complementary technology. All control centers and central offices have been interconnected with the MPLS protocol. With respect to the LV side of the network, smart metering solutions are used with the implementation of the Endesa smart meters, meaning that the NB-PLC has been used for the communication of the smart meters and in particular, the "Meters and More" technology. In addition, the MV distribution substations communicate with one or several HV substations through the access grid. Issues like energy storage and micro-generation have also been studied with the implementation of photovoltaic panels, wind turbines and electric vehicles. It is worth noting that the total renewable energy generation capacity reached the amount of 11 MW [118].

4.7.2. Sustainable

Another project that dealt with grid management has been the "SUSTAINABLE" project that had to do with the distribution network management and its real-time monitoring. The project involved participants from five countries. Two control levels have been implemented, an intermediate control level at the HV/MV primary substation and one at the MV/LV secondary substation. Smart meters have also been used for the project realization and mainly PRIME smart meters. However, for specific functionalities, like the voltage control functionality, smart meter communication has been achieved via GPRS [119].

4.7.3. Grid4EU

Grid monitoring from the LV as well as from the MV point of view are issues dealt with in the "Grid4EU" project. The project involves participants from six countries and it focuses on managing electricity supply and demand, while it facilitates the integration of decentralized energy resources in the MV network. The project entails 6 sites, where on most of them smart metering solutions are applied. The technology chosen depends on the site. In most cases PLC is preferred for data transferring from the smart meter to the data concentrator, thus PRIME, G3-PLC, Meters & More are used depending on the site. On the other hand, GPRS is selected for data transmission from the data concentrator to the control center. Connection between MV/LV substations and between an HV/MV and a MV/LV substation is realised through the substation (MV/LV) router. The communication is fulfilled through a wireless network or a system based on the MV power lines. The supervisory control and data acquisition (SCADA) technology andRemote Terminal Units (RTUs) are also used to complete the picture of LV and MV monitoring [120].

4.7.4. Discern

LV and MV monitoring is also the survey topic of the "DISCERN" project, which involves participants from five countries. The project deals with MV network automation and monitoring as well as LV monitoring plus measurement solutions for AMR. The PLC technology is primarily used for smart metering purposes and especially the PRIME technology. Some end user smart meters are connected to concentrators via GSM, GPRS or 3G, particularly when few customers are connected to the LV side of the transformer. Several methods are available for communication between the data concentrator and the AMR system, like PLC, GSM, GPRS, UMTS or the LTE. SCADA technology is also employed, whereas the MV points communicate through GSM [121].

4.7.5. Bidelek

The Bidelek project, realised in Spain and is led by the Spanish Iberdrola and the Basque Energy Agency, has to do with monitoring and automation of the MV network and the deployment of future substations. The project does not only include the implementation of smart meters, but it is also planned to configure 1100 transformer stations with various services, like remote management (250), remote management and supervision (700) and remote management plus automation and supervision (165) [122].

4.7.6. Remarks on Projects for LV and MV Monitoring and Management

Subsection 4.7 describes mainly the projects that apart from examining smart metering issues on the LV network, they also focus at a great extent on aspects of the MV grid, thus achieving LV and MV monitoring. In three of the projects we can find information about telecommunication technologies in the MV network. GSM is used for such purposes in DISCERN project, wireless connection is used between MV/LV substations in Grid4EU project, whereas more options are used in Smartcity Malaga project, like BB-PLC, WiMAX and 3G. In Bidelek project, substation automation, remote management and supervision issues are examined.

All of the projects involve smart meters implementation, whereas information can be found in four of them about smart meter technologies. NB-PLC technology is used in Smartcity Malaga, SUSTAINABLE, Grid4EU and DISCERN projects. Additionally, in Grid4U and DISCERN projects, wireless solutions are used for data transmission from the data concentrator to the control center. Particularly in the later project, it is reported that several technologies are used for both links of transmission, like NB-PLC, GSM, GPRS, 3G for the first link and PLC, GSM, GPRS, UMTS, LTE for the second link. Table 9 shows the characteristics of the projects discussed in this subsection. Figure 6 shows an example of monitoring options within a substation.

Table 9. Summary of projects for LV and MV monitoring and management.

Project	Aim	Characteristics	SM Technologies Used	Other Technologies
Smartcity Malaga	Smart Grid network management, LV and MV	MV and LV networks are monitored, data from all network points are transferred to control center	NB-PLC (Meters & More)	BB-PLC, WiMAX, 3G for data transmission in the MV network, MPLS for interconnection of control centers
SUSTAINABLE	Distribution network monitoring	Control levels at: HV/MV and MV/LV substations, Smart meters installed	NB-PLC—PRIME (some cases), GPRS (some cases)	
Grid4EU	LV and MV grid monitoring	Smart meters installation, connection between MV/LV substations and MV/LV—HV/MV substations, usage of RTUs and SCADA for grid monitoring	NB-PLC (first link) GPRS (second link)	Wireless connection between MV/LV substation and MV/LV—HV/MV
DISCERN	MV network monitoring and automation, LV monitoring	Smart meters installation, communication both in the LV and MV network	NB-PLC technologies—especially PRIME, GSM, GPRS, 3G (first link), PLC, GSM, GPRS, UMTS, LTE (second link)	GSM for communication in the MV network
Bidelek	Monitoring and automation of MV network	Configuration of 1100 transformer stations with various services		

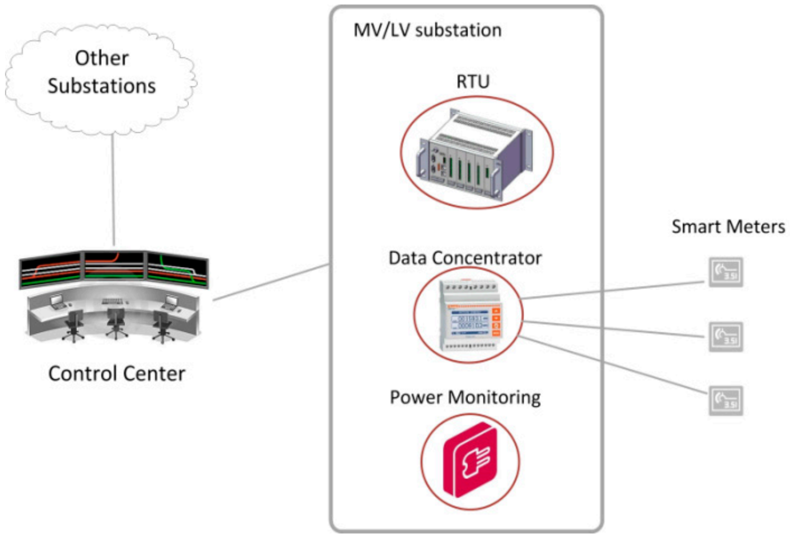

Figure 6. Monitoring options in a substation.

