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Smart metering trends, implications and necessities: A policy review

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ABSTRACT

Renewable generation, energy storage, electric vehicles and energy management systems are examples of increasingly widespread products and services that the electricity grids must accommodate safely and efficiently. The fulfillment of this objective involves innovation and, more specifically, the modernization of the existing electricity infrastructure into so-called smart grids, which are based on the interaction between suppliers and consumers through control systems and smart metering. However, the development of these systems requires regulations that take into account the technological capabilities and the needs of users both in the present and in the immediate future. This paper starts with a review of the energy policies aimed at the implementation of smart metering infrastructures (SMI) in Spain, Europe, and around the world. It then addresses the trends in the energy sector that will shape the future and the contribution that SMI are likely to make given its current status, its potential, its limitations, and the implications they would have. Lastly, the paper set outs the conclusions reached and makes recommendations for the adaptation of policies.

Contents

1. Introduction

The reality of the liberalization of the electricity market, together with increasing sustainability and energy efficiency requirements, is making it necessary to introduce more versatile and flexible equipment and systems and to standardize the processing of the associated data in order to bill the service more efficiently and to keep users informed. In short, it is necessary to make the electricity metering system smart.

A smart metering infrastructure (SMI) is an electronic system that is capable of measuring energy consumption whilst providing more information than a conventional meter and that can transmit and receive data using a form of electronic communication [1]. Concern about the development of these systems, which are now commonplace, is not new. Several legislative and regulatory

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initiatives have been taken at a national and international level with the aim of modernizing the measurement of consumption and power generation. The data thus gathered, which is essentially simple, is the basic element for the effective transformation of the existing electricity distribution networks into the so-called smart grids, where new products, services and agents are possible, creating a new framework for competitiveness, sustainability and business opportunities.

This paper is based on a detailed study of the implementation of SMI in Spain, which is an interesting example because it is a country to which the European legislation on the matter has been transposed. Based on this regulatory framework for implementation, the authors propose their ideas here for developing SMI beyond the basic requirements that have already been established internationally in any given geographical area. The main aim is to take advantage of the potential capabilities of these systems with a view to addressing the key challenges that are about to affect the electricity sector worldwide: the increasingly widespread presence of renewable generation and energy storage, the mass use of electric vehicles, the widespread use of information about energy use, and software applications that enable people to use energy in the most efficient way possible.

The objectives of this paper are threefold: (1) to thoroughly and objectively analyse the shortcomings and virtues of the rules governing SMI in the main global geographical areas; (2) to introduce the liberalization of the concept of energy supply point as a means to permanently increase the penetration of renewable generation and energy storage; (3) to present the establishment of unambiguous and universal communication standards for the effective integration of end-user energy applications with SMI, especially in the case of recharging infrastructures and demand management systems.

This paper is organized as follows: Section 2 presents the strengths and weaknesses of specific regulation for SMI in Spain and the most important countries in this field, critically analysing key issues such as the minimum functions required and the context in which implementation is taking place. Section 3 addresses the challenges facing the electricity sector and presents the views of the authors and their proposals on how to overcome them with the help of SMI, as well as the limitations and other implications that these innovations could entail. Finally, Section 4 presents the conclusions and the fundamental ideas discussed in the paper.

2. Existing energy policies

The authors' study begins with the regulations of the European Union, an institution with a strong commitment to the implementation of smart grids and SMI. Spain, as a member of the EU, has adapted its legislation with some success and with some failures, but also with room for improvement in the authors' opinion as discussed in Sections 3 and 4. Having said that, this country is a worthy case study and a good model to follow. This is thanks to the combination of its technical architecture, roll-out planning, and the minimum functionalities that have been established, which are more than adequate in the opinion of the authors, even more regarding other SMI implementations both within Spain's geographical area and beyond.

2.1. European regulatory framework

At an EU level, there are several agreements, regulations and directives relating to sustainability in all its forms. These show that current regulation in the electricity sector is clearly oriented towards transparency, competitiveness and equality for all of the actors involved.

The first reference to note is Directive 2009/72 /EC [2], which states that the electricity market must be based on the real possibility of choice for all consumers and the creation of new business opportunities, for all of which SMI are essential elements; in fact, the document explicitly states that European Union member states should encourage the modernization of distribution networks and mentions the introduction of smart grids as a way to promote decentralized generation and energy efficiency [2].

It is therefore clear that SMI are essential tools for gaining access to information regarding energy consumption in an objective and transparent manner. Thus, the Directive states that consumers should be given access to data about their consumption and the associated prices so that they can invite competitors to make offers based on them, without any additional cost being billed to them for these services [2]. Also each member state must ensure, individually, that the roles and responsibilities of any market participant are defined and reviewed by the corresponding national regulatory authority with respect to contractual arrangements, commitment to customers, data exchange and information ownership [2]. This means that each European country determines, within that framework, the particularities of its market; for example, in Spain data collected from electricity meters is the property of the distribution companies, but there is a mandatory requirement to provide it to retail companies for billing purposes and to customers for their information.

