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THE ITALIAN GAS SMART METERING OBLIGATION: A STRATEGIC ANALYSIS OF IMPLICATIONS AND OPPORTUNITIES

Masters Graduation Thesis by:
Giacomo Rotigliano
768297

Supervisor: Prof. Alessandro Perego
Assistant Supervisor: Angela Tumino

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To my brothers and best friends Niccolò, Emanuele and Gianluca

Abstract

Italy is the first mover among European Member States towards the introduction of smart gas meters with an ambitious plan set by the regulatory order ARG/GAS 155/08 requiring the installation of 17.5 million smart meters (initially by 2016 then postponed to 2018). This represents an opportunity for the Italian energy system, but as it often occurs in the innovation process being first movers represents a significant risk especially when fostering the acceleration of the diffusion process of the technological breakthrough. This research work therefore aims at assessing the economic implications of fulfilling the smart gas metering roll-out obligation in Italy.

The smart metering technology can be classified in the wider category of Internet of Things technologies. In fact, the “Internet of Things” is a paradigm that is emerging – sustained by the progress in nanotechnologies, sensing, software and communication technologies – and which allows the transformation of various common objects into smart interconnected objects – able to sense their environment, elaborate and communicate information – in an economically sustainable manner. The second macro objective of this thesis is the investigation on opportunities not sought by the 155/08 regulatory order but which may increase the sustainability of the business case by leveraging on synergies with other “Internet of Things” field of application.

Sommario

L'Italia è il primo paese tra gli Stati membri dell'Unione Europea verso l'introduzione di contatori del gas intelligenti con un piano ambizioso fissato dalla normativa ARG / GAS 155/08 che prevede l'installazione di 17,5 milioni di contatori intelligenti (inizialmente entro il 2016, poi rinviata al 2018). Ciò rappresenta un'opportunità per il sistema energetico italiano, ma come spesso accade nel processo d'innovazione tecnologica, essere i "first movers" rappresenta un rischio rilevante soprattutto quando occorre accelerare il processo di diffusione del progresso tecnologico. Questo lavoro di ricerca si propone quindi di valutare le implicazioni economiche all'adempimento della normativa che prevede il roll-out dei contatori del gas intelligenti.

La tecnologia "smart metering" può essere classificato nella categoria più ampia delle tecnologie "Internet Things". In effetti, l'Internet degli oggetti è un paradigma che sta emergendo - sostenuto dai progressi nelle nanotecnologie, sensori, tecnologie software e di comunicazione - e che permette la trasformazione di vari oggetti di uso comune in oggetti intelligenti interconnessi, in grado di percepire il loro ambiente, elaborare e comunicare informazioni in modo economicamente sostenibile. La seconda parte di questo lavoro si concentrerà sulle opportunità tralasciate dalla normativa 155/08, ma che permetterebbero di aumentare la sostenibilità del business case facendo leva su sinergie con altri ambiti applicativi dell'"Internet of Things".

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Last but not least, I wish to express my infinite love and gratitude to my beloved parents for their support and advice throughout my life, and without which the achievement of this goal would have been impossible.

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Executive Summary

Premise

The environmental impact of humans' behaviours is getting nowadays an increasing importance in the international community, in the way companies operate and in governments' policies and decision making. This led to a comprehensive examination and redesign of the entire energy lifecycle in all its sectors and forms, aimed at increasing its economical and environmental sustainability. Into this process, essential is the inclusion of each actor of the energy supply chain and without any doubts smart metering, through its pervasiveness, represents a major lever for embracing the vast domestic energy consumption market. The topic has recently attracted much attention, mainly driven by the current technological breakthrough represented by the evolution towards smart grids. Indeed smart electric meters are the cornerstone for the realization of this upcoming paradigm given their ability to real-time monitor customer's consumption behaviours. Countless scientific papers and articles tackled the topic of smart metering focusing on the electricity sector, but often generalizing the results of the study to broad-spectrum smart metering systems in a more or less explicit manner. This tendency can also be recovered when reviewing the European directives. These aspects led to a general misunderstanding of the capabilities of smart gas metering systems, resulting in a general confusion on similarities and differences with electric smart metering systems.

