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Review

State of the Art and Trends Review of *Smart Metering* in Electricity Grids

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Abstract: Climate change, awareness of energy efficiency, new trends in electricity markets, the obsolescence of the actual electricity model, and the gradual conversion of consumers to *prosumer* profiles are the main agents of progressive change in electricity systems towards the *Smart Grid* paradigm. The introduction of multiple distributed generation and storage resources, with a strong involvement of renewable energies, exposes the necessity of advanced metering or *Smart Metering* systems, able to manage and control those distributed resources. Due to the heterogeneity of the *Smart Metering* systems and the specific features of each grid, it is easy to find in the related literature a wide range of solutions with different features. This work describes the key elements in a *Smart Metering* system and compiles the most employed technologies and standards as well as their main features. Since *Smart Metering* systems can perform jointly with other activities, these growing initiatives are also addressed. Finally, a revision of the main trends in *Smart Metering* uses and deployments worldwide is included.

Keywords: communication technologies; electricity grids; smart grid; *Smart Metering*

1. Introduction

The need to address metering issues arises practically at the same time as the development of distribution electricity grids. There is a remarkable evolution from the first known electricity meter, patented by Samuel Gardiner in 1872 [1], which only provided information about the length of the electricity current flow, to the up-to-date systems, which are able to provide a wide range of applications rather than just metering. The first automatic and commercialized remote meter is attributed to T. Paraskevakos in 1977 [2]. However, the remote metering concept was not realized in the expected electricity context for many years. Climate change, awareness of energy efficiency, new trends in electricity markets, and the gradual conversion of consumers towards more active agents are promoting not only the use of *Renewable Energy Resources* (*RES*), but also the *Distributed Generation* (*DG*) and *Distributed Storage* (*DS*), which urge a dramatic evolution of the actual electricity model. Evolution towards an electricity grid model able to manage numerous generation and storage devices in an efficient and decentralized manner determines the core of the *Smart Grid* (*SG*) concept, making the deployment of advanced metering systems or *Smart Metering* one of the basic techniques to reach this goal. The European Parliament, in the 2012/27/EC directive, defined a *Smart Metering* or intelligent metering system as "an electronic system that can measure energy consumption, providing more information than a conventional meter, and can transmit and receive data using a form of electronic communication" [3]. Regarding communication, *Machine-to-Machine* (*M2M*) communications happen in devices with capabilities to communicate among them without the need of human intervention. The captured event-driven data is sent through the communication channel (wired or wireless) to the servers in charge of extracting and processing the data and generating responses [4]. Therefore, *M2M* capabilities are key for *Smart Metering* performance, since they allow the required bidirectional communication between consuming points and monitoring and control centers [5].

Besides the control and management capabilities provided by the implementation of the *Smart Metering*, the obtained metering data together with additional information can be used by automatized systems to lead new applications, such as predictive and load management systems.

2. Trends of the *Smart Metering* Systems

The metering side of the distribution system has been the focus of most recent infrastructure investments. The first attempts at metering automatization, or *Automated Meter Reading* (*AMR*), allowed utilities to remotely read the consumption records and basic status information from customers' premises [6]. Due to its one-way communication system, *AMR* is limited to remote reading and cannot run additional applications, which prompted utilities to move towards the *Smart Metering* or *Advanced Metering Infrastructure* (*AMI*). *Smart Metering* provides utilities with bidirectional communication to the meter but also the ability of evaluating the status of the grid. Recent *Smart Metering* systems, equipped with an improved architecture, and working together with smart sensors and more sophisticated distributed control technology, allow utilities to perform grid control and management [7]. Figure 1 shows the evolution from *AMR* to *AMI* with lists of stakeholders and benefactors for each step.

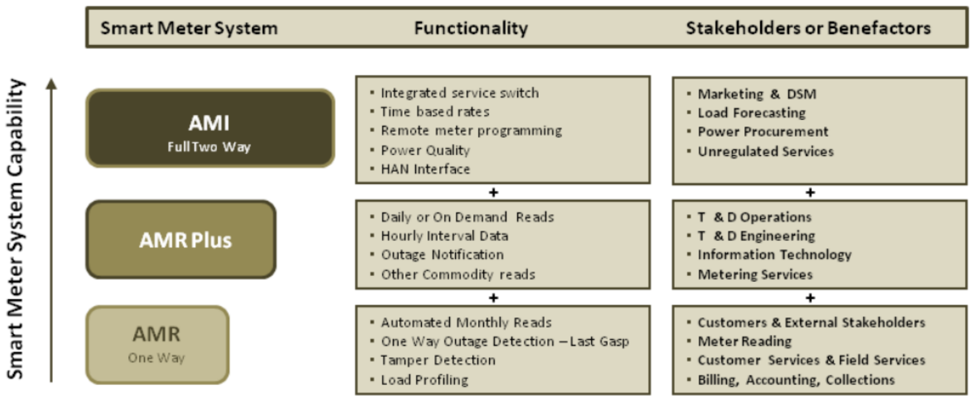

Figure 1. Evolution of *Smart Metering* [8]. Reprinted with the permission of the Edison Electric Institute, "Smart Meters and Smart Meter Systems: A Metering Industry Perspective", published by the Edison Electric Institute, 2011.

2.1. *Architecture of a Smart Metering System*

A *Smart Metering* system implies the deployment of a heterogeneous infrastructure, including metering devices, communication networks, and data gathering and processing systems, as well as the associated management and installation duties. A *Smart Metering* system is based on four main pillars:

- A *Smart Metering* device, *Smart Meter* (*SM*);
- A data gathering device, *Data Concentrator* (*DC*);
- A communication system used for data flow;
- A centralized management and control system, *Control Center* (*CC*).

Smart Metering systems are heterogeneous deployments with different requirements and features since they highly depend on the intended use. In addition, different types of measurement can be found in the same *Smart Metering* system. Three main measurement groups can be differentiated: (i) *on-demand*: measured data flows from the consuming points to the *CC*s upon specific request of the utility when needed; (ii) *scheduled:* measured data flows from the consuming points to the *CCs* by pre-programmed tasks and between four and six times a day per meter; and (iii) *bulk*: the utility collects metering information from all devices several times per day [9].

2.1.1. Smart Meter

The most recent evolution of the Smart Meter (*SM*) is based on the introduction of bidirectional capabilities and the progressive appearance of new applications. Bidirectional capabilities must be understood from two different points of view: *energy* (energy flows towards/from consumption/generation points, mainly due to the *DG*, *DS*, and prosumers figures) and *communication* (data travels from the *SM*s to the *CC*, but the *CC* can also communicate with them, as the *SM* includes an embedded communication node, within a configurable and multifunctional network).

An *SM* can present a wide range of features. Although there is not a directive or norm that defines them in terms of quantity or functionality, different bodies have established some guidelines. The *European Smart Meters Industry Group* (ESMIG) has reduced the minimum features of an *SM* to the following four:

- Remote reading
- Bidirectional communication
- Support of advanced tariff systems and billing applications
- Remote energy supply control.

On the other hand, the European Union extends the minimum desirable requirements for an electricity *SM* as published in 2012/148/EU recommendation, described in Table 1.

Table 1. Minimum requirements for electricity *SM*s according to 2012/148/EU recommendations.

2012/148/EU Recommendation
Consumer
Provide readings directly to the consumer and/or any third party.
Update the readings frequently enough to use energy saving schemes.
Metering Service Operator
Allow remote reading by the operator.
Provide bidirectional communication for maintenance and control.
Allow frequent enough readings to be used for networking planning.
Commercial Service Issues
Support advanced tariff system.
Allow remote ON/OFF control supply and/or flow or power limitation.
Security and Data Protection
Provide secure data communications.
Fraud prevention and detection.
Distributed Generation
Provide consumed, generated, and reactive metering data.

2.1.2. Data Concentrator

The main function of the *DC* is to gather metering data from the *SM*s. In addition, *DC*s are usually the master node of a communication subnetwork formed by itself and a set of *SM*s, which implies that they also include an embedded communication node. *DCs* are usually located inside *Power Transformers* (*PTs*) and substations. Modern *DCs* also include additional features such as *low-voltage* (*LV*) supervision, since they include an embedded *SM*.

2.1.3. Communication System

The transmission of data must be guaranteed in terms of quality, time, and security. Therefore, the communication technologies play a key role, as they have to be cost-efficient and should provide good coverage, security features, bandwidth, and power quality with the least possible number of repetitions [10]. Section 5 addresses the main challenges that the *Smart Metering* communication system must face. Communications in power grids have evolved from one-way communication systems and radial topology to bidirectional systems with network topology. A wide review of communication features, requirements, and technologies for *SG* and *Smart Metering* communication networks can be consulted in [11].