Recommendation (2010) 639 [3] establishes the priorities to be followed in respect of energy innovation, including the recommendation to accelerate the deployment of SMI, to promote smart grids and to ensure the large-scale interoperability and integration of renewable energy and electric mobility [3].

Recommendation (2011) 202 [4], meanwhile, mentions the direct relationship between SMI and the new generation of electricity grids, by presenting smart metering as an inherent part of smart grids. Smart grids are discussed in this document as opening up new possibilities for consumers, firstly through the options for control and management of consumption that they introduce, and secondly due to the way they can incentivize the efficient use of energy if they are combined with an appropriate pricing model based on the time period in which energy is consumed [4].

Directive 2012/27/EU [1], which specifically relates to energy efficiency, brings a fresh approach to the electricity distribution sector. With regard to the implementation of individual smart meters, it adds that this must be subject to it being technically possible, financially reasonable, and proportionate to the potential energy savings [1], conditions which have not been taken into consideration in all member states, as many of them (including Spain) have imposed the obligation to implement them without regard to the ultimate technical and economic feasibility.

This directive also states that SMI must comply with the applicable safety standards related to data transmission equipment and systems, as well as with requirements connected with the privacy of end users [1]. Furthermore, they must also provide accurate information about the input and output of electricity in an easily understandable format, which must also be made available to the end user via the internet or by means of the meter's interface [1]. Again, it appears that making the information understandable and useful to the consumer is essential in order to achieve the objectives of the European Union.

Lastly, Recommendation 2012/148/EU [5] is deeply focused on the deployment of smart metering infrastructures, which must reach 80% implementation by 2020, and on the minimum functional requirements that the SMI must have.

These legislative guidelines are largely based on the recommendations of technical and scientific bodies such as the Joint Research Center [6], which has publications that are useful for cost/benefit analysis of the deployment of SMI [7] and the implementation of smart grids [8] in the member states of the European Union. Also of great interest are their lines of work on privacy and security in information and communication technologies, which are fully applicable to SMI [9].

Furthermore, at a European level it is worth mentioning the position of associations such as the Council of European Energy Regulators (CEER), which represents the national regulators of electricity and gas in the member states of the European Union [10]. According to the CEER, the effective implementation of SMI is one of the great changes that is expected to take place in the sector over the coming years, along with the increased penetration of renewable energy, smart grid technologies and demand side response, which must be accompanied by the appropriate development of regulations [11,12].

2.2. Spanish regulatory framework

In Spain, it is worth highlighting five documents for their close bearing on SMI, and which, ultimately, transpose the European regulatory and legislative framework into national law, as should be the case in all member states of the European Union. These texts provide detailed definitions of the legislative foundations of the meters, the applications for the management of information and the communications that make up these systems based on a variety of criteria, among others, metrological, functional and economic.

They therefore determine, among other details, the components of smart metering infrastructures, the equipment types and the minimum functionalities of each of them, the deadlines for implementation, the associated costs, the billing methods and the competencies of each of the agents involved.

Royal Decree 1110/2007 [13] is the document that establishes the minimum requirements for SMI in Spain, thereby addressing the technological leap represented by the introduction of SMI: the measurement will not simply use meters, as was the case with the old electromechanical equipment, but rather SMI are defined as the sets of devices, from the electronic counter to the central systems of the System Operator and the companies responsible for the measurement, as well as the telecommunication networks used, whether they belong to external operators or are deployed across electricity grids [13].

It is worth noting the requirement that the meters include the term of billing of reactive power, in all directions and quadrants, and control of the power demanded [13]. This Royal Decree also includes the possibility of using one or more metering devices at the same energy supply point, as appropriate [13]. The latter may be considered inefficient, as pointed out in Section 3, given the capabilities of a single smart meter in managing multiple active and reactive power flows and all related electrical parameters.

With regard to the communications protocols, this Royal Decree establishes that they should preferably be public, but that they may exceptionally be specific or private, forming part of a comprehensive remote management solution [13]. This, therefore, opens the door to the development of different models: first, the option of interoperable models with multiple suppliers that are more open, and, secondly, the option of proprietary models, in which the developer has the rights to the technology and, in addition to making use of it as necessary, can make it the basis of a business model.

Order ITC/3022/2007 [14] goes into greater detail about the metrological requirements presented in Royal Decree 1110/2007 for electrical energy meters for power supplies with contracts for up to 15 kW, which are the most common in the Spanish electricity market: time discrimination, remote management, replacement, inspection, installation phases, and so forth. It is worth noting, due to their potential applications, the obligation to record the time curves of active power and reactive power, which enables dynamic rate updates and makes it possible to manage charges so as to reduce customer demand at critical times, as long as there is a regulatory, legal and contractual basis for it [14].

Furthermore, in general, the meter will present information on the direction of the energy (consumed/generated), the presence and order of the electrical phases to which it is connected and the status of communications [14]. This makes smart systems tools with extraordinary potential for the integration and operation of distributed renewable generation, energy storage and electric vehicle infrastructure, as well as for a more advanced operation of the low voltage network in general.