Italy is the first mover among European Member States towards the introduction of smart gas meters with an ambitious plan set by the regulatory order ARG/GAS 155/08 requiring the installation of 17.5 million smart meters (initially by 2016 then postponed to 2018). This represents an opportunity for the Italian energy system, but as it often occurs in the innovation process being first movers represents a significant risk especially when fostering the acceleration of the diffusion process of the technological breakthrough. In fact the menace of remaining "locked in" to wrong technological solutions may cause catastrophic economic returns particularly when the decision has such long term repercussions.

Objectives

In the present state, the balance between costs and benefits deriving from the introduction of smart gas meters on a large scale is not granted. In fact there is a great level of uncertainty regarding on one hand the technology and instruments enabling telemetering, and on the other on the actual value of the benefits which may be obtained.

In early 2008, the regulating Authority AEEG (Autorità per l'Energia Elettrica ed il Gas; i.e. the Italian authority for gas and electricity) performed a cost-benefit analysis for the introduction of smart gas meters which led it to the ratification of the regulatory order Arg/Gas155/08 mandating their roll-out. Unfortunately, the outputs of this study are only partly published, and therefore an accurate evaluation of the methodology and outputs provided can't be pursued. However, by reviewing the published outcomes a certain level of ambiguity emerges regarding the real amounts of benefits enabled. Indeed, the fact that, besides stating that the costs of introducing smart meters for domestic consumers (representing 95% of the total customers) outweigh the benefits (AEEG, 2008) the roll-out decision has been taken, reflects the AEEG conviction that other benefits enabled by the smart gas metering allow the sustainability of the investment. These benefits however, are not elucidated. Moreover, given the high level of investments needed to achieve the ambitious targets set by the Italian regulator – requiring an estimated total investment of €3,520 Millions (Tani et al., 2011) – it seems necessary to deepen the analysis into the state of art technology available on the market, to assess the technical and economic barriers to their diffusion, with a particular focus on the costs and benefit impacts for major stakeholders. Indeed the regulatory order 155/08 introduces severe obligations for some actors of the gas supply chain (in particular for distributors: the owners of the physical distribution grid) seeking a wide set of benefits for the entire sector.

Objective 1. The first macro objective of this research work is the assessment of the economic implications of merely fulfilling the smart gas metering roll-out obligation in Italy:

- What is the real amount of benefits enabled by the 155/08 regulatory order?
- What are the minimum functionalities that a smart gas metering system should provide for the realization of these benefits and their costs?
- Can the electric smart metering case be brought as an example to appreciate the enabled benefit of smart metering in the gas sector?
- Does the status of technology allow the implementation of these benefits in an economically sustainable manner?

The first part of this work will guide you through these questions focusing on the Italian smart gas metering plan, but incorporating results of various projects in Europe and outside.

The smart metering technology can be classified in the wider category of Internet of Things technologies. In fact, the "Internet of Things" is a paradigm that is emerging – sustained by the progress in nanotechnologies, sensing, software and communication technologies – and which allows the transformation of various common objects into smart interconnected objects – able to sense their environment, elaborate and communicate information – in an economically sustainable manner. This process of innovation is further fostered by the current commitment of the EU, and in cascade of Member States and local authorities towards the implementation of the smart city concept (which as well strongly leverages on the opportunity enabled by that paradigm). Indeed the Internet of Things paradigm represents a necessary requisite to facilitate the development of smart cities as it allows the realization of a ubiquitous infrastructure made of objects aimed at sensing the needs of cities and citizens through their real-time context awareness. The proliferation of these smart objects (such as meters, lamp posts, traffic lights or buildings) implies the creation of various communication network infrastructures to support different applications in diverse fields.