4.8. Consultation—Informative Projects

4.8.1. SGIH

Apart from the above-mentioned projects, there have been also others that have as a general scope to promote smart grid development through consultation and informative means. Such a project is the Smart Grid Innovation Hub (SGIH), with the aim of providing consultation support to each company. The overall objective is to develop innovative smart grid ideas in Ireland, reinforcing the use of low carbon energy sources and accommodating an increased number of RES [123].

4.8.2. SmartRegions

The "SmartRegions" project involved participants from eight countries and its goal was to provide information for policy and regulatory issues for the promotion of smart metering applications and to create a tool for analyzing the economic and social effect of smart metering services [124].

4.8.3. Meter-ON

Another project that aims at providing information to the stakeholders about smart metering solutions is the "Meter-ON" project. Participants from four countries took part in this project and the main objective has been to give information on smart metering options [125].

4.8.4. Remarks on Consultation—Informative Projects

As a conclusion, it can be said that two of the aforementioned projects focus mainly on providing information on smart metering options (SmartRegions and Meter-ON), whereas the third one (SGIH) provides mainly consultation support to each company for smart grid ideas. Table 10 summarizes the characteristics of the consultation projects.

Table 10. Summary of consultation projects.

Project	Aim	Characteristics
SGIH	Consultation support	Focus in Ireland: Reduce CO_2 emissions, Integrate RES
SmartRegions	Informative purpose for policy and regulatory issues	Creation of a tool for analyzing the economic, social effect of smart metering
Meter-ON	Consultation	Informative purposes to stakeholders about smart metering

4.9. Remarks—Technological Trends on Telecommunication Technologies

It can be concluded that there is a growing interest in the smart grid field, with an extended number of ongoing/realised projects. As it can be observed from our analysis presented in previous subsections, the telecommunication technologies listed in Section 2 are used for the smart grid projects' realization. Different technologies are used, depending on different objectives and goals of each project, different locations and different circumstances under which the technologies are tested.

Smart metering plays an important role on the smart grid as a whole. All of the projects described are directly or indirectly linked to smart metering applications. It is noteworthy that 26 of them have among their immediate goals smart meters' installation and utilisation. In general, the concept of the two telecommunication links is followed, as explained in Section 1. In 21 of the analysed projects, explicit information is found about the telecommunication technologies used regarding smart meter data transmission. Power Line Communications and specifically NB-PLC are popular solutions for the first link of transmission, since 15 out of these 21 projects use smart meters based on this technology. Wireless solutions are used by eight out of these 21 projects for data transmission from the smart meter to the data concentrator, whereas in four of the projects it is explicitly mentioned that both NB-PLC and wireless technologies are used. One factor for such a selection can be the topology of the site. Among the wireless options for the first transmission link, ZigBee is a popular solution along with GSM/GPRS. Regarding the second link of transmission, wireless options are the dominant solutions for the aforementioned projects, with GSM, GPRS, 3G being popular technologies for this purpose, since in 12 of the 21 projects information about the usage of such technologies can be explicitly found. More sophisticated solutions, like UMTS and LTE are mentioned in one project, whereas PLC is also found in one project for the second transmission link. As an alternative to these 21 projects, smart meter data transmission to the utility center through the customer's internet link is realised in another project.

Apart from smart metering data transmission, other telecommunication technologies are used for various purposes. In five of the projects analysed in the previous subsections, we can find information about in-home networks or communication networks within the building. The ZigBee protocol is utilized for such purposes in four out of these five projects, BB-PLC is chosen in two of them, whereas in one of them both BB-PLC and ZigBee are used. The HomePlug specification is mentioned in one of these projects (HomePlugGreenPhy) as well as the IEEE 802.11 protocol for communication issues within the building. The technologies used for sensor networks are explicitly mentioned in three of the projects examined in the previous subsections. ZigBee is the solution selected in two of these projects, whereas wireless connections are mentioned in another project. In one of these projects the usage of wired solutions is also mentioned along with ZigBee.

Another topic for which information can be extracted is the data transmission on the MV network. In 3 of the examined projects, the technological solutions for data transmission through the MV network are mentioned. In all of these three projects, wireless solutions are chosen, like GSM, WiMAX and 3G. In one of them, BB-PLC technology is also used along with the wireless solutions. It should be noted that in this work the examined projects that consider research on the MV field are the ones that involve also smart meter applications. However, telecommunication technologies used in the MV smart grid is an important topic for investigation and several relevant papers can be found in the literature. For example, wireless technologies (GSM, GPRS) are studied for grid monitoring and remote automatic grid reconfiguration in [126], whereas BB-PLC has been studied for the MV grid management and meter data gathering [127].

4.10. Remarks—Trends on the Smart Grid Research Field

By taking a closer look at the projects analysed in the previous subsections, some conclusions can be deducted regarding the topics that mostly attract the scientific interest in the smart grid field. It should be noted that all the projects selected to be examined in this survey involve directly or indirectly smart meter applications. The list of projects is not exhaustive. Other projects examining similar topics may have been realized.