2.1.4. Control Centre

The *CC* or *Data Management System* (*DMS*) is in charge of receiving and storing the metering data for processing purposes. The *CC* can be seen as a modular system formed by the *Meter Data Management System* (*MDMS*), which manages the metering data, and additional secondary modules in charge of end-users applications, weather forecasting systems, geographical information systems, control applications, and load management, among others. The *MDMS* includes the tools that enable communication among different modules, as well as being in charge of validating, processing, and editing the metering data for a suitable information interchange among the different parts of the *Smart Metering* system [12]. *CCs* have evolved with the progressive increase of *Smart Metering* systems' capabilities from mere data compilers and storage devices, typical of *AMR* systems, to more sophisticated systems able to take decisions and manage the entire system in real time. Generated data from measurements is a very valuable resource for utilities, since they are able to make a wide range of forecasts (available energy, probability of power failures, customers' consumption predictions) by using predictive analysis, which enables utilities to take proactive action rather than simply reacting to events after they happen [13]. Making the most of information from *SM*s and *SG*s increasingly requires dealing with what is called *Big Data.* Diamantoulakis *et al.* present a roadmap of *Big Data* analytics in *Demand Energy Management* that includes, among other strategies, load patterns categorization, predictive analytics, distributed data mining, and cloud computing, to assess different aspects of the *SGs* that cannot be solved with conventional data processing techniques [14].

2.2. Considerations for a Smart Metering System

A *Smart Metering* system can be seen as three differentiated phases: planning, rollout, and operation. The widely ranging requirements and characteristics of each specific application, technology, and deployment scenario make the planning of a *Smart Metering* system a nontrivial task [15]. Table 2 summarizes some of the most important consideration to take into account when designing a *Smart Metering* system. The rollout phase refers to the actions involved in replacing all the meters included in the initial scope of the project. This phase also includes deploying the communication infrastructure, including all components and devices. Finally, the operation phase refers to actions carried out on the infrastructure after the rollout, that is, after the scheduled replacement, initial configuration of devices, and initial setup of the central system [16].

Table 2. Planning considerations for a *Smart Metering* system.

Planning Aspects	
Technological	Election of the most suitable technology according the final end Implementation of software
Physical aspects	Resilience and strength
Communication	Type of network (wired, wireless, hybrid) Range of network Bandwidth Quality of signal Security & privacy
Costs	Costs of devices Costs of communication network infrastructure Maintenance
Customers	Service providing Access to personal data

2.3. Smart Metering Applications

Beyond management and control, the implementation of a *Smart Metering* system allows several applications that join the metering data together with additional information and other devices from which both utilities and end-users should benefit. Most of them are currently under development and are experiencing a remarkable growth since 2006 [17]. A summary of the main *Smart Metering* applications is described below.

- Electricity signal quality:

In the traditional power distribution networks, the control devices are solely located in the substations; however, with the progressive introduction of the *SG*, the complexity and number of required controlled assets increase and more detailed, distributed, and frequent control information is required. *SM*s′ capabilities of real-time voltage measurement and communication between the consumers and network controllers are potential key players in voltage control [18]. Several projects implementing voltage control techniques include *SM*s in their solutions [19].

- *DG* and *DS* control:

The control and management of *DG*, especially regarding *RES*, is more complicated than conventional sources due to its less predictable behavior and varying availability. These uncertainties hinder *CCs*′ operations and represent a barrier for distributed resources in general. *SM*s can help in those issues by providing accurate, frequently-updated, and real-time generation and charge/discharge metering data from *DG* and *DS*, respectively, which may facilitate *CCs*′ duties and foster *RES*′ introduction in electricity grids.

- Billing:

Smart Metering systems are necessary in billing applications. The *SM*s get the tariff costs in real time, in advance or through pre-programmed tariffs and then the cost of the supplied energy is calculated. In addition, the *SM*s can remotely cut or restore the power supply if needed. The most common billing techniques are pricing depending on the time of use, real-time pricing, and peak consumption-dependent pricing [9].

- *Demand Response*:

The dynamic coordination of the power consumption curve of end-users within existing supplying conditions or *Demand Response* (*DR*) contributes to the efficiency of the system. Additionally, *DR* provides an opportunity for consumers to play a significant role in the operation of the electric grid by reducing or shifting their electricity usage during peak periods in response to time-based rates or other forms of financial incentives. Such programs can lower the cost of electricity in wholesale markets, and, in turn, lead to lower retail rates [20].

- HAN applications:

The role of *Smart Metering* in the end-user′s premises is very promising. From metering data consumers can know and control their electricity consumption. Additionally, a wide range of services is emerging, such as consuming profiles, load control, remote switching of home devices, and remote consumption monitoring, among others. For instance, in [21] the data from domestic energy consumption is used together with an algorithm to establish categories of energy consumers, while [22] contains an analysis of generated energy savings after the installation of *SM*s in Korean homes. Nevertheless, some energy managers are expected to play an important role in the progressive deployment of the *triple play* (confluence of audio, video, and Internet access).

- Anti-fraud techniques:

Bypassing or disrupting the internal performance of a *SM* and using methods to avoid electric bill payment are considered as electrical frauds. Several countries are developing anti-fraud techniques through *Smart Metering* systems. For instance, Depuru *et al.* present in [23] a complex system formed by *SM*s, harmonic generators, and filters that detect and warn users who commit fraud.

3. *Smart Metering* Technologies

The successful implementation of a *Smart Metering* system highly relies on the choice of communication technology. Different aspects such as the final application, the features of the location, and the topology electricity grid, among others, highly influence the choice of the most suitable technology. There is a wide range of available technologies for the communication network of a *Smart Metering* system; however, there is currently no communications technology that fits all needs and sometimes more than one technology is used in the same deployment [11,24,25]. Figure 2 shows a worldwide tendency for communication technologies from 2011 to 2020.

Two main groups can be distinguished in *Smart Metering* technologies*: wireless* and *wired*. Wireless technologies usually entail less deployment costs and quicker installation than wired options. Additionally, they are more suitable for remote or hardly accessible locations [26]. However, wired alternatives for *Smart Metering* do not present interference problems from other sensors of the network that may occur in wireless technologies. Table 3 summarizes the main technologies and their features for *Smart Metering* systems.

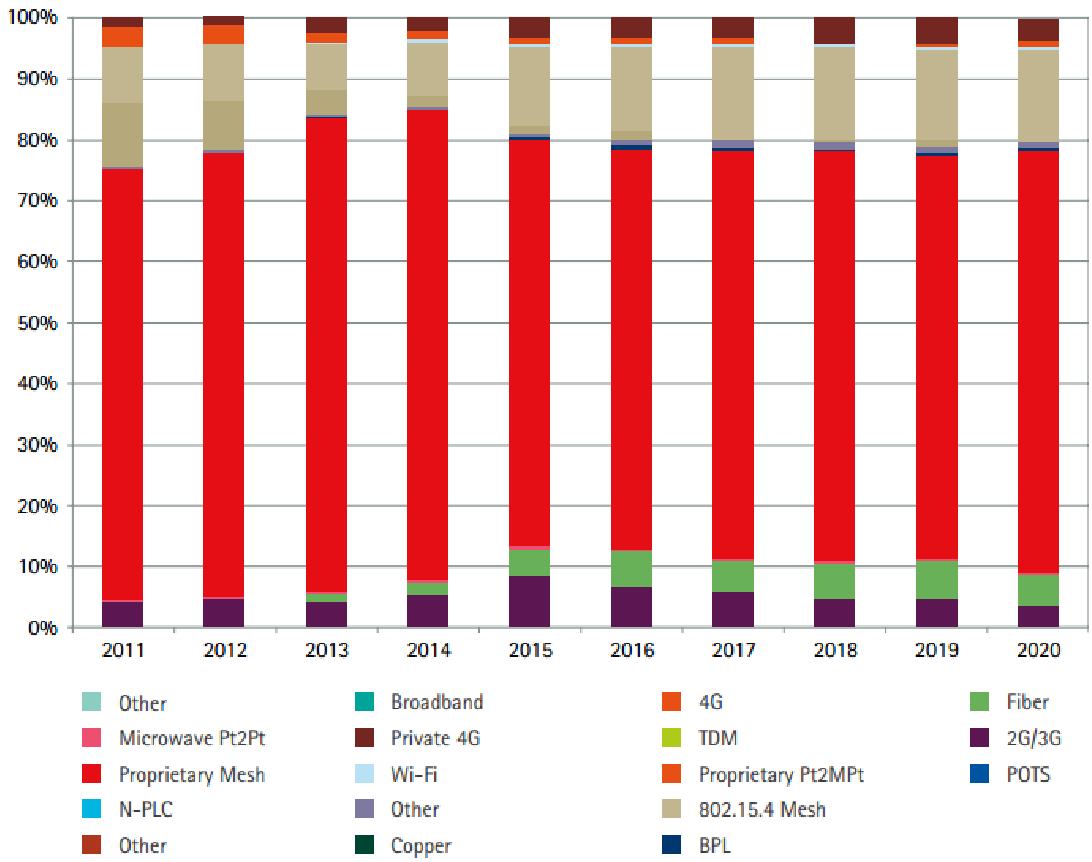

Figure 2. Communications node segmentation by technology, world markets, 2011–2020 (Source: Navigant Research [27]). Reprinted with the permission of Navigant Research, "Smart Grid Networking and Communications", published by Navigant Research, 2012.