Objective 2. The second macro objective of this thesis is the investigation on opportunities not sought by the 155/08 regulatory order but which may increase the sustainability of the business case:

- Could synergies with other "Internet of Things" and "Smart City" fields of applications be leveraged on to reduce the burden of the smart metering investment?
- What is the state of art picture of each smart city field of application's development in Italy and its future trends?
- What would be the economic impact on the smart metering investment of exploiting synergies with the most prominent fields of application?

Methodology

In order to reach the goals described in the previous paragraph, the research project is structured into six main phases which will be described as follows (cf. Figure 28).

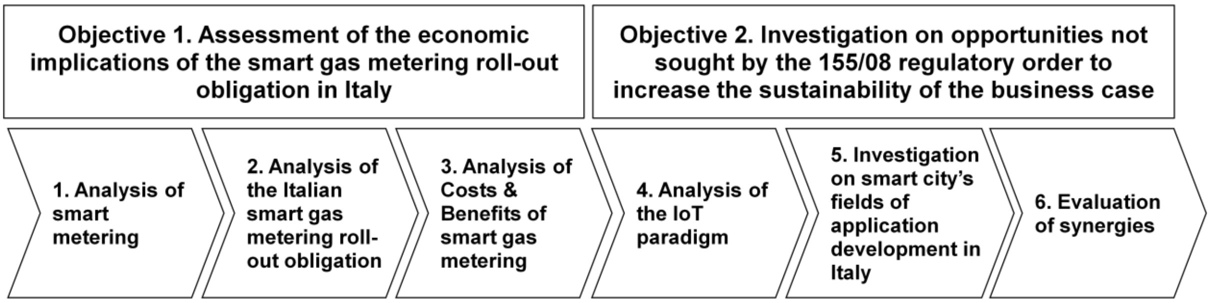

Figure 1: The research steps

- *Phase 1 - Analysis of smart metering:*

There is a confined but growing body of literature both in the academic and generalist press dealing with the emergence of the "Internet of Things" paradigm and more specifically on the smart metering topic. The comprehensive review of 60 papers of these articles has been the first step of this work, with the objective of setting a common comprehension of the concepts and findings of previous studies and providing the lecturer a state of art context framework to better appreciate this research thesis. This first analysis emphasized the lack of research articles tackling the smart metering topic in the gas sector exclusively resulting in a general confusion on similarities and differences with electric smart metering systems therefore implying a general misunderstanding of the capabilities of smart gas metering systems.

- *Phase 2 – Analysis of the Italian smart gas metering obligation*

Subsequently, the description of the Italian gas supply chain and of the regulatory framework has been carried out. In particular, the analysis of the regulatory framework was undertaken considering first the European directories, and then focusing on the Italian framework taking into account the six regulatory orders and consultations emitted by AEEG in the last four years. A face to face interview with the AEEG responsible of the smart gas metering division has also been carried out and resulted precious for eliminating the ambiguity and controversies present on the progressively emitted acts.

- *Phase 3 - Analysis of costs and benefits of smart gas metering:*

Following, the economical valuation of the Italian roll-out plan has been performed. After performing the analysis of the supply market, the benefits and costs of the smart metering roll-out were analysed discussing for each of them the economic mechanism through which they should be achieved, the actors of the supply chain impacted, the methodology and main parameters to take into account for assessing their economic value, a qualitative assessment of the impact in relative terms, and the alternative solutions that may derive the realization of the same benefit. To this aim, in addition to the analysis of major projects undertaken in Italy and abroad, nine meetings with key players in the gas sector have been organized, with the objective of studying the implications and opportunities related to the fulfilment of legal requirements. These meetings emphasized the concerns and hardships different actors in the supply chain were facing.
Given the general confusion between the enabled benefits of smart metering in the electricity and gas sectors perceived both in the European and Italian regulator's approaches, as well as in the literature – through misleading generalizations of results obtained from the electric sector – the comparison between these sectors seemed of utmost importance to highlight the innovative contribution of this master thesis. After clarifying the similarities and differences between the two sectors, and their consequences for smart metering capabilities, an item-per-item comparison with the smart electric metering enabled benefits was performed.