Order IET/290/2012 [15] sets out the details for the effective implementation of SMI in Spain, where all meters for supplies of up to 15 kW have to be replaced by new smart devices before 31st December 2018, based on deadlines that have been set taking into account the time required for the industrial development of these new measuring devices and the difficulty of having enough stock in the right places by the right time. This Order states that 35% of meters must be replaced by 1st January 2015, 70% by 1st January 2017 and 100% by 1st January 2019, whilst any meter that is installed today must of course be ready for integration into the eventual relevant SMI [15].

This review of Spanish regulations ends with the recent Royal Decree 216/2014 [16], which establishes the new program of regulated electricity tariffs in Spain, which applies to more than 90% of Spanish consumers [17]. Its main novelty is that the pricing is to be based on hourly measurements of energy consumption, to each of which a regulated hourly price shall apply which shall be determined based on the daily and intra-day price of energy in the markets and the applicable costs associated with the system and its marketing [16].

However, this type of pricing is way ahead of the current capabilities of the SMI being introduced in Spain. For example, it requires the ability to manage a volume of data, in addition to handle frequencies of sending and processing of information, much higher than those determined by the law applicable up until now. If the customer does not have a smart meter that is effectively integrated into the corresponding SMI, billing will be carried out by applying an average consumption profile to the actual reading, i.e. based on a daily weighted average that will be published by Red Eléctrica Española, the grid manager and transmission agent in Spain, one day in advance [16]. This formula will be valid from July 2014 for an indefinite period of time until the distribution companies are able to adapt [16], which is not expected to be before the end of 2015.

2.3. International regulatory framework

The implementation of smart metering infrastructures is a subject that is currently being discussed worldwide. It is not only being considered by developed countries, but developing countries are also considering it in their energy roadmaps. Therefore, it is very important to study the international regulatory and legislative framework not only in European countries, but also in those at the same socio-economic level, in order to gain a clear picture of their strengths and weaknesses with regard to the implementation and development of SMI: the existence of implementation plans and the amount of progress made, their expected scope, the minimums that they establish, etc.

One of the leading countries in this area is Italy, where smart metering was ordered to be implemented by law in order to reduce non-technical losses rather than energy efficiency reasons [18]. Deployment began in 2008 and, by the end of 2011, 95% of the country's 36 million customers had smart meters installed [19], and deployment can therefore now be considered complete.

Active and remote control of power demand (remote load control) is currently limited to very large industrial customers, whilst the net balance function (net metering) is now more widely available [20]. Customers are also expected to have a web site that they can use to access information about their energy use [19], a feature which, along with in-home displays, has already been implemented in several pilot projects [18].

Making this information about their energy consumption available to users is a disruptive step for increasing efficiency, given that early experiments have found savings of up to 10% [4] can be made, not counting the added value that electric companies can bring to the service they provide to their customers.

Spain is also in a leading position internationally. Currently, the electricity distribution companies are undertaking the process of full-scale adoption of SMI [15]. However, it is worth noting that, unlike other neighboring countries, Spain has not carried out a cost-benefit analysis on a national [18] public scale, either before or during the process, to determine its definitive economic viability.

After the initial pilot projects carried out in 2010 and 2011, these mass replacement plans were drawn up along with the implementation of the information technology (IT) and telecommunications systems necessary for remote metering and management [18]. The number of smart meters installed in Spain at the end of 2013 amounted to 7,910,569 m, of which just over 7.5 million were installed by the five major Spanish electricity distribution companies (Endesa, Iberdrola, Gas Natural-Fenosa, EDP-Hidrocantábrico, and E.ON), with nearly 75% of them effectively integrated within smart metering systems [21]. Whilst the possibility of applying demand management strategies is one of the minimum functionalities required [14], in these early stages of implementation this is not being carried out.

Germany is at an earlier stage of implementation. In July 2013, Germany's Federal Ministry of the Economy (BMWi) published a cost/benefit analysis whose outcome was to recommend not carrying out the implementation of smart metering infrastructures in accordance with the European route map established for 2020 [22]. This means that now, in general terms, smart meters must be implemented in new buildings, major consumers and facilities for renewable generation and co-generation whenever it is technically possible [23]; in all other cases, the implementation will be carried out only if it is economically and technically feasible, for which the law has defined different standards aimed mainly at small consumers [24].

In addition to the obligation to show the current energy consumption and time of use, the law initially included the requirement of being integrated into a communications network [22]. It is still necessary to develop standards and guidelines related to interoperability, data protection at all levels and interaction with manageable elements such as electric vehicles and heat pumps [22].

The aforementioned technical and economic feasibility analysis proposed 2029 as the target date for completion of a deployment that will be made up of 38,500,000 smart meters, of which some will be fully integrated into smart metering infrastructures and others, although they are smart meters, will initially not necessarily be integrated into such systems [22]. This is therefore an approach that considers the economic sustainability of the system more of a priority than large-scale and widespread deployment.