Concerning the projects examined in this work, it can be concluded that focus is given to energy consumption reduction, for instance through consumptions monitoring and customer feedback. In 15 of the 50 examined projects energy consumption reduction issues are studied. Such research can involve in-home or building energy management and consumption reduction. It is also worth noting that four of these projects deal with energy services in public buildings, like schools and sport facilities. Smart metering for grid monitoring has been the topic for 6 of the projects listed in Section 4. In particular, their scope has been to obtain real-time data resulting in an accurate network depiction. In one of these projects, PMUs have also been utilized for this purpose, whereas another one of them addresses issues of identifying an electrical device by the consumption characteristics it entails.

The integration and monitoring of RES in the grid is the subject of research for 19 of the 50 projects examined in this survey. In five of them, renewable energy sources are constructed for the projects' scope, like for instance photovoltaic systems, energy plants or wind turbines. In addition, two of these 19 projects focus on improving industrial areas, like ports, in terms of energy efficiency.

Among the examined projects, there are two that study issues related to microgrids and one that focuses on energy consumption reduction for lighting. In addition, among the examined projects, there are three that focus on consultation purposes. Two of these three projects aim at providing with information regarding smart metering options and promoting smart metering applications, while the third one targets the smart grid development through consultation to companies. Although there are many projects that entail customer engagement, regarding energy consumptions, an issue that lacks attention are the effects, if any and at which extent, to human health caused by the automation of the grid. For example, the insertion of numerous wireless transceivers within the home or not, increases the total transmitted radiation. It would be interesting to inform the general public about such issues, thus potentially enhancing the overall active involvement of individuals.

It is noticeable that from the analysed projects, only in three of them it is explicitly stated that interoperability issues are addressed. Interoperability for smart metering applications is very important, since it assures the correct function of the smart metering system, even in case the end users change energy provider. In general, interoperability among devices guarantees that the operation of the entire system is not compromised in case these devices are replaced by others. For the correct operation of the future grid, interoperability issues will need to be overcome. Therefore, it is a topic that is expected to attract more the scientific interest.

As it can be concluded from our analysis, a topic on which special attention is given is grid and energy management, since 20 out of the 50 projects analysed, address such issues. Grid automation, optimization, stabilization and grid control are some of the issues examined in these projects. It is noticeable that 10 of these 20 projects deal also with the integration of RES in the grid, mostly in terms of utilizing the energy produced by RES in the most effective way and studying the effect of the energy distribution on the grid. In detail, one of these projects focuses on how the consumers could adjust their electrical device utilization according to generated energy from RES. Two of these 10 projects aim at achieving positive energy neighborhoods with an efficient integration of RES and one of them specifically refers to energy management in public areas, like ports and airports. In addition, four of these 20 projects address issues regarding the real-time LV and MV network monitoring, while another one is related only on MV network monitoring.

It should be noted that in our work, the projects analysed that deal with MV smart grid issues are only the ones that combine such activities with smart metering applications. In general, the MV network is an important part of the smart grid and there have been several projects with relevant research work. According to the smart grid projects list, as it is presented in [6], there are over 30 projects, where it is explicitly stated in the projects' description that MV aspects are examined. Such aspects would be: balancing the power in the system, while the integration of RES increases; remote control and MV system automation; network management; regulating bi-directional energy flow; installation of intelligent components; dealing with faults in the network; communications issues; substation control; automation, control and measuring equipment; voltage regulation issues. Analysing the projects that focus on the MV smart grid is out of the scope of this paper.

5. Conclusions

In this paper we performed a survey around the smart grid projects in Europe, with emphasis on the role of smart metering LV applications. Special focus has been given on the technologies chosen for the realisation of the smart grid projects with the scope of providing with information about the practical solutions chosen. In addition, we referred to the technological solutions adopted by several European countries in terms of their national smart meter roll-out. For reasons of completeness, the main characteristics of the available telecommunication technologies for the LV smart grid are also presented. To sum up, the following conclusions can be deducted:

- Smart meters are key components for energy management and saving. It is expected that around 200 million smart meters will be installed by the year 2020. There are more than 50 European projects that are directly or indirectly linked to smart metering applications.
- Two popular technologies for data transmission from the smart meter to the data concentrator are the ZigBee and NB-PLC technology. For data transmission to the control center from the concentrator, wireless cellular solutions are proved to be widely used.
- Other popular topics are the energy and grid management, the integration of RES, energy consumption reduction through smart homes/buildings. These topics have been mainly or partly the subject of research for the 40%, 38% and 30% respectively of the projects analysed.

Acknowledgments: The work of this paper has been supported by the Joint Research Center, European Commission.

Author Contributions: Gianluca Fulli had the idea of the paper. Nikoleta Andreadou and Miguel Olariaga Guardiola worked and wrote Section 2 of the paper. Nikoleta Andreadou worked on Sections 3 and 4 of the paper and wrote the rest of it. Miguel Olariaga Guardiola and Gianluca Fulli corrected and finalized the paper.

Conflicts of Interest: The authors declare no conflict of interest. The views expressed are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.

References and Notes

1. The Smart Grid: An Introduction. How a Smarter Grid Works as an Enabling Engine for Our Economy, Our Environment and Our Future. Available online: http://energy.gov/oe/downloads/smart-grid-introduction-0 (accessed on 8 January 2015).
2. Farhangi, H. The path of the smart grid. *IEEE Power Energy Mag.* **2010**, *8*, 18–28. [CrossRef]
3. CEN-CENELEC-ETSI Smart Grid Coordination Group. *SG-CG/M490/C_Smart Grid Reference Architecture, Annex F, Communication Architecture Version 3.0*; CEN-CENELEC: Brussels, Belgium, 2012; p. 55.
4. Ferreira, H.C.; Lampe, L.; Newbury, J. *Power Line Communications: Theory and Applications for Narrowband and Broadband Communications over Power Lines*; John Wiley & Sons Ltd.: Chichester, UK, 2010; pp. 1–6.
5. Gungor, V.C.; Sahin, D.; Kocak, T.; Ergüt, S.; Buccella, C. Smart Grid Technologies: Communication Technologies and Standards. *IEEE Trans. Ind. Inform.* **2011**, *7*, 529–539. [CrossRef]
6. Covrig, C.F.; Ardelean, M.; Vasiljevska, J.; Mengolini, A.; Fulli, G.; Amoiralis, E. *Smart Grid Projects Outlook 2014*; JRC Science and Policy Reports; European Commission: Brussels, Belgium, 2014; pp. 138–153.
7. Narrowband Powerline Communications: Applications and Challenges. Available online: https://elearning.renesas.com/file.php/1/CoursePDFs/DevCon_2012/Connectivity/2C05B_Baraboi_NarrowbandPowerlineCommunicationApplicationsandChallenges.pdf (accessed on 12 January 2015).
8. Galli, S.; Scaglione, A.; Wang, Z. For the Grid and Through the Grid: The Role of Power Line Communications in the Smart Grid. *IEEE Proc.* **2011**, *99*, 998–1027. [CrossRef]
9. G3-PLC Powerline Communication Standard for Today's Smart Grid presentation, G3-PLC Alliance. Available online: http://www.g3-plc.com/content/presentations (accessed on 14 January 2015).
10. PRIME Alliance Technical Working Group. *Draft Standard for PoweRline Intelligent Metering Evolution (PRIME)*; PRIME Alliance Technical Working Group: Brussels, Belgium, 2010.