- *Phase 4 - Analysis of the Internet of Things paradigm*

This research phase is aimed at analyzing the "Internet of Things" reference architecture, its main enabling technologies, their state of art picture and future trends, as well as understanding the barriers to its diffusion. This research phase represents the trait-d'union between the first and second objective of this master thesis as smart metering can be classified in the broader IoT paradigm, and the identification of all its field of application paves the way for the proper realization of the following phase of the work. To this aim the Literature review methodology has been exploited as well as the participation to a set of 4 workshops and 4 worktables with experts and professionals representing the leading Italian companies in this technological innovation sector. These brainstorming sessions were aimed at sharing the experience of professional with the results of the academic research.

- *Phase 5* - Investigation on smart city's fields of application development in Italy

This research phase is aimed at assessing the state of art picture of each "Internet of Things" field of application encompassed by the smart city concept development in Italy based on the projects implemented in each of these fields. The analysis is based on the explorative case study tool: 17 case studies have been analyzed through different sources of information to allow data triangulation (among which direct interview, review of material provided from companies and/or retrieved online) in order to get a clearer picture of the decision making process that led to the implementation, the expected benefits, the encountered criticalities, the differences between forecasted and actual results and finally the ways forward. An additional 62 projects, for a total of 84 Internet of Things applications technologies in Italy and abroad have been studied through the analysis of indirect sources with the objective of assessing the state of art picture of each field of application's development, judging their adherence to the IoT paradigm and their maturity and diffusion to better value their future growth.

- *Phase 6 – Evaluation of synergies*

Finally, the evaluation of the exploitable synergies with each smart city field of application on which the smart metering infrastructure could leverage for reducing the burden of the investment was performed. The methodological approach used for this analysis consisted in the following steps:

- Evaluation of the infrastructural requirements and costs to adapt the smart metering solution for the integration with other services.
- Identification of the most prominent fields of application for the integration with smart gas metering based on the outcome of the previous phase.
- Development of a network architectural solution for exploiting synergies with most prominent fields of application.
- Discussion of the strength and weaknesses of the identified solution.

Results

Coherently with the twofold goal of this research thesis, the results will be presented in two sections, each aimed at fulfilling the previously set objectives.

1. Assessment of the economic implications of merely fulfilling the smart gas metering roll-out obligation in Italy

The introduction of smart meters allows the realization of benefits affecting different actors in the gas supply chain; these can be classified in two major categories: reduction of operative costs – through the optimization of activities in the industrial processes; and non-operative benefits and future options. Following these benefits will be discussed as well as the costs deriving by the smart metering implementation.

- **Operative benefits**

These benefits can further be subdivided into four major categories (cf. Figure 2):

(i) *Mandatory reading costs:* smart gas meters allow the complete elimination of the burden of the yearly physical meter reading. However, given its low impact on the overall operating cost in the pre-introduction scenario, the benefits this cost item result marginal both in the electricity and gas sectors

(ii) *Interventions on the meter:* this cost item conversely has a great impact in the pre-introduction scenario as it encompasses the cost of sending operators at clients' households whenever a security issue is detected or a request from the supplier or customer is received. These include meter readings for commercial purposes (e.g. meter reads when a customer switches between different suppliers), interaction with the meter to assess its status, and telemanagement, i.e. the remote de-activation and enablement of activation of gas withdrawals. This is particularly enabled by the presence of an electrovalve in the meter which can be remotely shut, therefore de-activating gas supplies. Through this mechanism, delinquent behaviours and customer's arrears are also expected to diminish as the menace of deactivating gas supply becomes real in consumers' perspective. However major criticalities were encountered towards the effective use of the electrovalve relative to security issues (i.e. the valve cannot be opened remotely thus requiring the outgoing of an operator) as well as to the technical and functional requirements and implications of this component (i.e. its utilization significantly burdens on the meter's battery lifetime). This voice item represents a major element of distinction between the potentialities of smart metering in the electric and gas sector. Indeed, the possibility of remotely adjusting, activating and deactivating power supplies in the electric sector allows automating many processes (e.g. enabling the possibility of reducing the power provision to arrear' customers unless they pay the bill), while significantly reducing the labour force required by distributors (DSOs)

(iii) *Billing process:* This voice encompasses all the costs for customer's withdrawals estimates, validation process, the issue of adjustment invoices and customers' invoice complaints handling processes. Smart meters allow their automation and optimization in both sectors, representing for the gas supply chain the major operative benefit.