Table 3. Main technologies and features for *Smart Metering* systems.

Wireless		Data Rate	Frequency Bands	Distance	Advantages	Drawbacks	Deployments/Projects
RF- Mesh		-	902–928 MHz	Depends on hops	Coverage can be increased with multiple hops. *Ad hoc* communication links formed dynamically.	Tends to be a proprietary offering. Performance decreases over long distances.	Most rollouts in USA
Cellular	3G–4G	60–240 kbps	824–894 MHz 1900 MHz	Up to 50 km	Wide-range coverage Low maintenance Low power consumption High flexibility	Individual connections are expensive. Moderate bit rates	China Southern Power Grid (CHN) Smart Grid Smart City (AUS) Essential Energy (AUS)
	GSM	14.4 kbps max.	900–1800 MHz	1–10 km			Telegestore (IT)
	GPRS	170 kbps max.	900–1800 MHz	1–10 km			PRICE-GEN (ES) Eandis and Infrax (BE) Linky (FR)
IEEE 802.15 Group	ZigBee	20–250 kbps	868 MHz/915 MHz/2.4 GHz	10–1000 m	Low cost Low power consumption	Low bit rates Security issues (specially Bluetooth)	Energy Demand Research Project, EDRP (UK) National *Smart Metering* Programme, NSMP (IRL)
	6LoWPAN						
	Bluetooth	721 kbps	2.4–2.4835 GHz	1–100 m			
IEEE 802.11 Group	Wi-Fi	54 Mbps max.	2.4 GHz/5.8 GHz	Up to 100 m	High degree of reliability and availability	Affected by surrounding emitting devices	CMP *AMI* (US) National *Smart Metering* Programme, NSMP (IRL)
	Enhanced Wi-Fi	54 Mbps max.	2.4 GHz				
	IEEE 802.11 n	600 Mbps max.	2.4 GHz				
IEEE 802.16	WiMAX	70 Mbps	1.8–3.65 GHz	50 km	Good performance over larger distances Able to supply thousands of end-users	Higher costs than similar technologies	Victorian Smart Meter Rollout (AUS)
Wired		**Data Rate**	**Frequency Bands**	**Distance**	**Advantages**	**Drawbacks**	**Deployments/Projects**
NB-PLC		up to 500 kbps	3–500 kHz	Several km	Medium already deployed Devices do not depend on batteries.	Power cables are a harsh medium for communications.	Most rollouts in Europe and China Telegestore (IT) Woodruff Electric Cooperative (USA) Pacific Northwest Boulder SmartCityGrid (US) PRICE-GEN (ES) Eandis and Infrax (BE) Linky (FR) Energy Demand Research Project, EDRP (UK)
BB-PLC		Up to several hundred of Mbps	1.8–250 MHz	Several km			
xDSL	ADSL	800 kbps upstream 8 Mbps downstream	From 25 kHz to 1 MHz	5 km	Medium already deployed Quite high data rates	High maintenance costs Efficiency decreases with distance	PRICE-GEN (ES) Eandis and Infrax (BE)
	HDSL	2 Mbps		3.6 km			
	VHDSL	15–100 Mbps		1.5 km			
Euridis	IEC 62056-31	9.6 kbps	80 MHz–1 GHz	Hundreds m	Low cost Known technology	Low data rates	Wide rollout of SMs in France
PON		155–2.5 Gbps	500 MHz-km	60 km	High data rates Noise immunity Good performance over km	High cost	Boulder SmartCityGrid (US) PRICE-GEN (ES) Austin (US)

Radio Frequency (*RF*) technologies for *Smart Metering* deployments are specially spread in the United States. In *RF* technology, measurements and other data are transmitted by wireless radio from the *SM*s to a collection point. The data is then delivered to the *CC* for processing. The best-known topology is *RF mesh*, in which the *SM*s talk to each other and form a *Local Access Network* (*LAN*) cloud to a collector [8]. *RF mesh* has an acceptable latency and large bandwidth and generally operates at free license bands. In addition, the *self-healing* characteristic of the network enables the communication signals to find another route via the active nodes, if any node should drop out of the network [28]. However, this tends to be a proprietary offering and the terrain and long distances typical of rural areas are a challenge for its deployment.

It is common to find *RF-cellular* technologies used in *Smart Metering* deployments in the United States. Their strengths are the wide coverage and low maintenance costs that they offer. In addition, cellular technology has experienced a rapid growth, resulting in better bit rates and more potential applications.

However, individual connections are still expensive. Several U.S. carriers such as T-Mobile and Verizon have adopted *4G Long Term Evolution* (*LTE*) since the cost of upgrading the existing *3G* network is lower [11].

Despite the fact that most European countries use wired alternatives, cellular networks, especially *GPRS*, can also be found in some deployments [29]. *GPRS* is an open standard technology and an effective and reliable technology. Several trials performed in Cork (Ireland) with *SM*s using *GPRS* reported a good performance of this technology (success rate of 97.89% for first-time reads) and easy deployment [30]. However, the data rate is moderate.

Other wireless technologies such as *ZigBee*, *6LoWPAN*, and *Bluetooth* are based on *IEEE 802.15* standard [31]. These technologies are characterized by low bit rates, low power consumption, and low cost. *ZigBee* is a widely-known technology and the most used in domestic networks so far. It is considered a good option for *Smart Metering* and energy management due to its simplicity, mobility, robustness, low bandwidth requirements, and low cost of deployment [32]. However, the limited size of the devices that implement *ZigBee* restrict the battery life, the internal memory, and the processing capabilities. On the other hand, *6LoWPAN* uses the *Internet Protocol* (*IP*) over *WPAN* (*IPv6 over Low Power Wireless Personal Area Networks*). Since it is based on the same features as *ZigBee*, they compete with each other in the same market. The main advantage of *6LoWPAN* is that it identifies every node by means of an *IP* address, which allows ubiquity, versatility, and resilience [33]. As an example, Lu *et al.* present in [34] both a *ZigBee*-based and a *6LoWPAN*-based *SM* network architecture. Finally, *Bluetooth* is a low-power and short-range option, mostly used in local applications. It allows both point-to-point and point-to-multi-point configurations. Despite being less used, *Bluetooth* technology can be a possible option for communication of control signals and transmitting energy consumption data. Koay *et al.* proposed in [35] a *Bluetooth* based energy meter that can collect and transmit the energy consumption data wirelessly to a central base station. However, this provides a lower degree of security in comparison with other technologies [36].

Another family of standards is *IEEE 802.11* (see Table 3) or *Wireless Neighborhood Access Network* (*WNAN*), also known as *wireless Ethernet* [37]. They are technologies with a high degree of reliability and availability (although lower than wired options). However, the electromagnetic interferences affect their data rate and the radiofrequency that they emit may influence surrounding devices.

Finally, *Worldwide inter-operability for Microwave Access*, *WiMAX*, comes from *IEEE 802.16* standard for *Wireless Metropolitan Area Networks* (*WMAN*) and is a complementary technology to *IEEE 802.11* standard. *WiMAX* is able to supply to thousands of end-users at larger distances and with better *QoS* systems [36]. Some U.S. companies are proposing *WiMAX* for *SG* solutions and *WiMAX* has also been used as a backhaul in a wide Smart Metering deployment in Australia [38]. However, it is still an expensive technology.