11. Lower Layer Profile Using OFDM Modulation Type 2. Available online: http://www.erdf.fr/sites/default/files/documentation/G3_Specifications_%20low_%20layers.pdf (accessed on 15 January 2015).
12. Hoch, M. Comparison of PLC G3 and PRIME. In Proceedings of the IEEE International Symposium on Power Line Communications, Udine, Italy, 3–6 April 2011.
13. Oksman, V.; Zhang, J. G. HNEM: The new ITU-T standard on narrowband PLC technology. *IEEE Commun. Mag.* **2011**, *49*, 36–44. [CrossRef]
14. De Craemer, K.; Deconinck, G. Analysis of state-of-the-art smart metering communication standards. In Proceedings of the 5th Young Researchers' Symposium, Urbana-Champaign, IL, USA, 17 August 2010.
15. Smart Metering 2.0 Technologies, Meters and More Technology: Key Figures of a Success Story, Presentation. Available online: http://www.metersandmore.com/wp-content/uploads/2013/11/20131017-EUW-ITP-Meters-and-More.pdf (accessed on 16 January 2015).
16. Hrasnica, H.; Haidine, A.; Lehnert, R. *Broadband Powerline Communications—Network Design*; John Wiley & Sons: Chichester, UK, 2004; p. 19.
17. Varela Sanz, J.; García Martín, E. Open PLC European Research Alliance (OPERA) Project—Plenary session. In Proceedings of the IEEE International Symposium on Power Line Communications, Zaragosa, Spain, 31 March–2 April 2004.
18. Corral, G.; Selga, G.M.; Zaballos, A.; González-Tarragó, D.; Torres, L.M.; Haberler, B. Security in OPERA Specification Based PLC Systems. In Proceedings of the Advanced International Conference on Telecommunications (AICT), Barcelona, Spain, 9–15 May 2010; pp. 474–478.
19. Chen, Y.; Zhang, Q.; Ge, Y.; Hu, Y.; Chen, J.; Ding, N.; Zeng, X.; Huang, D. Algorithm and VLSI architecture of channel estimation impaired by impulsive noise in PLC. In Proceedings of the IEEE International Midwest Symposium on Circuits and Systems (MWSCAS), Columbus, OH, USA, 4–7 August 2013; pp. 932–935.
20. Sendin, A.; Pena, I.; Angueira, P. Strategies for Power Line Communications Smart Metering Network Deployment. *Energies* **2014**, *7*, 2377–2420. [CrossRef]
21. Hashiesh, F.; Soukal, P. A Proposed Broadband Power Line Communication System for Smart Grid Applications in a Typical Egyptian Network. In Proceedings of the Telecommunications Forum—TELFOR, Belgrade, Serbia, 24–26 November 2009; pp. 433–437.
22. Dominiak, S.; Andersson, L.; Maurer, M.; Sendin, A. Challenges of Broadband PLC for Medium Voltage Smart Grid Applications. In Proceedings of the Workshop on Power Line Communications (WSPLC), Rome, Italy, 20–21 September 2012.
23. Press Release on TIA-1113 Data Modem on Power Lines—Telecommunications Industry Association (TIA) Issues Standard for Data Modem Operating on Power Lines, TIA, Advancing Global Communications. Available online: http://ftp.tiaonline.org/TR-30/TR-30_MAIN/Public/2008%20Meetings/2008-07%20Arlington/00807005b%20Press%20Release%20on%20TIA-1113%20Data%20Modem%20on%20Power%20Lines.pdf (accessed on 2 February 2015).
24. Oksman, V.; Galli, S. G. hn: The New ITU-T Home Networking Standard. *IEEE Commun. Mag.* **2009**, *47*, 138–145. [CrossRef]
25. Digital Subscriber Line (DSL), SGIC—Smart Grid Information Clearing House. Available online: http://www.sgiclearinghouse.org/Technologies?q=node/2138 (accessed on 4 February 2015).
26. Communication technologies and networks for Smart Grid and Smart Metering—White Paper by CDG 450 Connectivity Special Interest Group. September 2013. Available online: https://www.cdg.org/resources/files/white_papers/CDG450SIG_Communication%20_Technologies_Networks_Smart_Grid_Smart_Metering_SEPT2013.pdf (accessed on 20 January 2015).
27. ZigBee Specification, ZigBee Alliance. 2008. Available online: http://home.deib.polimi.it/cesana/teaching/IoT/papers/ZigBee/ZigBeeSpec.pdf (accessed on 21 January 2015).
28. Parikh, P.P.; Kanabar, M.G.; Sidhu, T.S. Opportunities and challenges of wireless communication technologies for smart grid applications. In Proceedings of the IEEE Power and Energy Society General Meeting, Minneapolis, MN, USA, 25–29 July 2010; pp. 1–7.
29. Geelen, D.; Kempen, G.V.; Hoogstraten, F.V.; Liotta, A. A Wireless Mesh Communication Protocol for Smart-metering. In Proceedings of the IEEE Workshop on computing, Networking and Communications (ICNC), Maui, HI, USA, 30 January–2 February 2012; pp. 343–349.
30. Smart Grid Wireless Technology Comparison Chart, Aviat. Available online: http://blog.aviatnetworks.com/2011/06/17/smart-grid-wireless-technology-comparison-chart-z-card (accessed on 21 January 2015).