(iv) *Call centres and materials:* These items account for the personnel and organizational costs related to the use of the call centre and the costs of materials (i.e. mainly the burden of keeping meters in stock). They represent a marginal voice as they account together for 2.7% of all operating activities impacted.

Figure 2 illustrates how, conversely to the electricity sector, no killer application is detected from the introduction of smart gas meters.

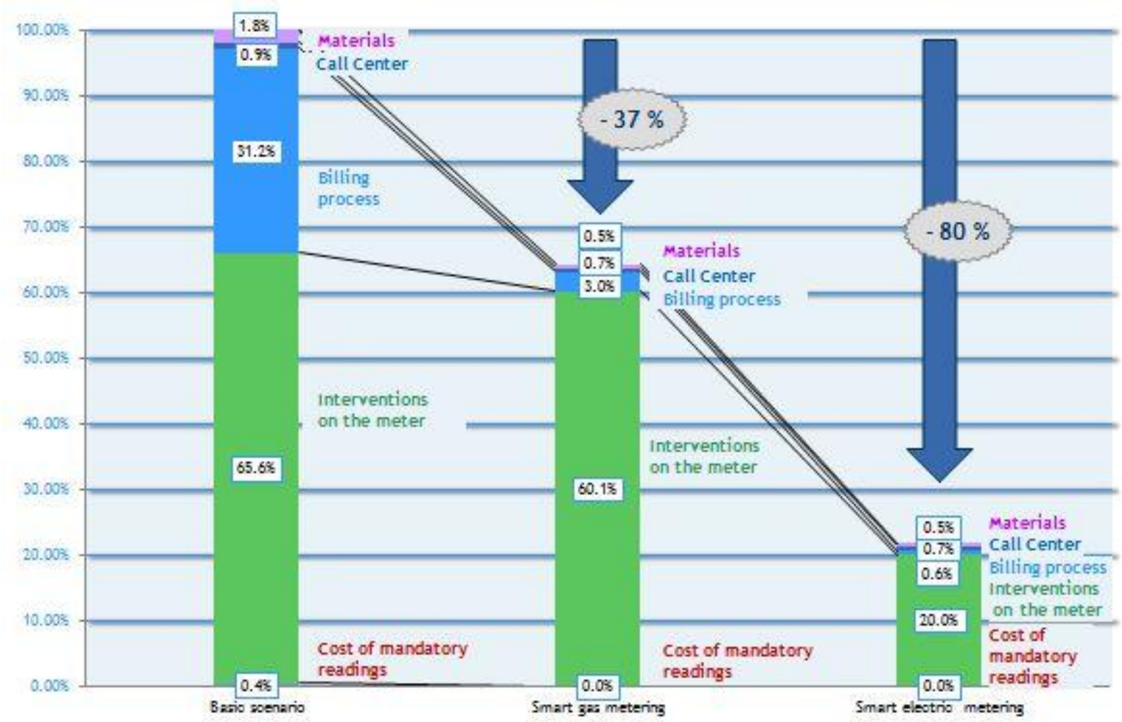

Figure 2: Operating benefits of the smart gas and electric metering roll-out

- **Non operative benefits and future options:**

The introduction of smart meters speeds up the liberalization process affecting the energy sector in Italy and increases the transparency and competitiveness of the market. In one hand because the switching procedure between different gas supplier is lightened – as operators visits at customer's household for reading the meter are not required anymore –

and on the other hand because they allow a more accurate determination of the costs caused by consumers withdrawals and their allocation, therefore consenting an increased alignment between the price of supplied gas and its actual cost.