Among the existing wired technologies for *Smart Metering* systems, *Power Line Communication* (*PLC*) is one of the most widespread technologies and the most used in Europe and China [39]. A great advantage of *PLC* is that the communication channel is part of the electricity grid, and therefore it is already deployed. Additionally, transmitter devices do not depend on batteries since they use the power supply directly [40]. However, as the electricity grid was not conceived for data transmission, it is a harsh medium and communications are subject to disturbances due to spurious emissions and supra-harmonics from the devices connected to the grid (inverters, turbines, lamps, and appliance engines, among others) [36]. The *PLC* frequency bands differ from one region to another. In Europe, *PLC* is regulated by CENELEC and specifies four different bands: energy providers (standard and proprietary protocol), users (standard and proprietary protocol), users (*CSMA* access), and users (standard protocol) from 3 to 148.5 kHz. FCC regulates the ranges in the United States (10–490 kHz), ARIB in Japan (10–450 kHz), and EPRI in China (two bands from 3 to 500 kHz). Two main groups can be distinguished among *PLC* technologies: (i) *Broadband PLC* (*BB-PLC*), which uses frequencies up to 30 MHz and enables high data rates; and (ii) *Narrowband PLC* (*NB-PLC*), which uses frequencies up to 500 kHz and provides moderate data rates. *NB-PLC* is currently experiencing an expansion due to its good performance, a consequence of adapting advanced modulation techniques such as *OFDM*. Although its data rates are moderate, it is sufficient for *Smart Metering* applications. *NB-PLC* is especially popular in Europe, where nearly all countries have performed at least a pilot, and a wide range of deployments use this technology. Among *NB-PLC* standards it is worth mentioning *G3*, *PRIME*, and *IEEE 1901.2*. Poland and Spain have performed massive deployments using *PRIME* while Japan, France, and Luxembourg have used *G3*. Both *IEEE 1901.2* and *G3* offer "phase detection," a popular feature that allows the node coordinator of the network to determine on which phase a single-phase *SM* is connected. Then, the utility can balance the power demand across the three phases and improve the quality of the supply [41].

Digital Subscriber Line (*DSL*) is also a popular wired technology that uses the wires of the voice telephone network. Its main advantage is that in most cases the medium is already deployed and the data rates are quite high. Hence, some companies have chosen *DSL* technology for their *Smart Metering* projects, such as Stadtwerke Emden in Germany by Deutsche Telekom, where *DSL* is used to transmit the consumption information from customers' premises to the municipal utilities [42]. However, the maintenance cost of *DSL* is high and its efficiency decreases with distance.

It is worth mentioning *Euridis*, a low-cost solution, well known (it was first introduced in the early 1990s) and with a long history of deployment (approximately 6 million *SM*s worldwide use this technology). *Euridis* allows simultaneous access to up to 100 *SM*s connected in the same bus and it is considered the unique existing standardized interface for *Smart Metering* applications over twisted pair cable. It is part of the IEC 62056-31 standard [43]. A considerable number of *SM*s in France are equipped with a *Euridis* interface [44].

Finally, the fiber optic, well known for its very high data rates and noise immunity over several kilometers, has experienced a moderate expansion due the cost of deployment, especially if it is only used in the *SG* context. For this reason, its use in *Smart Metering* systems is limited to the Medium Voltage network and as a communication backbone in the transmission network by connecting *DCs* and *CCs*. *Passive Optical Networks* (*PONs*) are the most suitable option for *Smart Metering*, since they use optical splitters and one single fiber can serve several end-users.

Within the standardization process, it is worth noting the work conducted by CENELEC, which has developed more than 60 standards and has 40 more underway. Additionally, CENELEC has joined forces with CEN and *ETSI* (*European Telecommunications Standards Institute*), coming into the *Smart Meters Coordination Group* (*SM-CG*). In North America, it is worth mentioning the work developed by *ANSI* (*American National Standards Institute*) and *NIST* (*National Institute of Standards and Technology*), as well as *IEC* (*International Electrotechnical Commission*), *IEEE* (*Institute of Electrical and Electronics Engineers*), and *ISO* (*International Organization for Standardization*) on an international level.

4. Development of *Smart Metering* Worldwide

The deployment of *SM*s is on the rise worldwide: around 1000 million *SM*s are expected to be installed worldwide by 2022 [45]. Figure 3 represents the evolution of *SM* deployment worldwide from present to 2023. As discussed in Section 4, there is a wide range of available technologies and the most suitable one depends on a number of factors.

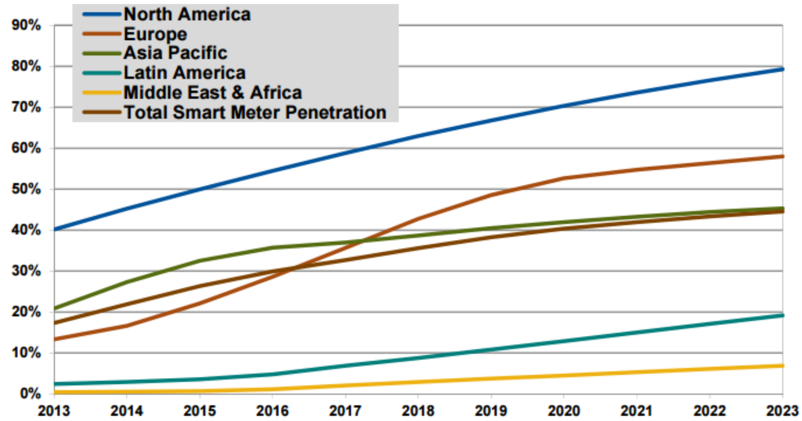

Figure 3. Evolution of *SM* deployment worldwide (Source: Navigant Research [45]). Reprinted with the permission of Navigant Research, "Smart Electric Meters, Advanced Metering Infrastructure, and Meter Communications: Global Market Analysis and Forecasts" published by Navigant Research, 2014.

The architecture of the electricity system highly influences the adopted approach for a *Smart Metering* solution. Hence, the topology of the network defines the topology of the *Smart Metering* system and may determine the equipment and the technology to be used. For example, while in the United States a single transformer serves a few end-users, in Europe it can easily reach several hundred. Then, *PLC* technology is more profitable in Europe than in the United States, where wireless solutions are more desirable. The drivers of the deployments also vary. While in some regions, especially in Europe, *SG* and *Smart Metering* projects have been driven by governmental initiatives, funding, or mandates, other regions seek to improve the efficiency of the energy supply system and eliminate electricity theft, as with emerging countries [46,47]. Additionally, it is worth mentioning the differences in development approaches. For instance, in the U.S. the goal is the security and stability of the electricity network, with a clear objective towards *self-healing*. By contrast, in European countries the trend is towards reduction of greenhouse gases and the promotion of *DG*, *DS*, and *RES* [48]. In addition, the regulation of public band frequencies use in the U.S. is more flexible than in Europe, which has reinforced wireless options in the U.S. Australia, Canada, and Japan have also largely adopted wireless *Smart Metering* solutions, while China relies on either *PLC* or *BPL*. In Europe, the strict regulation of public and unlicensed bands initially encouraged early adoption of *PLC* solutions. Despite recent concerns about *PLC* reliability, which have prompted European consideration of wireless options, *NB-PLC* technology is still the most widespread technology for *Smart Metering* systems in Europe with a wide range of existing pilot projects and massive deployments [41,46]. The early adoption of *PLC*-enabled *SM*s in Italy, Spain, and China has given this technology its current momentum. Meanwhile, cellular connectivity is witnessing a growing adoption, especially in cases where meter implementations are dispersed. It is also gaining wider acceptance as a feasible, primary connectivity technology, with subscription costs decreasing and utilities becoming more open to using public networks for their *SM* deployments [49].

There are also differences in the application approach of the *Smart Metering* systems. Among the European member states, the technical design of *Smart Metering* systems varies from one country to another. Generally, there is a common understanding of what capabilities a *SM* should have but often a subset of these capabilities is chosen for their rollout. A recent report from the *CEER* (*Council of European*

Energy Regulators) groups the most common functionalities of the *Smart Metering* system developed by European countries into five main categories: injected and consumed energy; energy interruptions; exceptional energy consumption; connection to open gateway; and possibility of software update [50]. In general, countries are more likely to have remote upgrade and the measurement of injected and consumed electricity than they are to have interruption alerts, exceptional usage alarms, or an open gateway for access and control of consumption. Apart from that, according to a recent survey from the *FERC* (*Federal Energy Regulatory Commission*), the uses of *Smart Metering* in the U.S. are more numerous: enhanced customer service; outage detection; theft detection and other line losses; outage restoration; remote connection/disconnection; power quality; asset management; outage mapping; load forecasting; remote change metering parameters; remotely upgraded firmware; price-responsive demand response; interface pre-pay; pricing/event notification; and *HAN* applications [17]. Enhanced customer service is the most commonly used service and there is an increased use of newer types of advanced metering functionality, especially the use of advanced metering to perform remote outage management and to remotely upgrade firmware on the advanced meters. The report also highlights the significant increase of *Smart Metering* penetration from 2006 in the United States.