31. UMTS Long Term Evolution, (LTE)—Technology Introduction, Rohde & Schwarz. Available online: http://www.rohde-schwarz.com/en/applications/umts-long-term-evolution-lte-technology-introduction-application-note_56280-15658.html (accessed on 22 January 2015).
32. WiMAX, Wikipedia, the Free Encyclopedia. Available online: http://en.wikipedia.org/wiki/WiMAX (accessed on 22 January 2015).
33. WiMAX Forum. Whitepaper: Empowering the Smart Grid with WiMAX. 2010. Available online: http://resources.wimaxforum.org/sites/wimaxforum.org/files/document_library/SenzaFili_SmartGrid.pdf (accessed on 19 January 2015).
34. Margelis, G.; Piechocki, R.; Kaleshi, D.; Thomas, P. Low Throughput Networks for the IoT: Lessons learned from industrial implementations. In Proceedings of the IEEE 2nd World Forum on Internet of Things (WF-IoT), Milan, Italy, 14–16 December 2015; pp. 181–186.
35. Gozalvez, J. New 3GPP Standard for IoT. *IEEE Veh. Technol. Mag.* **2016**, *11*, 14–20. [CrossRef]
36. NB-IoT—Enabling New Business Opportunities, Huawei Whitepaper. Available online: http://www.huawei.com/minisite/hwmbbf15/img/nb-iot-white-paper-mbb-forum-2015.pdf (accessed on 14 March 2016).
37. Meters and More Open Technologies—Technology. Available online: http://www.metersandmore.com/technology/ (accessed on 20 January 2015).
38. Rogai, S.; Keynote, I. Telegestore Project Progresses and Results. In Proceedings of the IEEE International Symposium on Power Line communications and its Applications (ISPLC), Pisa, Italy, 26 March 2007; p. 1.
39. Smart Meters Europe: Iberdrola Rolls out over 4 m, Linky's Brittany Pilot. Available online: http://www.metering.com/smart-meters-europe-iberdrola-rolls-out-over-4m-linkys-brittany-pilot/ (accessed on 10 March 2016).
40. Iberdrola Awards One Million Smart Meters for Its Projects in Spain. Available online: http://www.iberdrola.es/press-room/press-releases/national-international/2012/detail/press-release/120316_NP_01_ContadoresInteligentes.html (accessed on 10 March 2016).
41. Endesa Reaches the Figure of 7 Million Smart Meters Installed. Available online: http://www.endesa.com/en/saladeprensa/noticias/Endesa7MillionSmartMeters (accessed on 10 March 2016).
42. Smartgrid or the Intelligent Network. Available online: http://www.erdf.fr/smartgrid-or-intelligent-network (accessed on 10 March 2016).
43. ERDF Has Chosen Landis + Gyr for Its First Step in the Deployment of Linky Meters. Available online: http://www.prnewswire.com/news-releases/erdf-has-chosen-landisgyr-for-its-first-step-in-the-deployment-of-linky-meters-274064481.html (accessed on 10 March 2016).
44. Smart Meter: ERDF Ensures Linky Modules are "Made in France". Available online: http://www.metering.com/smart-meter-erdf-ensures-linky-modules-are-made-in-france/ (accessed on 11 March 2016).
45. Linky Project—Presentation, Joint EURELECTRIC-ESMIG Workshop. Available online: http://esmig.eu/sites/default/files/presentation_by_pierre_mallet.pdf (accessed on 10 March 2016).
46. Smart Metering Equipment Technical Specifications, Smart Metering Implementation Programme. Available online: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/299395/smets.pdf (accessed on 9 March 2016).
47. Explanatory Document to Support the Designation of the First Version of the Smart Metering Equipment Technical Specifications (SMETS 1), Smart Metering Implementation Programme. Available online: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65685/7339-exp-doc-support-smets1.pdf (accessed on 9 March 2016).
48. Smart Metering Equipment Technical Specifications—Version 2, Smart Metering Implementation Programme. Available online: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/68898/smart_meters_equipment_technical_spec_version_2.pdf (accessed on 9 March 2016).
49. Government Response to the Consultation on the Second Version of the Smart Metering Equipment Technical Specifications—Version 2; Smart Metering Implementation Programme. Available online: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/209840/SMIP_E2E_SMETS2_govt_consultation_response_part_2_final.pdf (accessed on 9 March 2016).
50. ScottishPower Trials Smart Meters in "Hard to Reach" Areas, ComputerWorld UK. Available online: http://www.computerworlduk.com/news/public-sector/3400106/scottishpower-trials-smart-meters-in-hard-to-reach-areas/ (accessed on 26 January 2015).