In France, ERDF is the company responsible for deployment, with a total of 35 million smart meters to be installed by 2020 [25]. The smart metering model to be used was successfully tested in pilot projects in Indre-et-Loire and Lyon in 2010 and 2011 [26] and between 2015 and 2016 the number of devices installed is expected to reach 3 million meters and 80,000 hubs [27].

The French smart meter has three functions that are worth highlighting: monitoring the status of the low voltage network in order to improve responsiveness in the event of a fault, controlling the production of electricity in the low voltage network, and managing the charging of electric vehicles [26]. Furthermore, the SMI can also send information about energy use to the user's PC or mobile phone and thereby provide analysis, historical records and an alert system in the event of excessive energy consumption, among other possibilities [28].

In the UK, suppliers of electricity rather than distributors are responsible for the deployment, which will take place mainly between the end of 2015 and 2020, although many companies have already begun [29]. The total number of smart meters to be installed will amount to about 30 million, which will be installed in homes and small businesses [29].

Users will be offered an in-home display (IHD) on which they can see their energy use and cost in near real-time, with the aim of promoting energy and money saving [29]; as in the other countries mentioned in this paper, this system will allow remote reading based on quarter-hourly measurement, exact billing of the user, and remote management of the contractual details of supply and changes to them, but it also includes other new features such as the ability to support prepaid contracts [29].

Once the stages of regulatory design and consultation with the agents involved had been passed, the Data and Communications Company was created. This is the body responsible for the communication functions between the smart metering infrastructure and the energy supplier's systems, the grid operators and the energy services companies, the running of which will be put out to public tender [29].

The UK, like Germany, carried out a cost/benefit analysis prior to the implementation of their smart metering infrastructure plan. Up until 2030, it expects a net profit of 6.2 billion pounds for the whole of the country, resulting from an investment of 10.9 billion [29].

The USA, meanwhile, is divided into a dozen electrical areas but, according to the 2005 Energy Policy Act, regulatory responsibilities reside with each of the states, which illustrates the complexity of the existing legal and regulatory environment, although the Department of Energy establishes the overall framework for the implementation of smart metering infrastructures [30].

The 2007 Energy Independence Act established the national goal of modernizing the electricity grids and making the transition to smart grids [31]. To end, California, based on its strategic plan for energy efficiency, carried out several pilot projects between 2009 and 2011, and between 2012 and 2015 it implemented the deployment phase of remote management systems [32], making it a leader in the international arena.

In California there are a lot of voluntary demand management programs that customers can participate in, with a time margin ranging from 24 h in advance to real time, which enables the use of strategies that allow the user to save energy and money and that help companies to improve the management of the electrical system at the times of high demand [33]. Apart from this example, smart measurement systems have enabled the deployment of advanced rates with several periods of time discrimination, the creation of flat rates for electricity and the application of price signals in real time for large customers, as well as customer access to data regarding their energy use [32].

It should also be mentioned that in the US in general, and in California in particular, there have been strong movements against smart metering with arguments based on health risks due to the use of wireless communication devices [34]; these have been publicly refuted by the relevant authorities on the basis of a number of scientific studies [35].

In Brazil, the leading country in the implementation of smart metering infrastructures in South America, the executive committee of the national electricity regulator (ANEEL) launched a public consultation in 2010 regarding the functionalities of smart metering infrastructure [36]. Minimum functionality requirements were finally specified in 2012 in Normative Resolution No. 502, which provides for the installation of smart meters for domestic, commercial and industrial customers with supply voltages of less than 2.3 kV, as well as other related regulatory developments such as rates involving time discrimination [37]. The country is still working on defining the application of smart metering to generation facilities in residential areas.

With regards to the practical implementation of these systems, ANEEL plans to replace the 63 million electricity meters in the country over the long term [36], although right now there are several pilot projects underway such as that carried out within the framework of the Búzios Smart City Project, where the first smart meters to receive national certification have been deployed with an initial scope of 10,000 customers [38]. As in the other examples described in this paper, these devices keep a record of the active and reactive energy and power consumed, the number and duration of service interruptions and the value of the voltage supplied, along with a range of other functions [37].

3. Facing future trends

In the short and medium term, the electricity sector has to cope with a dynamic and changing socio-economic environment. The demands, needs and requirements of users of electrical energy will evolve and become more complex, but will remain centered on a common element: information that is detailed, accurate and more accessible. In other words, changes in the electricity sector depend on SMI. And, as can be seen in Section 2, this is an opinion that is strongly held not just in the European Union but around the world.

The following trends, according to the authors, will shape the future development of SMI, as has been stated in recent years by the International Energy Agency in its annual report entitled Energy Technology Perspective.

In the following section these trends will be examined one by one and, specifically, it will be stated what the contribution of SMI should be, what additional new developments should be made alongside it, and what the implications, limitations or current difficulties are.