A further macro objective sought by the regulator and clearly revealed in its cost-benefit analysis is related to the reduction of CO_2 emissions. Indeed, the continuous provision of accurate consumption data to customers, together with adequate price signals might foster customers' consumption awareness; this in turn could be translated into a change on consumption behaviours resulting in a general reduction of the cost of the withdrawn gas. Though, to this aim an appropriate interface to provide consumption feedbacks to the client should be foreseen (e.g. in-home-display, information through a web portal, etc.) but the Italian regulator does not seem to appreciated the relevance of this aspect, as the only reference to the provision of information to clients is pursued by setting the requirement of a display to be placed on the meter (whose access results often not ease for customer as meters are often placed in balconies, basements, building common areas, etc.). Besides, conversely to the electricity sector where many scientific studies tackle this issue, no evidence emerges in the Literature regarding the real possibilities of changing customer's gas consumption behaviours – in fact the real price elasticity of customer's gas consumption patterns is doubted as its uses mainly refer to heating purposes, cooking and production of sanitary hot water (mainly showering). The analysis of the international initiatives on smart gas metering highlighted the greater relevance given to this aspect by most advanced countries on the topic. Indeed the cost-benefit analysis performed in France and in the UK considers the provision of consumption feedbacks to clients the core element allowing the sustainability of the business case.

Anyhow, it must be stated that the potential impacts on consumption behaviours result significantly lower than in the electricity sector where the emergence of the smart grid paradigm, besides increasing customer's energy awareness, is expected to pave the way for an active participation of the consumers in the energy market. Indeed future options seem to be the engine of the smart electric meters development as their roll-out represents the first step towards the realization of smart grids whose benefit are expected to increase the efficiency, effectiveness, safety and independence of the all power system itself. In the gas sector there is not an equivalent of the smart grid as its development is mainly related to the impossibility of storing the electric power – electricity has to be consumed simultaneously upon its production; and to the development of distributed generation enhanced by the growth of renewable energy production.

Referring to the electric case for highlighting the benefits of smart gas metering therefore results inappropriate and misleading as the structure of enabled benefits presents substantial differences and represents a marginal part of the ones enabled in the electricity sector.

- **Costs**

Furthermore the realization of the above mentioned benefits, and therefore the sustainability of the business case strictly depend on the technical solution opted for. To this respect the 155/08 regulatory order introduces a set of severe constraints as it is not limited to planning the smart gas meters roll-out but introduces noteworthy novelties and innovations regarding functionalities and uses of gas meters: newly conceived temperature correction mechanisms, telemetering, telemanagement, electrovalve, etc. These innovations, despite having fostered remarkable progresses in the sector, caused relevant practical and technical problems, and resulted in an increased cost of the meter of 40% (with severe repercussions on the sustainability of the business case as the meter acquisition cost represents a major voice of the total capital expenditure for introducing smart gas metering). To give a picture of the differences in the capital expenditures in the electricity and gas sector it can be pointed that the simple cost of acquisition and installation of smart gas meters results 2.25 times higher than the total smart electric meters roll-out cost. To this cost than needs to be added the cost of the IT system, of the communication infrastructure needed to transmit the data from customers' households to the central acquisition system requiring the deployment of different hardware components (concentrators, repeaters, translators of signal, etc.) and of other minor cost voices.

Also the operative costs result increased when compared with the electricity sector and whether compared with the operative benefits the actual unsustainability of the smart gas metering roll-out in the domestic market becomes evident. This is mainly due to the higher maintenance and operation costs derived by the impossibility of feeding the meter through the power line (because of security issues), requiring the need of a battery and the design of a communication architecture aimed at optimizing its usage (a real-time data communication would result unfeasible). The presence of a battery also impacts on distributor's inclination towards the use of the electrovalve as its remote de-activation drastically reduces the battery life-time, therefore impacting on the actual amount of benefits enabled.