51. GE Smart Meters Make UK Community More Energy Efficient. 2011. Available online: http://www.businesswire.com/news/home/20110602005911/en/GE-Smart-Meters-UK-Community-Energy-Efficient (accessed on 27 January 2015).
52. UK Power Networks. *Low Carbon London Project Progress Report*; UK Power Networks: London, UK, 2014.
53. What Are Smart Meters? Transforming How We Interact with Energy. Available online: http://www.britishgas.co.uk/smarter-living/control-energy/smart-meters/what-are-smart-meters.html (accessed on 25 January 2015).
54. Opening the German Smart Meter Market; Greentechgrid. 2012; Available online: http://www.greentechmedia.com/articles/read/opening-the-german-smart-meter-market (accessed on 4 February 2015).
55. 10.000 Smart-Meter-Programm in Bayern, Effiziente Energiesysteme. Available online: http://www.effiziente-energiesysteme.de/projektlotse/eon-pilotprojekt-10000-smart-meter-programm-in-bayern.html (accessed on 6 February 2015). (In German)
56. R & D Project "Mülheim's into Metering": Largest Smart Meter Field Test throughout Germany with More Than 100,000 Devices Completed—Accompanying Scientific Research Study Presents Results. Available online: http://www.rwe.com/web/cms/mediablob/en/2032054/data/238130/5/rwe/innovation/projects-technologies/energy-application/smartmeter/Results-of-accompanying-research.pdf (accessed on 5 February 2015).
57. Ihr Intelligenter Stromzähler, Ihr Online-Handbuch für den Intelligenten Stromzähler. Available online: https://www.enbw.com/media/privatkunden/docs/tarife-und-produkte/online-handbuch-isz.pdf (accessed on 10 May 2016). (In German)
58. Yello Strom Uses Microsoft technology for the Yello Sparzähler, Microsoft Newsroom. Available online: https://news.microsoft.com/de-de/?s=Yello+Strom+Uses+Microsoft+technology#sm.0000j5wqj4ny5cnazmf1c77k5ocki (accessed on 6 February 2015).
59. In Germany, Yello Strom Meter Does More than Measure. Available online: https://www.microsoft.com/spain/medioambiente/software_showcase/articles/yello_strom.aspx (accessed on 10 May 2016).
60. Smart Meter Pilot Project in Berlin: Vattenfall, Device and GreenPocket Realize Live Presentation of Smart Metering Data. Available online: http://www.greenpocket.de/en/wp-content/uploads/2010/06/PM_100928_englisch.pdf (accessed on 5 February 2015).
61. Vattenfall Testet Devolo G3-PLC: Erfolgreicher Feldtest in Berlin Unterstreicht die Praxistauglichke, Nachrichten. *net—Informationen Rund um Die Uhr*. Available online: http://www.nachrichten.net/details/199806/Vattenfall_testet_devolo_G3_PLC_Erfolgreicher_Feldtest_in_Berlin_unterstreicht_die_Praxistauglichkeit_von_Access_Powerline_im_150_500_kHz_Bereich.html (accessed on 5 February 2015). (In German)
62. Andresen, T. Technical and Economic Aspects of Remote Data Transmission Ways for Smart Metering. Master's Thesis, Department of Energy and Environment, Chalmers University of Technology, Ratingen, Germany, 2009.
63. Vattenfall's Deployment of Echelon's NES System—An Industry Benchmark, Metering.com, August 2009. Available online: http://www.metering.com/vattenfall-s-deployment-of-echelon-s-nes-system-an-industry-benchmark/ (accessed on 9 February 2015).
64. Smart Meter Roll out Experiences from Vattenfall. Available online: http://www.eurelectric.org/media/68816/soderbom.pdf (accessed on 10 February 2015).
65. MTR 1020 Series, IEC Single Phase Smart Meters, A Proven Residential Smart Meter and Powerful Grid Sensor All-in-One. Available online: http://www.echelon.com/assets/bltdba4e7c638879d4c/Smart-Meter-MTR-1020-IEC-Single-Phase-datasheet.pdf (accessed on 9 March 2016).
66. MTR 5000 Series ANSI, Smart Meters. Available online: http://www.echelon.com/assets/blt6b8a91498df28864/Smart-Meter-MTR-5000-ANSI-datasheet.pdf (accessed on 9 March 2016).
67. Smart Grid Gotland—Electricity Network for the Future. Available online: http://www.smartgridgotland.se/eng/index.pab (accessed on 9 February 2015).
68. Key Technology: Smart Metering, E.on Website. Available online: http://www.eon.com/en/about-us/structure/company-finder/eon-metering-gmbh.html (accessed on 9 February 2015).

69. Lindmark, J.; Hakansson, M. Smart Grid Using 1st Generation AMR Meters—An Operational View. In Proceedings of the International Conference on Electricity Distribution (CIRED), Stockholm, Sweden, 10–13 June 2013; pp. 1–4.
70. Fortum Deploys Automatic Meter Management Across 860,000 Customers in Sweden, Capgemini—Consulting, Technology, Outsourcing. Available online: http://www.fr.capgemini.com/resource-file-access/resource/pdf/ss_Fortum_Deploys_Automatic_Meter_Management_Across_860_000_Customers_in_Sweden.pdf (accessed on 10 February 2015).
71. Information Security for the Future Smart grid, Lecture Chalmers—Svenska Kraftnät April 2013. Available online: http://www.cse.chalmers.se/edu/year/2013/course/DAT285B/SLIDESNOTES/CyberSecGEricsson.pdf (accessed on 9 February 2015).
72. PLEEC—Planning for Energy Efficient Cities. Available online: http://www.pleecproject.eu/ (accessed on 10 February 2015).
73. Pilot Telemetering and Management System for the Electric Power Supply Demand by Residential and Small Commercial Consumers and Implementation of Smart Grids—Project's Technical description, HEDNO S.A. (Hellenic Electricity Distribution Network Operator S.A.). Available online: http://www.deddie.gr/el/diakirukseis/kanonismos-ergwn-promitheiwn-kai-upiresiwn-kepu (accessed on 12 February 2015). (In Greek)
74. InovGrid—Best Practices of Smart Metering Based End-User Services, Portugal: Automating the Energy Management (InovGrid Project). Available online: http://www.smartregions.net/default.asp?sivuID=28300 (accessed on 13 February 2015).
75. MeRegio Project Results—The Solution. Available online: http://www.meregio.de/en/index.php?page=solution (accessed on 13 February 2015).
76. Networks for a Low Carbon Community. LCN Fund Tier 1, Close Down Report. Smart Hooky; Western Power Distribution. 2013. Available online: http://www.westernpowerinnovation.co.uk/Document-library/2014/Tier-1-Hook-Norton-Close-Out-Report-Dec-2013-Final.aspx (accessed on 13 February 2015).
77. Energy Demand Research Project: Final Analysis. Available online: https://www.ofgem.gov.uk/publications-and-updates/energy-demand-research-project-final-analysis (accessed on 11 February 2015).
78. E2SG—Energy to Smart Grid Poster Presentation. 2013. Available online: http://www.e2sg-project.eu/ (accessed on 12 February 2015).
79. Using Wireless Smart Meter Networks for Power Quality Monitoring, Swedish ICT—SICS. Available online: https://www.sics.se/projects/nobel-neighbourhood-oriented-brokerage-electricity-monitoring-system (accessed on 25 February 2015).
80. Mirubee Project Description. 2011. Available online: http://mirubee.pswebshop.com/en/home/8-mirubox.html (accessed on 26 February 2015).
81. ICT-Based Service for Resource Saving in Social Housing, ICE-WISH Leaflet. 2011. Available online: http://www.ice-wish.eu/uk/dissemination/project-leaflet.asp (accessed on 26 February 2015).
82. Messervey, T.; Scotto, M.; Pestarino, A.; Decorme, R.; Buron, J.L.; Mardaras, J.; Dymarski, P.; Salmon, N.; Torres, I.; Landek, J.; *et al.* D6.2 Methodology for the Implementation of ICT-based Energy Efficiency Solutions targeted for European Social Housing—Version updated after the 3rd project review. E3SoHo Project, May 2013.
83. EnergyTIC: Technology, Information and Communication Services for Engaging Social Housing Residents in Energy and Water Efficiency, Factsheet: EnergyTIC, European Commission—Information Society Projects. Available online: http://ec.europa.eu/information_society/activities/sustainable_growth/funding/prj_buidings/index_en.htm (accessed on 25 February 2015).
84. Feltin, L.; Guillevic, F.; Danov, S.; Cobos, G.; Stieler, C.; Ruoff, E.; Schaffer, C.; Fabre, O.; Gomes, B.; Weihrauch, P.; Rossi, S.; *et al.* D3.2 eSESH Service Specification—Revision 2.0. Saving Energy in Social Housing with ICT, eSESH project, October 2011.
85. The Smart Build Project—Presentation, Smart Solutions Forum, PVSEC 2012, 2012. Available online: http://www.smartbuild.eu/images/pdf/downloads/SB_Pub01_WIP_SCaneva_SmartBuildProject.pdf (accessed on 18 February 2015).
86. Deliverable D 1.1—Performance Criteria and Requirements, Version 3, WP 1: Sport Facilities Energy Assessment & System Architecture. Energy Efficiency for European Sport Facilities, Sport E2 project, June 2013.