The following subsections describe the aforementioned features by countries in the most remarkable projects and deployments worldwide.

4.1. Europe

Despite its relatively low starting point, *Smart Metering* deployments are currently especially successful in Europe, largely due to the legislation of many countries promoting, or even forcing, the replacement of old metering devices with *SMs*. In fact, legislation for electricity *SMs* is in place in the majority of the member states of the European Union, providing a legal framework for deployment and/or regulating specific matters such as a timeline of the rollout or setting technical specifications for the meters [51]. According to the European Commission, member states have committed to deploy 200 million *SMs* by 2020 (Electric Directive 2009/72/EC). This implies that more than 70% of end-users will be covered by Smart Grid technology [52]. Figure 4 shows the evolution of *SM* rollouts in European countries. In 2013, the total number of installed *SMs* was estimated at 61 million [53]. Figure 5 depicts an estimation of the total number of installed *SMs* in Europe by 2020. By mid-2012, there were about 90 *Smart Metering* pilot projects and national rollouts catalogued in Europe, the most important of which are listed below.

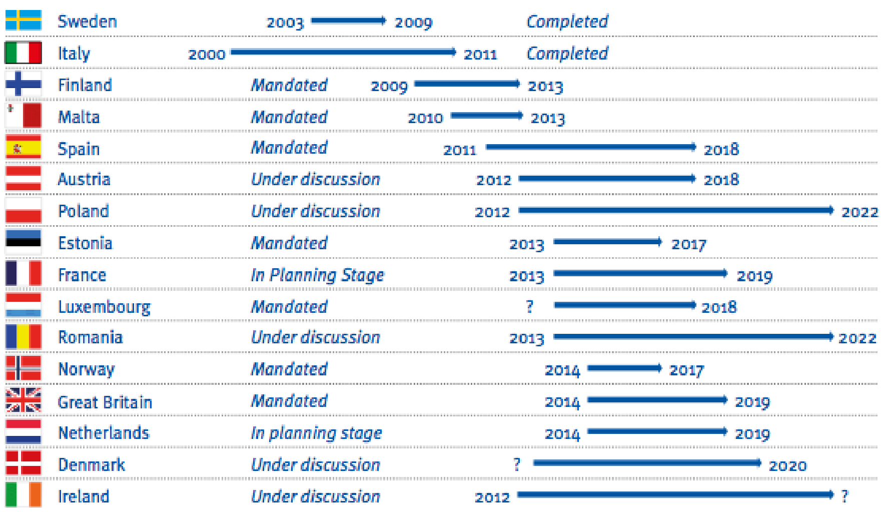

Figure 4. *SM* rollout status in Europe by country (Source: European Commission [52]). Reprinted with the permission of the European Commission, "Cost-benefit analyses & state of play of *Smart Metering* deployment in the EU-27", published by the European Commission, 2014. © European Union, 1998–2016.

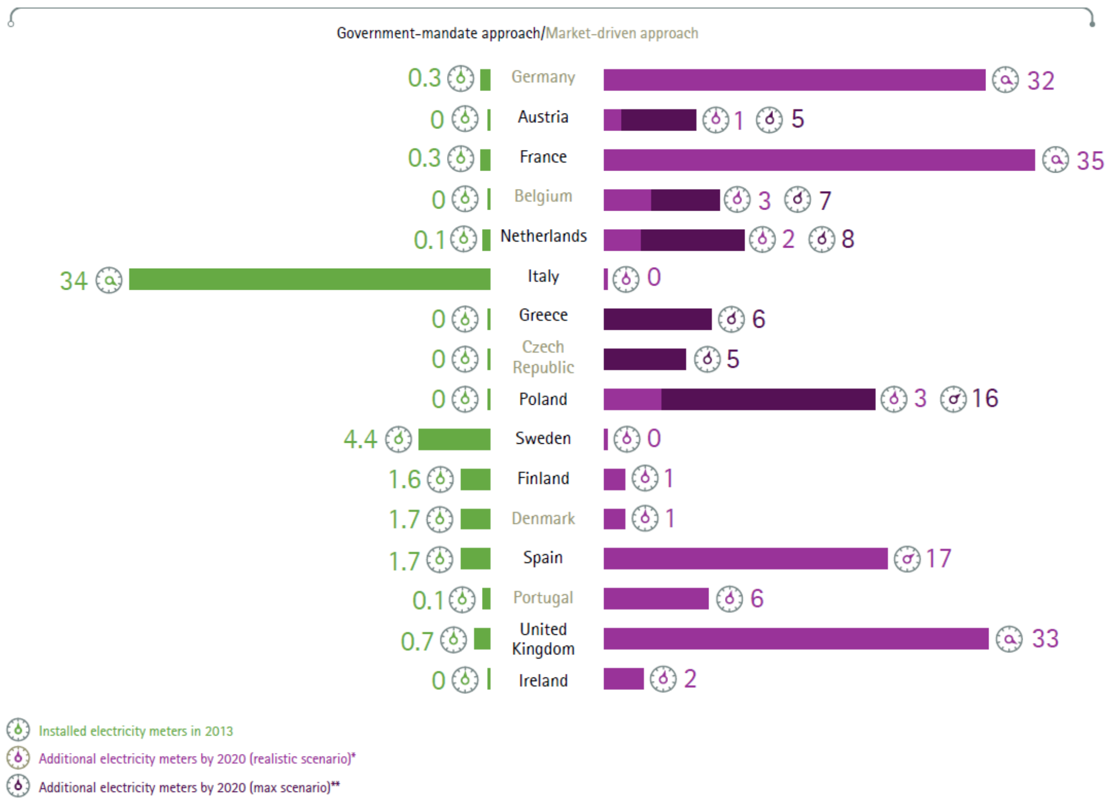

Figure 5. Estimation of the total number of *SM*s installed in Europe by 2020 (Source: Accenture [55]). Reprinted with the permission of Accenture, "Realizing the Full Potential of *Smart Metering*", published by Accenture, 2015.

Italy was one of the forerunners of *Smart Metering* in Europe, as the utility ENEL started deploying *SM*s in 2001 under the scope of the "*Telegestore*" project, which employs a combination of *PLC* (for communication between *SM*s and substations) and *GSM* (data gathering of *CC*s in the backbone). By the end of 2013 its rollout was almost complete (95% of costumers). It is also worth mentioning the "*Insernia*" project, with approximately 8000 installed *SM*s implementing *PLC*, which offers a new approach to demand response and aims at promoting distributed generation [54].

Also by 2013, Sweden was the only member state whose rollout was completed. However, there was no legal decision on the rollout of *SM*s itself; on the contrary, a legal decision was made to make monthly meter reading available to customers, which in turn led to a decision by distribution companies to roll out *SM*s in order to meet this requirement [50]. Sweden was a member of the "*EnergyWatch*" project together with Finland, whose purpose was to help utility consumers to gain awareness, change behavior, and reduce energy consumption and bills [54].

In the Netherlands, from 2012 until 2014 there was a small-scale rollout for experienced purposes. The Dutch parliament evaluated this pilot project and approved additional implementing regulation for the large-scale rollout of *SM*s from 2015, aiming to have an *SM* fitted in at least 80% of households and small businesses by 2020 [54]. Additionally, the utility Continuon started in 2006 a pilot project with the installation of 50,000 *SM*s implementing *PLC* technology, for both electricity and gas metering, while the company Oxxio started a similar project with *SM*s implementing *GSM/GPRS* [56].

The United Kingdom took its first steps towards *Smart Metering* in 2007 with the project "*Energy Demand Research Project*" (*EDRP*), with around 58,000 installed *SM*s, showing that the combination of an *SM* and in-home display made a real difference to the level of energy savings that people were able to make [57]. Later, in 2011, the U.K. government announced a mandate consisting on a full rollout of *SM*s by 2014 and running through 2019 to install 53 million *SM*s in

30 million homes and businesses. However, in 2013 the government announced that the *SM* rollout phase would be delayed until 2015 since the communication infrastructure needed further trial and testing [46].

France started a pilot smart meter program for a widespread deployment of 35 million *SMs* by 2020 [54]. The "*Linky*" project, led by ERDF, which employs around 250,000 *SMs* and 4600 *DCs*, aimed at improving knowledge of residential consumption through the combined effects of an appropriate customer panel and a modeling method adapted to more frequent reading of consumer indices [58].