3.1. Growing importance of renewable generation and distributed energy storage

Energy storage is still far from being a widespread and pervasive element, mainly due to its cost, although its usefulness as a complement to renewable generation is one of its main advantages [39]. Distributed generation, meanwhile, is increasingly present in low voltage networks and in the form of small power plants, thanks to its technological maturity and the resulting decrease in prices to the point that in countries such as Germany and Italy grid-parity has already been reached for solar photovoltaic systems [40,41]. Furthermore, the figures for consumers and generators will gradually evolve towards the concept of the prosumer, i.e. an agent capable of both generating and consuming energy, who consumes the electricity generated for their own purposes, but can also feed it into the grid, which increases the need for bidirectional information and control in order to optimize integration [42]; this model still requires legal development in countries such as Spain [43,44].

In the authors' opinion, the implementation of SMI is essential in order to maximize the use of a flexible grid model in which any point in the network can consume or generate electricity at any voltage.

Having such a model would dramatically, safely and reliably increase the penetration of renewable generation and storage because the use of smart meters would mean that the electric companies would always know the behavior of individual users (such as whether they are generating or consuming electricity) and the network to which they are connected (e.g. whether they are having any problems or not) and be able to act accordingly (e.g. they would know whether or not to inject more power into the grid and whether to regulate the power demanded or generated), whilst the user would be able to freely choose their modality and change it at different moments in time as it suits them (only consuming, only generating, or both).

Therefore, in the opinion of the authors, the traditional concept of supply point needs to be liberalized, leading to the concept of'energy spots' which do not distinguish between users and electric companies, as noted above, with no duplication in the use of measurement and control equipment, given that a single smart meter would be necessary and sufficient.

This, in any case, is not without limitations. According to the authors, there first need to be changes made to the regulations and legislation, with the aim of acknowledging the roles and functions that the operators of the distribution networks need to take on in order to control this type of installation and the rules to follow to ensure the transparency and fairness of the process, treating them as simply another asset of these networks, rather than (as is sometimes advocated) transferring these powers to the System Operators, which should continue to be responsible for the management of large generating nodes and the overall demand/generation balance of the system, as they are now. And secondly, appropriate mechanisms should be put in place to ensure that it is the market that decides whether or not to accept the injection of power to the grid from a prosumer or, in other words, to ensure that the grid does not become a drain into which excess energy can be poured without any control, that this energy production does not rely on subsidies or premiums, and that each type of'energy spot' pays the corresponding tolls for the use and support of the networks.

The implementation of SMI also impacts on power infrastructure investments since it could delay the expansion of transmission and generation. Given the strong relationship between the two, as proven by a number of authors [45–48], this effect of the introduction of SMI on investment in system expansion needs to be carefully studied.

3.2. Growing presence of electric vehicles

The number of electric vehicles will continue to grow in the short term and they will make up 2% of the world's vehicles in 2020, mainly due to government subsidies for their purchase, a change of attitude among consumers, the global economic recovery, and technical progress in the areas of autonomy and recharge times [49].

In the opinion of the authors, SMI are ideal tools for reducing the risks associated with the large-scale market penetration of electric vehicles, as they would make it possible to control the demand for electrical energy due to the recharging infrastructure at any moment in time and therefore avoid compromising the stability and security of the supply to the different users of the electricity grid.

SMI could easily communicate with the recharging infrastructure connected downstream of the smart meters. And furthermore, in line with the previous point, SMI could not only monitor the vehicle recharging processes that take place at each moment in time but could also control and regulate them based on technical criteria as well as economic criteria (giving priority to particular infrastructure types or users over others, applying dynamic tariffs, etc.).

The authors therefore believe that a communication protocol between smart meters and recharging infrastructure should be established so that the operators of electricity grids can know the demand for energy from electric vehicles in real time, make predictions based on this information, and act on these processes if necessary, based on the particularities of the contractual framework for the user involved in each case. This is the best way to harness the potential of SMI, once it is overwhelmingly distributed all over the country, in order to ensure the maximum presence of electric vehicles.

It is important not to overlook the great need for the development of policy and consensus that this implies, firstly in order to avoid overlapping competencies or functions with the recharging managers, i.e. the organizations responsible for the recharging infrastructure. In any case, correct definition during the early stages of implementation would help to avoid major problems in the future when there are larger fleets of vehicles. On this point, it is worth noting the case of the Spanish instruction regulating the technical requirements for low voltage recharging facilities, recently approved after many years of discussion [50], which has overcome problems holding back the uptake of electric vehicles by users living in apartment buildings. Another common example at an international level is the lack of standardization of the means of identifying users and subsequent billing problems associated with the recharging of electric vehicles, preventing users from using chargers belonging to different managers without holding different cards, user records or contracts [51]; this is notably not the case with mobile telephony, for example, where roaming contracts are regulated and widespread, thus improving the user experience.