87. Galatà, A.; Andreoli, P.G.; Moneghan, P.; Kerrigan, R.; De Ferrari, A.; Uggè, A. D8.6 Mid-Term Exploitation Plan, Valuable EneRgY for a smart School, VERYSchool project, July 2013.
88. Privat, G.; John, D.; Socorro, R.; Dherbecout, Y.; Boëda, D.; Ploix, S.; Chatzipapadopoulos, F.; Lefkolikos, E.; Perdikeas, M.; Bella, V.; Lucio, J. D 4.3 Smart Building Functional Architecture. Future INternet for Smart ENergY, FINSENY project, March 2013.
89. Vogt, G.; Birov, S.; Renda, F.; Carbonell, J.; Milivojevic, A.; Savic, R.; Lazic, D.; Schuster-James, H.; Black, H.; Alsbury, S.; *et al.* Deliverable D1.2—Use Cases for SMARTSPACES services and systems. Saving Energy in Europe's Public Buildings using ICT, Smart spaces project. December 2012.
90. D3.1—Communication technologies and protocols, Project title: Embedded iNtelligent COntrols for bUildings with Renewable generAtion and storage. Embedded iNtelligent COntrols for bUildings with Renewable generAtion and storaGE, ENCOURAGE project, August 2012.
91. Schrenk, M.; Wasserburger, W.W.; Music, B.; Dörrzapf, L. SUNSHINE: Smart UrbaN ServIces for Higher eNergy Efficiency. In Proceedings of the GI_Forum, Rome, Italy, 20–23 May 2013; pp. 18–24.
92. Piira, K.; Pinto-Seppä, I.; Klebow, B.; Purvins, A.; Hildebrandt, D.; Pae, D.; Rasi, J.; Finnilä, T.; Judex, F. Requirements specifications & modelling approach for neighbourhood energy management information model, WP2 Report. Energy management and decision support systems for Energy POSitive neighbourhoods, EEPOS project, December 2012.
93. COOPERaTE—Control and Optimization for Energy Positive Neighbourhoods, Project Description. Available online: http://www.cooperate-fp7.eu/index.php/home.html (accessed on 17 February 2015).
94. D1.1 Operational Scenarios Requirements, version 2. Energy Positive Neighbourhoods Infrastructure Middleware based on Energy-Hub Concept, EPIC-HUB project, February 2014.
95. Celidonio, M.; Di Zenobio, D.; Fionda, E.; Pulcini, L.; Sergio, E. The EDISON Project: Enhanced Energy Saving Solution for Lighting using DC Power Supply. In Proceedings of the IEEE Online Conference on Green Communications (GreenCom), Piscataway, NJ, USA, 29–31 October 2013; pp. 143–149.
96. Smart City Kalundborg—About the Project. 2013. Available online: http://www.copcap.com/newslist/2012/smart-city-kalundborg-has-been-launched (accessed on 17 February 2015).
97. Mander, S.; Ghanem, D.A. D5.2 Key societal factors influencing the adoption of the ADDRESS Smart Grids architecture v1.0, Deliverable of the ADDRESS project. Active Distribution network with full integration of Demand and distributed energy RESourceS, ADDRESS project, May 2013.
98. Bliek, F.; van den Noort, A.; Roossien, B.; Kamphuis, R.; de Wit, J.; van der Velde, J.; Eijgelaar, M. PowerMatching City, a living lab smart grid demonstration. In Innovative Smart Grid Technologies Conference Europe (ISGT Europe), Gothenburg, Sweden, 11–13 October 2010; pp. 1–8.
99. D 1.2 Use Cases and the Pilot Test, PRICE-GDE Project—Executive Summary (PRICE Project, December 2014). Available online: http://www.priceproject.es/en/interesting-documents (accessed on 19 February 2015).
100. STAmi—Project Description (Smart Grid Project). Available online: http://en.openei.org/wiki/STAmi:_Advanced_Metering_Interface_%28Smart_Grid_Project%29 (accessed on 18 February 2015).
101. Bletterie, B.; Kadam, S.; Stifter, M.; Abart, A.; Burnier De Castro, D.; Brunner, H. Characterising LV Networks on the Basis of Smart Meter Data and Accurate Network Models. In Proceedings of the Integration of Renewables into the Distribution Grid Workshop (CIRED), Lisbon, Portugal, 29–30 May 2012; pp. 1–4.
102. Northern Isles Energy Solutions (NINES) Active Network Management (ANM) System: Enterprise Architect Use Case Models—Presentation, Scottish and Southern Energy, Power Distribution. 2009. Available online: http://www.ninessmartgrid.co.uk/wp-content/uploads/2013/11/Shetland-Active-Network-Management-System_Use-Cases_Sep20121-v-0.1.pdf (accessed on 17 February 2015).
103. About ELECTRA IRP, Project Structure. Available online: http://www.electrairp.eu/ (accessed on 19 February 2015).
104. ERDF: Leading smart grid research in France—Interview with Marc Boillot, Senior Vice President, Strategy and Project Development, ERDF. *Metering Int.* **2013**, *3*, 96–97.
105. The Moma Project (Model City Mannheim). Available online: http://www.gridinnovation-on-line.eu/Articles/Library/Model-City-Mannheim-Moma.kl (accessed on 16 February 2015).
106. Climate-Smart Hyllie—Testing the Sustainable Solutions of the Future, Informative Brochure. Available online: http://malmo.se/download/18.760b3241144f4d60d3b69cd/1397120343885/Hyllie+klimatkontrakt_broschyr_EN_2013.pdf (accessed on 16 February 2015).
107. Nice Grid—Project Description. Available online: http://www.nicegrid.fr/ (accessed on 17 February 2015).