Spain has also participated in the wide deployment of *SMs*: almost 2 million *SMs* by 2013 and a rollout of 100% by 2018, in compliance with a Royal Decree in 2007. A group of Spanish utility companies formed the "Spanish Utility Consortium" to establish the foundation of Spain's *SMs* rollout project in 2009 [59]. Two main technologies are present in the rollout: *PRIME* and *Meters and More.* While *PRIME* only can perform over power lines, *Meters and More* is able to work on power lines, public communication networks, and local optical links.

Although in Germany the installation of *SMs* has been mandatory after major renovations and in new buildings since 2010, there has not yet been an explicit commitment made to a national rollout. In fact, the rollout to existing homes (up to 500,000 *SMs* by mid-2012) has remained in a pilot phase. After a report of the Federal Ministry of Economics indicating the lack of economic benefits of a full rollout of *SMs* for German consumers, Germany has delayed it until at least 2020 [60]. To date, much of the focus has been on pilot projects and small-scale trials, of which five major projects were still ongoing in 2014 [54].

By 2014 Finnish utilities had completed their *SM* rollouts, covering 98% of all consumers, who now have access to their hourly consumption data through utility online information. In addition, utilities and other market players have introduced further new *Smart Metering*-based services and products, such as in-home displays, real-time feedback systems, demand response, and smart home products [54].

4.2. America

The Unites States leads the *SM* rollout in America, with a strong presence of *RF-mesh* technologies, followed by Canada, while deployments in most countries of Latin America have not started yet. Figure 6 depicts an estimation of the total number of *SMs* installed in North America by 2020.

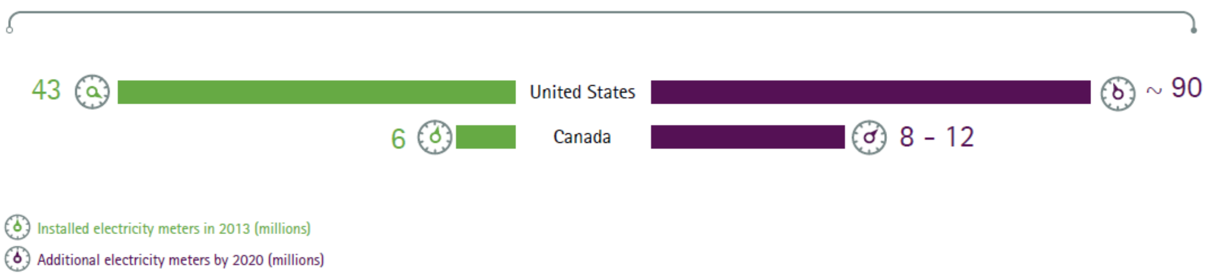

Figure 6. Estimation of the total number of *SMs* installed in North America by 2020 (Source: Accenture [55]). Reprinted with the permission of Accenture, "Realizing the Full Potential of *Smart Metering*", published by Accenture, 2015.

4.2.1. The United States

The largest driver of the rollout of *SMs* in the United States has been the *American Reinvestment and Recovery Act* (*ARRA*) program. With the end of *ARRA* funding, the installation of *SMs* is moving much more slowly than it did in 2009–2011 [46]. However, the deployment of *Smart Metering* solutions is still increasing: the Institute for Electric Innovation reported a total of 50.1 million *SMs* installed in 2014, which implies a penetration rate of 36.3% [61]. Most of the installed *SMs* are for residential use (43% of U.S. homes have an *SM*), since many U.S. commercial customers have long had *SMs* to monitor facility electricity usage more accurately. Applied technologies vary from *2G* and *3G* for end-users and *BB-PLC* for *HANs*. The evolution of installed *SMs* in the last five years can be seen in Figure 7.

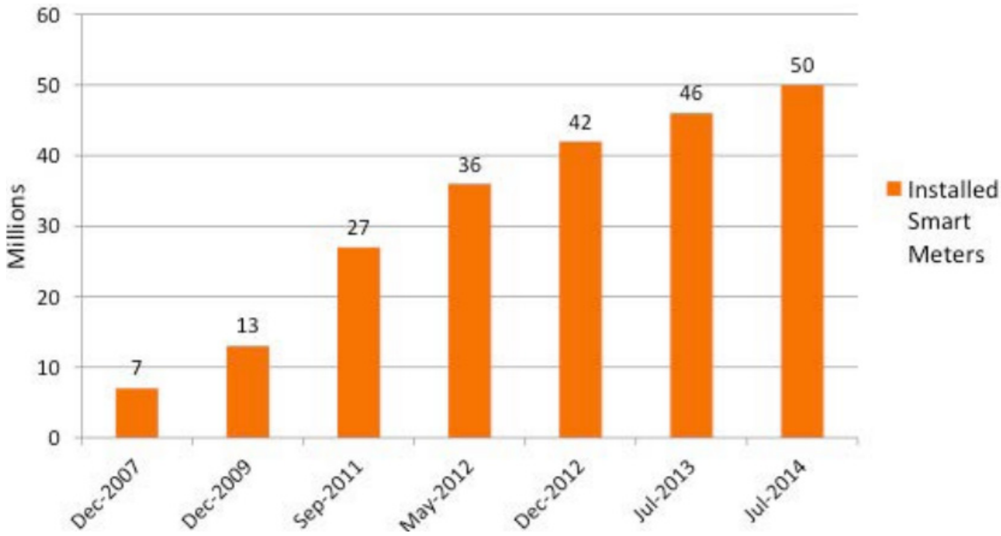

Figure 7. Evolution of *SMs* installed in recent years in the U.S. [62]. Reproduced with the permission of A. Cooper, "Utility-Scale Smart Meter Deployments: Building Block of the Evolving Power Grid"; published by Edison Foundation, 2014.

By 2014, more than 43 million out of the 50.1 million *SMs* were installed by investor-owned utilities, while almost 7 million were installed by municipal and cooperative-owned utilities. Among the *Smart Metering* systems performed by investor-owned utilities, 16 of them deployed more than 1 million *SMs*, according to a report published by the Institute for Electric Innovation [62]. The largest deployment was performed by Pacific Gas & Electric utility, with 5.14 million *SMs* equipped with *RF* mesh technology in 2013 as part of its *SmartMeter* Project. The main objectives of the deployment are: (i) customer service (customers with *SMs* can participate in a voluntary critical peak pricing rate plan that will help manage system load during hot summer days and receive notifications of when they are moving into higher-priced electricity tiers); (ii) demand response, focusing on energy efficiency and renewable energies; and (iii) setting a platform for future innovative solutions such as *HAN* services and *EV* appliances [63]. According to the project development report, the most challenging issue has been the coordination and integration with other enterprise initiatives that are part of the project [64]. Another large deployment started in 2007 and finished in 2012, consisting of almost 5 million installed *SMs* equipped with *ZigBee*, was performed in California under the *SmartConnect* program by the Southern California Edison utility. At present, the project offers different tariff rates to consumers. Several appliances and services such as energy storage, distributed control, and artificial intelligence are currently being developed and are expected to be ready by 2020. Specifically, the key roles of *SMs* in this project are: (i) enabling customers to actively participate in grid operations; (ii) allowing maximum access by third parties to the electric grid; (iii) promoting demand response, energy efficiency, and *DG* and *DS* into energy markets; and (iv) lowering the carbon footprint of the electric distribution system. The project reported some disgruntled responses from customers regarding remote supply disconnections and magnetic radiation emissions from *SMs* [65]. Two more *SM* deployments are over and above the 4 million installed *SMs*: the Florida Power and Light Company installed 4.6 million *RF* mesh-based *SMs* as part of its *Smart Meter* program to residential consumers in 2014. In addition to providing several services (such as monitoring their energy use by hour, day, and month as well as the energy they delivered to and received from the company) and reliable supply to customers, FPL plans involve the prediction and prevention of outages through the *SMs* and the deployment of monitors, sensors, and controls on their transmission and distribution grid [66]. On the other hand, the Southern

Company utility installed 4.2 million *SM*s equipped with *RF* mesh technology in 2014. The objective of the deployment integrates advanced metering, communications, and other appliances to provide customer service at reduced operating costs [62]. Other remarkable deployments are: Oncor utility with 3.3 million installed *RF*-based *SM*s and focused on customer services, power quality monitoring, reliability, and outage prevention [67]; and CenterPoint Energy utility, with 2.2 million *RF*-based *SM*s in 2012, with the aim of improving customer service and remote connections/disconnections and enhancing system reliability [68]. Additional *Smart Metering* deployments in the U.S. are discussed in [62].