3.3. Increased use of applications to improve energy efficiency and actively manage demand

According to the International Energy Agency, energy efficiency has played, and still plays, a key role in the sustainable development of the global economy [52]. Furthermore, the Agency states that efficiency has improved most in the residential sector, where energy consumption has fallen by 14% in comparison to the level of 2001, mainly due to improvements in heating and hot water, lighting and appliances [52]. Applications for improving energy efficiency are therefore products and services that have great potential for users, electric companies and society in general, as the former can make more rational and more economical use of energy and the latter can generate new business and more actively control energy demand, whilst the third can make better use of natural resources and reduce its environmental impact.

It is the view of the authors, once again, that SMI are basic tools for increasing the usefulness of energy efficiency applications in domestic, industrial and service environments as they bring the best means of providing accurate and reliable information to customers, which can subsequently be used for billing.

Smart meters, distributed throughout the country, would provide data in real time, or with sufficient frequency, regarding the energy consumed and generated by the user, which could also be integrated into more complete energy management applications that would provide not only general information about the'energy spot' but also about internal uses (appliances, rooms, generators, storage systems, electric vehicles, etc.), as well as the ability to control the demand, generation or energy storage taking place.

In the opinion of the authors, a communication protocol should be established between smart meters and energy efficiency applications so that the operators of electricity grids have precise information about energy demand, the availability of stored energy, and the generation possibilities at each'energy spot' and take this information into account in their predictions and for the operation of the network infrastructure, acting on these processes collectively or individually if necessary, based on the particularities of the contractual framework established with the user involved in each case, as has been done in different parts of the world. Going further still, it would be possible to use even higher transmission frequencies for data that are intended for local user applications, i.e. those which do not make use of the communications networks of the SMI in order to enhance the perception of precision and reliability by the end-user of these applications, whilst only transmitting the necessary information at the necessary time intervals between the meter and the rest of the SMI.

The success of energy efficiency applications requires the proper regulation of access to information (who can access it, what costs are associated with it, and so on) and its exchange between agents (who owns the data, who is obliged to share it and who should not be given access it, how the privacy of users can be protected, etc.). Furthermore, the standardization of the type of information accessible and the frequency with which it is provided [53] would make it possible to definitively create a new business model for customers, resellers, demand and generation consolidators, etc. based on energy saving and the active management of energy [54,55]; this would require the use of fewer resources by avoiding the duplication of measurement equipment, improving the use of IT systems and optimizing investments [56].

4. Discussion and concluding remarks

Smart Metering Infrastructures (SMI) are basic public service equipment that make it possible to provide products and services to users and allow better management of electricity grids and of all the elements connected to them. These reasons amply justify their use but, in the opinion of the authors, for the sake of technical and economic sustainability, cost/benefit studies should be performed - either before or after deployment has started.

SMI implementation has significant shortcomings that need to be addressed through the appropriate development of regulations, such as the additional costs associated with the management of the new and more abundant information available, and the new competences that the operators of the grids and meters must take on. Obligations for each of the relevant participants must be established, and incentives must be created for a new energy business model that can be viable, profitable and sustainable for each of the participants.

In the opinion of the authors, if it is technically possible, all meters should be integrated into the SMI, regardless of the voltage level and the size and nature of the agent with which they are associated. It is therefore necessary to leave behind the concept of a supply point and transform it as an'energy spot' where generation and energy consumption can be carried out interchangeably, which can be managed efficiently through interaction with smart meters by means of general and free standards for use, whilst avoiding unnecessary duplication, inefficiencies and incompatibilities. This, among other advantages, would definitively enhance customers' access to information about their energy, either through local devices such as in-home devices or in-home displays, or via remote applications such as web portals and mobile applications. This worldwide access to data undoubtedly represents a key development, as viewed by the authors of this papers.

It should not be forgotten that, in the opinion of the authors, the current regulations are not complete and the technical requirements are not sufficient to deal with the impending challenges facing the electricity sector. SMI should therefore continue to be developed as recommended in this article in order to continue making them into useful tools for the effective transformation of traditional electricity grids into future-ready smart grids.

References

[1] Council of the European Union. Directive 2012/27/EU of the European Parliament and of the Council on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. Off J Eur Union 2012;315:1–56.

[2] Council of the European Union. Directive 2009/72/EC of the European Parliament and of the Council concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC. Off J Eur Union 2009;211:55–93.

[3] Council of the European Union. Communication (2010) 639 from the european commission 'energy 2020: a strategy for competitive, sustainable and secure energy'. p. 1–20.

[4] Council of the European Union. Communication (2011) 202 from the european commission smart grids: from innovation to deployment. p. 1–12.

[5] Council of the European Union. Commission Recommendation 2012/148/EU on preparations for the roll-out of smart metering systems. Off J Eur Union 2012;73:9–22.

[6] Joint Research Centre. JRC in brief; 2015. Date accessed: March 2015. 〈https://ec.europa.eu/jrc/en/about〉.

[7] Giordano V, Onyeji I, Fulli G, Sánchez M, Filiou C. Guidelines for cost benefit. Analysis of smart metering deployment. Luxembourg: European Union; 978-92-79-22323-5.