108. Deliverable D8.4, Validation Report for Prototype 2 in the three pilots, e-GOTHAM project, September 2015.
109. Deliverable D3.2.2, Architecture implementation (version 2), e-GOTHAM project, April 2014.
110. Deliverable D 1.3 of Work Package 1: Generation 1 Demonstrations, Conclusions, and Perspectives. Available online: http://www.arrowhead.eu/wp-content/uploads/2013/03/Arrowhead-Deliverable-Pilot-WP1-D1.3-v1.4.pdf (accessed on 16 February 2015).
111. Arrowhead D2.3 Appendix 2.2a, POs related to Multi-resources Smart Meter, Arrowhead project, June 2014.
112. ECO-Life Project Description—Sustainable zero carbon ECO-town developments improving quality of life across EU. Available online: http://www.ecolife-project.eu/ (accessed on 24 February 2015).
113. Christoforidis, G.C.; Chrysochos, A.; Papagiannis, G.; Hatzipanayi, M.; Georghiou, G. Promotion of PV Energy through net metering optimization (PV-NET project). In Proceedings of the International Conference on Renewable Energy Research and Applications (ICRERA), Madrid, Spain, 20–23 October 2013; pp. 1117–1122.
114. Intelligence in Energy Management—i-EM Project Description. Available online: http://www.i-em.eu/ (accessed on 19 February 2015).
115. Verbeeck, J.; Kuijper, F.; Wellbrock, P.; Gray, D.; Gordon, R.; Skog, D.; Schreuder, J.; Kooistra, S. The e-harbours Journey, Point of Arrival: Smart Energy Networks in the North Sea Region. e-harbours Project Report, e-harbours project, February 2014.
116. Ashton Hayes Smart Village—Close down report. SP Energy Networks, Ashton Hayes Smart Village project, January 2011.
117. Stockholm Royal Seaport Innovation—Project Description. Available online: http://www.stockholmroyalseaport.com/en/about/#.VzNAKU1f0uU (accessed on 24 February 2015).
118. White Paper: Smart City Malaga—A Model of Sustainable Energy Management for Cities of the Future, Dirección General de Distribución de Endesa. Available online: http://www.endesa.com/EN/SALADEPRENSA/CENTRODOCUMENTAL/Publicaciones/Smartcity-Malaga_ENG.pdf (accessed on 20 February 2015).
119. Smart DistribUtion System OperaTion for MAximizing the INtegration of RenewABLE Generation—SUSTAINABLE Project Description. Available online: http://www.sustainableproject.eu/ (accessed on 19 February 2015).
120. gD4.1 & gD4.2 Guidelines for standards implementation, v1.0, GRID4EU—Innovation for Energy Networks. GRID4EU project, October 2012.
121. Deliverable (D) No: 6.1, Identification of the scenarios and distributed intelligence solutions. Distributed Intelligence for Cost-Effective and Reliable Distribution Network Operation, DISCERN project, June 2014.
122. Bidelek—Project description. Available online: http://bidelek.com/en/ (accessed on 20 February 2015).
123. Smart Grid Innovation Hub (SGIH)—Project Description. Available online: http://www.smartgridinnovate.com/aboutus/ (accessed on 19 February 2015).
124. Hierzinger, R.; Albu, M.; van Elburg, H.; Scott, A.J.; Łazicki, A.; Penttinen, L.; Puente, F.; Sæle, F. *European Smart Metering Landscape Report 2012*; Smart Regions Deliverable 2.1. 2013.
125. Urban, R.; Mauri, G.; Wasserburger, W.; Marcoci, A. D2.1 Analysis of Smart Metering Projects, v2.1. Meter ON Project, January 2014.
126. Kosmecki, M.; Swiderski, J. Smart Peninsula Project: Application of wireless communication for MV grid control and monitoring. In Proceedings of Power Engineering, Energy and Electrical Drives (POWERENG), Istanbul, Turkey, 13–17 May 2013; pp. 1821–1825.
127. Della Giustina, D.; Andersson, L.; Casirati, C.; Zanini, S.; Cremaschini, L. Testing the Broadband Power Line Communication for the Distribution Grid Management in a Real Operational Environment. In Proceedings of the International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM), Sorrento, Italy, 20–22 June 2012; pp. 785–789.

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