U.S. utilities are now focused on integrating and optimizing information gathered by *SM*s to provide benefits and new capabilities to customers and system operators. Four main areas can be distinguished [62]:

- Systems integration: the introduction of outage and distribution management systems provides enhanced outage management and restoration services as well as improved distribution system and device monitoring.
- Integration of new resources: *SM*s position the grid as platform for the integration of distributed energy resources (DG, DS, EVs, microgrids, *etc.*).
- Operational savings: remote activities (reading, connection/disconnection) and the reduction of energy theft are some financial benefits of *SM*s.
- New customer services: *SM*s have enabled services to end-users such as automated budget assistance and bill management tools, energy use notifications, smart pricing, and demand response programs.

4.2.2. Canada

In contrast to other countries, whose *Smart Metering* initiatives have been highly promoted by governments and laws, in Canada they have also been driven by necessity: there are vast distances and hostile terrains separating power resources from consumers. In fact, Canada's *SG* technology is more advanced than that of most other nations [25]. As of June 2014 there were more than 6 million installed *SM*s and it is expected that two thirds of Canadian households will be equipped with *SM*s by 2016 [69]. Several provinces (Ontario, British Columbia, Saskatchewan, and Quebec) have already implemented or intend to implement a *SM* rollout [46]. To date, the Ontario *Smart Metering* initiative has been identified as one of the most successful deployments of Canada, with almost 4.5 million installed *SM*s. Initial *SM* testing involved *GSM* technology. Then, the utility decided to use radio mesh technology for most customers. The utility also deployed a *ZigBee HAN* within the *SM*s to communicate consumption data to market daily; however, they do not have remote connection and disconnection capability [38]. Along with *SM*s, the government introduced mandatory time-of-use pricing, making Ontario the largest electricity market in the world with mandated time-of-use rates and pilot programs at the start of the implementation showing peak savings of around 5%–8% [70]. However, a recent audit outlines some weaknesses of the deployment such as: (i) lack of cost-benefit study to support the deployment (as done in other provinces and also in Germany, Australia, and the U.K.); (ii) up to 73 distributed companies were in charge of the deployment, with the subsequent difficulty of ensuring a cost-effective implementation of *Smart Metering*. This situation also led to varied electricity billing amounts; (iii) the time-of-use pricing model has not had the expected impact on reducing peak demand since targets set by the Ministry of Energy have not been met; and (iv) complaints regarding time-of-use rates and billing errors have been reported [71].

Full rollouts of *SM*s are also taking place in British Columbia and Quebec. In 2011 BC Hydro initiated the *Smart Metering Program* in British Columbia as a first step towards modernizing BC's electricity grid, with approximately 1.8 million *SM*s equipped with *RF* technology installed in 2012. According to the utility, the *SM* deployment will detect and reduce energy theft, with subsequent energy savings, and will also enhance power outage control and provide new customer applications such as lower rates and customer money-saving tools [72]. On the other hand, Hydro-Quebec has already installed more than 2.7 million *RF*-based *SMs* and continues the rollout throughout Quebec, with an expected total number of 3.8 million *SMs* by 2017 [73]. The Canadian experience provides a great benchmark from which to learn, as it has already implemented *SMs* and time-of-use rates for millions of customers [70].

4.2.3. Latin America

The deployment of *Smart Metering* solutions in Latin America is still poor. Brazil and Mexico are currently the first potential markets and Argentina and Chile are also firm candidates for introducing *Smart Metering* solutions in the coming years [45].

The energy regulator in Brazil, ANEEL, replaced its ambitious goal of replacing all electricity meters with *SMs* in 2009 with a revised target of replacing 63 million by 2021 [74]. In 2012, ANEEL scaled down the *Smart Metering* rollout, making *SMs* mandatory only for new customers starting in 2014 and optional for existing consumers [46]. According to Brazilian utility companies, 4.5 million *SMs* are expected to be installed by 2017. The approach of Brazilian *Smart Metering* deployments is to help reduce fraud, electricity theft, and inefficiency, as occurs in other emerging countries, which cost the country close to $4 billion per year [47].

Mexico is the second-largest potential market for *SMs* in Latin America after Brazil, and is expected to have 21 million *SMs* installed by 2020 [74]. Many *SG* and *Smart Metering* pilot programs in Mexico are being boosted in an effort to respond to high rates of electricity theft, power outages, and poor energy infrastructure [46].

4.3. Asia-Pacific

China is by far the country with the largest number of installed *SMs* in the Asia-Pacific region and it is expected to almost double those figures by 2020. Japan has also performed several *SM* rollouts. The rest of the analyzed countries have also performed some deployments, but less numerous. *SM* rollouts in India are expected to increase in the coming years. Figure 8 depicts an estimation of the total number of *SMs* in installed Asia-Pacific countries by 2020.

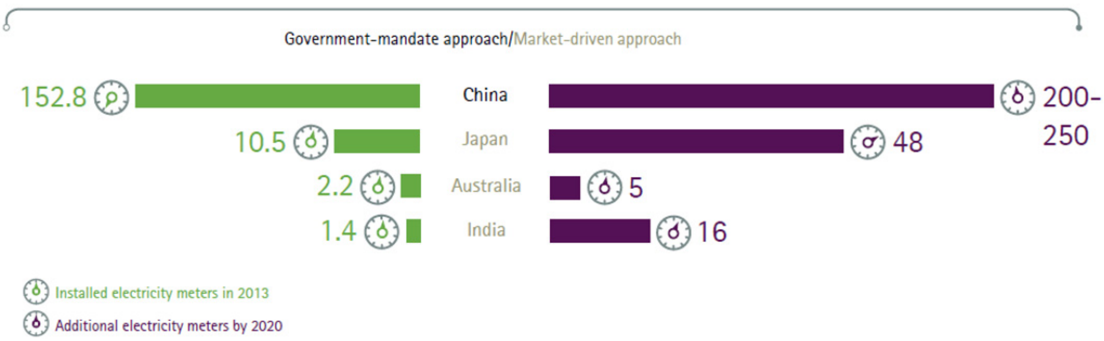

Figure 8. Estimation of the total number of *SMs* in installed Asia-Pacific countries by 2020 (Source: Accenture [55]). Reprinted with the permission of Accenture, "Realizing the Full Potential of *Smart Metering*", published by Accenture, 2015.

4.3.1. China

Electricity companies in China continue with an extensive deployment of *SMs* as part of a national plan that aims to improve the national electricity infrastructure and shift towards green energy supply. This situation has led China to become the largest market for *SMs* in the world [46]. The installed base of *SMs* is expected to grow from more than 139 million units in 2012 to 377 million units by 2020, reaching 74% market penetration [75]. The Smart Grid Corporation of China (SGCC) is China's sole state-owned electric utility company and the largest utility company in the world, covering power supply to 88% of China [76].

The most important *SM* deployment in China corresponds to the SGCC's Smart Grid Plan, which aims at developing a modern power grid based on a strong information and communication platform, with an *Ultra High Voltage* (*UHV*) grid backbone and subordinate grids coordinated at all levels [76]. By the end of 2011, SGCC had implemented 238 *SG* pilot projects ranging from connecting wind power plants to automating distribution networks to metering households. Regarding *Smart Metering*, there were three remarkable deployments: (i) 26 provinces and 2.2 million users in 2009; (ii) 33 million *SM*s installed in 2010; and (iii) 33 million *SM*s installed in 2011 [77]. Most of the installed *SM*s employ *PLC*; however, SGCC is also running an *SG* project with 86,000 premises connected to the grid using *PON* technology [78]. Additionally, under the Smart Grid Plan, SGCC has developed three standards related to *Smart Metering*: (i) Q/GDW 376.1 (communication protocol between master station and terminals); (ii) Q/GDW 376.2 (interface for local communication module of concentrators); and (iii) Q/GDW 377 (technical specification for security and protection).

4.3.2. Japan

Japan is betting on *Smart Metering* solutions, especially after the Fukushima earthquake disaster, and they expect to deploy a total of 80 million *SM*s [46]. The Japanese government has set a target for about 80% of the nationwide electricity consumption to be monitored using *SM*s, phased from 2015 to 2020. By 2024, virtually all of Japan's roughly 80 million residential customers are expected to have an *SM* installed in their homes. The *Smart Metering* plan deployment has been set with the aim of letting utilities see the demand in real time and adjust pricing accordingly, all without dispatching meter readers. The devices are also expected to encourage customers to save more energy [78]. One of the two main power utilities of Japan, TEPCO, announced that it was expanding its rollout program from 7 million to 27 million *SM*s—essentially, all the meters of their household customers. Installations began in the first half of 2014 and are to be completed by March 2021 [79]. On the other hand, KEPCO utility has already deployed about 2 million *SM*s. *Smart Metering* deployments in Japan employ wireless technologies.