[8] Giordano V, Onyeji I, Fulli G, Sánchez M, Filiou C. Guidelines for conducting a cost benefit analysis of smart grids projects. Luxembourg: European Union; 978-92-79-23339-5.

[9] Joint Research Centre. Security for privacy and data protection; 2014. Date accessed: February 2015. 〈https://ec.europa.eu/jrc/en/research-topic/security-privacy-and-data-protection?search〉.

[10] Council of European Energy Regulators. About the European Energy Regulators; 2015. Date accessed: January 2015. 〈http://www.ceer.eu/portal/page/portal/EER_HOME/EER_ABOUT〉.

[11] Council of European Energy Regulators. Final CEER 2015 Work Programme, Ref: C14-WPDC-26-05. Brussels: Council of European Energy Regulators ASBL; 2015.

[12] Council of European Energy Regulators. CEER 2013 Annual Report. Brussels: Council of European Energy Regulators asbl 2014.

[13] Ministry of the Presidency of Spain. Royal Decree 1110/2007. Off State Gazette 2007;224:37860–5.

[14] Ministry of the Presidency of Spain. Ministerial Order ITC/3022/2007. Official State Gazette 2007;250:42390–402.

[15] Ministry of the Presidency of Spain. Ministerial Order IET/290/2012. Official State Gazette 2012;44:15210–2.

[16] Ministry of the Presidency of Spain. Royal Decree 216/2014. Official State Gazette 2014;77:27397–428.

[17] Comisión Nacional de Energía (National Commission of Energy of Spain). Informe 25/2013 de la CNE solicitado por la Secretaría de Estado de Energía sobre el Proyecto de Real Decreto por el que se regula la actividad de comercialización y las condiciones de contratación y suministro de energía eléctrica. Madrid: Comisión Nacional de Energía; 2013.

[18] Hierzinger R et al. Smart Regions Project Deliverable 2.1: European Smart Metering Landscape Report 2012. Vienna: Austrian Energy Agency; 2012.

[19] Council of European Energy Regulators. Status Review of Regulatory Aspects of Smart Metering including an Assessment of Roll-Out as of 1 January 2013, Ref: C13-RMF-54-05. Brussels: Council of European Energy Regulators ASBL; 2013.

[20] Council of European Energy Regulators. CEER Status Review on European Regulatory Approaches Enabling Smart Grids Solutions, Ref: C13-EQS-57-04. Brussels: Council of European Energy Regulators ASBL; 2014.

[21] Gómez AG. Sin información no hay revolución: El impacto de la aprobación del Real Decreto 216/2014 (PVPC) sobre la actividad de comercialización. Cuadernos de Energía 2014;42:79–85.

[22] Edelmann H, Kästner T. Cost-benefit Analysis for the Comprehensive Use of Smart Metering, on behalf of the Federal Ministry of Economics and Technology. EY: Düsseldorf; 2013.

[23] Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway, Bundeskartellamt. Monitoringreport 2012. Bonn: Bundesnetzagentur, Bundeskartellamt; 2013.

[24] Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway, Bundeskartellamt. Monitoringreport 2013. Bonn: Bundesnetzagentur, Bundeskartellamt; 2014.

[25] Union of the Electricity Industry-Eurelectric. Communicating smart meters to customers – which role for DSOs? Brussels: Eurelectric AISBL; 2013.

[26] Électricité Réseau Distribution France (Electricity Distribution Grid of France). Frequently asked questions Linky; 2015. Date accessed: January 2015. 〈http://www.erdf.fr/ERDF_Questions_Frequentes_Linky〉.

[27] Newswire. PR. ERDF has chosen Landis+Gyr for its first step in the deployment of Linky meters. PR Newswire Association LLC 2014 Date accessed: January 2015.

[28] Électricité Réseau Distribution France (Electricity Distribution Grid of France). Press release: Smart Meters, ERDF continues deploying Linky; 2010. Date accessed: January 2015. 〈http://www.erdf.fr/medias/dossiers_presse/DP_ERDF_210610_1_EN.pdf〉.

[29] United Kingdom Government. Household Energy: Smart Meters; 2015. Date accessed: March 2015. 〈https://www.gov.uk/government/policies/helping-households-to-cut-their-energy-bills/supporting-pages/smart-meters〉.

[30] Ehrhardt-Martinez K, Donnelly KA, Laitner JAS. Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities. Washington: American Council for an Energy-Efficient Economy; 2010.

[31] State of California. Rulemaking 08-12-009, Order Instituting Rulemaking to Consider Smart Grid Technologies Pursuant to Federal Legislation and on the Commission's own Motion to Actively Guide Policy in California's Development of a Smart Grid System; 2008.

[32] U.S: Department of Energy. American Recovery and Reinvestment Act of 2009. Smart Grid Investment Grant Program: Progress Report II. Washington: U.S: Department of Energy; 2013.

[33] Cooper A, Wood L. Summary of Customer-Funded Electric Efficiency Savings, Expenditures, and Budgets. Washington: The Edison Foundation Institute for Electric Innovation; 2013.

[34] Perlingieri IS. Smart meters dangers: the health hazards of wireless electromagnetic radiation exposure. Global Research Centre for Research on Globalization 2014 Date accessed: February 2015.

[35] McBride M. Smart meter and cancer risk statement. Br Columbia Province 2011 Date accessed: February 2015.

[36] Brazilian Electricity Regulatory Agency. "Agência Nacional de Energia Elétrica opens hearing to set a new standard for power meter". Brazilian Electricity Regulatory Agency, 2010. Date accessed: January 2015. 〈http://www.aneel.gov.br/aplicacoes/noticias_area/dsp_detalheNoticia.cfm?idNoticia=3572&idAreaNoticia=347〉.

[37] Agência Nacional de Energia Elétrica (National Electrical Energy Agency of Brazil). Regulamenta sistemas de medição de energia elétrica de unidades consumidoras do Grupo B. Resolução Normativa n° 502, de 7 de agosto de 2012. Rio de Janeiro: Agência Nacional de Energia Elétrica; 2012.

[38] Endesa. "The Chairman of Endesa inaugurates Latin America's first Smart City in Brazil". Endesa, 2012. Date accessed: February 2015. 〈http://www.endesa.com/en/saladeprensa/noticias/Buzios_EN〉.

[39] International Energy Agency. Energy Technology Perspectives 2014: Harnessing Electricity's Potential. Paris: International Energy Agency; 2014. ISBN: 978-92-64-20800-1.

[40] Spertino F, Di Leo P, Cocina V. Which are the constraints to the photovoltaic grid-parity in the main European markets? Solar Energy 2014;105:390–400.

[41] Energy Research Centre of the Netherlands. PV Parity Project Deliverable 2.5: Grid Parity Definition. Petten: Energy Research Centre of the Netherlands; 2012.

[42] Di Giorgio A, Liberati F. Near real time load shifting control for residential electricity prosumers under designed and market indexed pricing models. Appl Energy 2014;128:119–32.

[43] Comisión Nacional de Energía (National Commission of Energy of Spain). Informe 19/2013 sobre la propuesta de Real Decreto por el que se establece la regulación de las condiciones administrativas, técnicas y económicas de las modalidades de suministro de energía eléctrica con autoconsumo y de producción con autoconsumo. Madrid: Comisión Nacional de Energía; 2013.

[44] Talavera DL, De la Casa J, Muñoz-Cerón E, Almonacid G. Grid parity and self-consumption with photovoltaic systems under the present regulatory framework in Spain: The case of the University of Jaén Campus. Renew Sustain Energy Rev 2014;33:752–71.

[45] Pozo D, Contreras J, Sauma E. If you build it, he will come: Anticipative power transmission planning. Energy Econ 2013;36:135–46.

[46] Sauma E. Inter-temporal Planning of Transmission Expansions in Restructured Electricity Markets. J Energy Eng – ASCE, 135; 2009. p. 73–82.

[47] Sauma E, Oren S. Economic Criteria for Planning Transmission Investment in Restructured Electricity Markets. IEEE Trans Power Syst 2007;22(4):1394–405.

[48] Sauma E, Oren S. Proactive planning and valuation of transmission investments in restructured electricity markets. J Regul Econ 2006;30(3):261–90.

[49] International Energy Agency. Global EV Outlook: Understanding the Electric Vehicle Landscape to 2020. Paris: International Energy Agency; 2013.

[50] Ministry of the Presidency of Spain. Royal Decree 1053/2014. Official State Gazette 2014; 316: 107446-107481.

[51] Perlo P, Gianinoni I, Celaschi S, Laarakkers J, González MI, Prada L. Green eMotion Project Deliverable 7.4: Year 1 Standardization Workshop-Gaps and recommended actions towards minimal features interoperable charging stations for EVs. Milan: Ricerca sul Sistema Energetico SpA; 2014.

[52] International Energy Agency. Energy Efficiency Market Report 2014: Market Trends and Medium-Term Prospects. Paris: International Energy Agency; 2014. ISBN: 978-92-64-21826-0.

[53] Reddy KS, Kumar M, Mallick TK, Sharon H, Lokeswaran S. A review of Integration Control, Communication and Metering (ICCM) of renewable energy based smart grid. Renew Sustain Energy Rev 2014;38:180–92.

[54] Khan AA, Razzaq S, Khan A, Khursheed F, Owais. . HEMSs and enabled demand response in electricity market: An overview. Renew Sustain Energy Rev 2015;42:773–85.

[55] O'Connell N, Pinson P, Madsen H, Malley O. Benefits and challenges of electrical demand response: A critical review. Renew Sustain Energy Rev 2014;39:686–99.

[56] Siano P. Demand response and smart grids—A survey. Renew Sustain Energy Rev 2014;30:461–78.