Unlike most other nations, reliability is not considered to be an issue in Japan. The country has already undertaken significant generation and transmission infrastructure improvements as a result of investments beginning in the 1990s. A key focus area for Japan is the introduction of advanced integrated controls for demand side management and connectivity to the end-user [80].

4.3.3. Australia

Australian *SG* and *Smart Metering* initiatives are focused on demand management, energy security, and energy efficiency and have been mainly propelled by governmental programs. Additionally, severe energy problems caused by energy shortages suffered in 2006 and 2007 have contributed to the attempt to improve the energy supply system [70]. In fact, in response to those energy shortages, there was a government committed to a national *SM* rollout as part of the National *Smart Metering* Program. The rollout areas were chosen from a cost-benefit analysis and the State of Victoria was the first to commence a mandatory rollout of *Smart Metering* infrastructure, which started in 2009 and finished in 2013 with 2.8 million installed *SM*s equipped with *RF* mesh technology and *WiMAX*. As happened with the Ontario deployment, a *ZigBee HAN* network was also implemented. The government determined minimum functionality and services to be conformed to by the distributors, specified in terms of four key services: (i) recording of energy imported or exported from a metering point by half-hour trading interval; (ii) remote reading of the *SM*s; (iii) remote power supply disconnection; and (iv) remote power supply connection [38]. All costs associated with this deployment were passed along to consumers, including the cost of the *SM* itself, which generated cost concerns from customers. This, together with customer implications and engagement, were identified as the two main problems of the deployment [75]. The Ausgrid utility has also performed several *Smart Metering* pilots. In 2010 a consortium led by Ausgrid won the tender for the Australian Government's "Smart Grid Smart City" project, consisting of the rollout of up to 50,000 *SM*s to homes across the trial sites. Residents are able to see a real-time analysis of electricity usage for their households, as well as for individual appliances. The deployment also improves the grid performance by controlling the efficiency and network operations for energy transmission. The project employs *LTE* for its *4G* communications network [39]. Additionally, the "Essential Energy" project, from 2004, consisting of the deployment of *SM*s for predominately residential customers, started with a size of approximately 2500 *SM*s equipped with mesh radio and *3G*. The pilot assesses demand management trial including in-home displays and critical peak pricing tariffs. The trial confirmed the importance of real-time consumption data in driving energy efficiency since customers involved in the trial achieved an overall reduction in energy consumption and up to 30% reduction in their peak demand [38]. Additional *Smart Metering* pilots and trials performed in Australia are discussed in [39,81].

4.3.4. India

Although India is one of the fastest-growing economies in the world, its industrial growth has been limited by inadequate energy availability, especially electricity transmission, distribution losses, and a mismatch of supply and demand in electricity [50]. This issue, along with theft, are the major concerns regarding power in India. Consequently, the Indian Ministry of Power is advocating for *SG* investment to solve those issues and in 2012 unveiled eight *SG* pilot projects that use a combination of *Smart Metering* and various technologies to improve the efficiency and reliability of the power system for sustainable growth. Initial steps towards *Smart Metering* in India have been encouraging, with the market for electricity meters both for static and electromagnetic witnessing a rapid expansion of 32% between 2008–2009 and 2010–2011. Under the India Smart Grid Task Force (ISGTF), an inter-ministerial group initiated by the Ministry of Power, a *Smart Meter* Task Group was formed to discuss the development of cost-effective metering solutions that can be applied within the Indian context [76]. Some remarkable *Smart Metering* pilots are the "Puducherry Smart Grid Project," with more than 1400 *SM*s equipped with different technologies; the "Bangalore Pilot Project," which will reach 2000 residential and commercial customers; and the deployment started in 2008 in New Delhi (with 500,000 *SM*s installed in 2011), where *SM*s include automated meter reading and a prepaid system utilizing *PLC* technology [80]. Industry reports estimate that India will install 130 million *SM*s equipped with both *PLC* and wireless technologies by 2021 [82].

However, despite the progress in *Smart Metering* across utilities at pilot level, there are still infrastructural development and capacity building issues that need to be addressed before a large-scale implementation. A considerable percentage of existing *SM*s are still being read manually; there is an absence of associated infrastructure for meter data analysis and also an insufficient regulatory focus and policy on *Smart Metering* [76].

4.4. Other Regions

Other regions of the Middle East, such as Libya and the United Arab Emirates, are also starting their path into *Smart Metering*; *Dubai Smart City* can be cited as a model. Regarding Africa, utilities from South Africa and Zimbabwe lead the *Smart Metering* introduction initiative, which is still very poor.

5. Challenges to be Addressed in the Near Future

With the exception of China, the pace of installation of *SM*s will reportedly slow in the short term, due in large part to a decline in the rate of meter rollouts in the United States and delayed implementation of large projects planned for Europe and Brazil [46]. Additionally, as stated by CEER, despite the many years of assessing European standards, Europe still faces a difficult situation because of the lack of a common standard for *SM*s and an absence of interoperability. This leads to a lack of economies of scale and innovation in customer services since *Smart Metering* should act as an enabler of additional services [50]. This situation complicates the penetration of multinational *SM* suppliers in certain foreign markets due to the imposition of local manufacturing standards that may require significant product modifications [46]. Although most of the countries have followed at least some of the recommendations listed in Table 2, a common approach should be envisaged for defining *SMs* and their functional requirements. According to the European Commission, the most challenging functionality to deliver relates to the frequency of consumption data update and its availability to consumers and third parties on their behalf [51]. Also data protection and security issues must be addressed. Not all technologies offer the same security levels and this needs to be faced. It is advisable to assess a specific framework and personal data protection must remain a central concern in the development of standards. In addition, most of the *Smart Metering* communication networks use a low/medium bandwidth, which generates high traffic and limits the quantity of data to be transmitted. Then, more modulation/demodulation devices and additional memory for storing the data logs will be required, with a corresponding increase of costs [83]. In addition, high levels of data traffic may lead to an inefficient system. Techniques such as reduction of data retransmissions and the introduction of hierarchy levels (priorities according to the type of data: measure, control, management, alarm, *etc.*) can help to improve efficiency in *Smart Metering* communications.

Additionally, communication systems may also face disturbances: wireless communications suffer interference from surrounding emitting devices and also *PLC* is affected by the inherent noise from the power cable and the devices connected to it. Those issues can be overcome by using more robust protection codes, redesigning emitting devices, and legislating on electromagnetic interferences [84].

At present, government investments have propelled a large proportion of *Smart Metering* deployments, especially in Europe. Most utilities are reluctant to invest in new systems and technology without a government mandate or incentive, despite the savings resulting from *Smart Metering* systems [46]. The European Commission has listed the advised next steps in the deployment of *Smart Metering* systems as follows:

- Gain the trust and confidence of consumers. An intensive communication effort is required to convince customers about three key aspects: understanding their rights as consumers, the benefits of installing *SMs*, and their participation in demand response programs.
- Achieve an innovative energy services market. Synergies with the *ICT* sector will be fundamental for promoting an innovative energy services market.
- Protection of sensitive data. The European Commission and the member states will have to assess the need for specific data privacy and security framework legislation.
- Management of data. Utilities and the *ICT* sector will have to work together and explore the possibilities of data management.
- Functions of *SMs*. Technical and commercial interoperability in *Smart Metering* will enable member states to identify common means of achieving cost efficiencies and ensure fit-for-purpose in their rollout.
- Long-term economic assessment of costs and benefits. A review of the critical parameters used and assumptions made in national rollouts will help to refine technology choices.

In the United States, *Smart Metering* is still a developing industry. The FERC highlights the lack of integration of *HANs* with *Smart Metering* systems, as well as existing uncertainty over the development and evolution of standards and their effect on networking technology, especially regarding *HAN* integration [17]. Utilities are also concerned about obsolescence, which may be addressed by adopting the most adequate technology for every particular case. Another subject under discussion, barely seen in Europe, refers to the impact of *Smart Metering* deployment on residential customers and its translation into real bill savings [10]. This issue can be addressed by allowing access to metering data in real time to end-consumers and by offering peak-time rebates. Additionally, most *Smart Metering* projects in the U.S. have had to deal with a lack of confidence among customers regarding magnetic radiation emissions, remote supply disconnections, and privacy issues [61].

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