Furthermore the simulations performed in collaboration with the Department of Electronics and Information on the battery lifetime depending on the communication technology used and the frequency of communication suggests the need of changing the battery of each domestic meter unit in the middle of its lifetime (as the meter metrological validity is of 15 years while simulations revealed an average duration of the battery of eight years) therefore implying a massive replacement operation further worsening the cost of maintenance and operations.

Finally the analysis emphasized that the business case has to be carried out on a long time horizon (15-20 years) deriving significant repercussions on customer's bills, therefore suggesting to reconsider the timing of the roll-out plan. Indeed, the cost benefit analysis of the AEEG (AEEG, 2008a) doesn't evaluate the sensitivity of the obtained results to the timings of the roll-out plan. The set of early deadlines and ambitious targets by the regulator in such a pre-mature phase seems to be a consequence of the brilliant experience Italy has had with smart electric meters (whose roll-out was completed over ten years before other Member States); indeed the roll-out regulatory framework seems aimed at maintaining this record. Nevertheless, it is not yet comprehensively completed as the most crucial technical specification emitted by the CIG regarding our analysis, the UNI/TS 11291-7 which deals with telemanagement systems, concentrators, repeaters and translators is still under elaboration. The innumerable news and adjustments to the original 155/08 order, together with the uncertainty regarding technical standards created a certain hesitation and wait-and-see policy on the actors responsible for making the investment. To conclude, being first movers in this technological innovation process – conversely to the electric sector where operative benefits justified the early implementation – doesn't derive any benefits for the country. In fact, the spontaneous technological research trend (related to the emergence of smart grids) is expected to produce in the next future a new generation of metering devices with augmented capabilities at lower costs. In addition, the smart metering investments undertaken in foreign countries would certainly derive positive impact on the technological development of the smart metering infrastructure as learning economies are generally relevant in the initial of introduction of a new technology. Thus projects launched later can leverage on the experience and know-how gained from the first movers. Finally, as the technology matures, the competition on the supply market of metering units should increase, thus reducing the overall cost of the project (recalling the great incidence of the meter acquisition cost on the overall Capex investment).

This said, distributors have to comply with the actual regulation setting clear deadlines and functional requirement for the solution to be implemented. The largely negative balance between the costs the distributor is asked to sustain and the benefits he perceives explains the general approach Italian distributors are following for complying with the 155/08 that is the minimization of the total cost. However, this approach might result in wasting an opportunity offered by this technological innovation.

2. Investigation on opportunities not sought by the 155/08 regulatory order but which may increase the sustainability of the business case

The smart metering roll-out presented distinctive field technical peculiarities and infrastructural constraints which involve the need of a flexible solution which has to be technically optimized considering each installation area separately. The intrinsic flexibility of the smart metering solution allows the opportunity of envisioning a communication network which can be shared with other smart city components, whether these are available (at present or in the future). To be exploited as a component of the larger smart city infrastructure, the smart metering infrastructure needs to present some features and characteristics which need to be planned and foreseen in the initial roll-out phase with a forward looking approach: an increased interoperability, flexibility and scalability, besides foreseeing the appearance of an independent actor for managing the communication network and transmitting the data to each of its users.

In the vast majority of Italian cities, the smart city infrastructure is not yet a reality; many components of it are still missing and the analysis of all smart cities' fields of application revealed an inhomogeneous state of art picture of the different fields considering their technological development towards the IoT paradigm, their maturity, diffusion and development trends. Figure 3 illustrates the state of art picture of each "Internet of Things" field of application based on the projects analyzed. The investigation on other fields of application which could share the same communication infrastructure with the smart gas metering is performed focusing on the fields of application which resulted to have a certain degree of maturity (i.e. experimental or consolidated), implying that their diffusion might experience a significant growth in the next future (within the lifetime of the smart gas metering investment). Furthermore, the fields of application which result having a low degree of adherence with the IoT paradigm are left out of the analysis as this implies that their communication infrastructure doesn't present the requirement for integration with other services (e.g. based on custom communication solutions, reduced interoperability, no multi-functionality, etc.; cf. Figure 3 the red area).

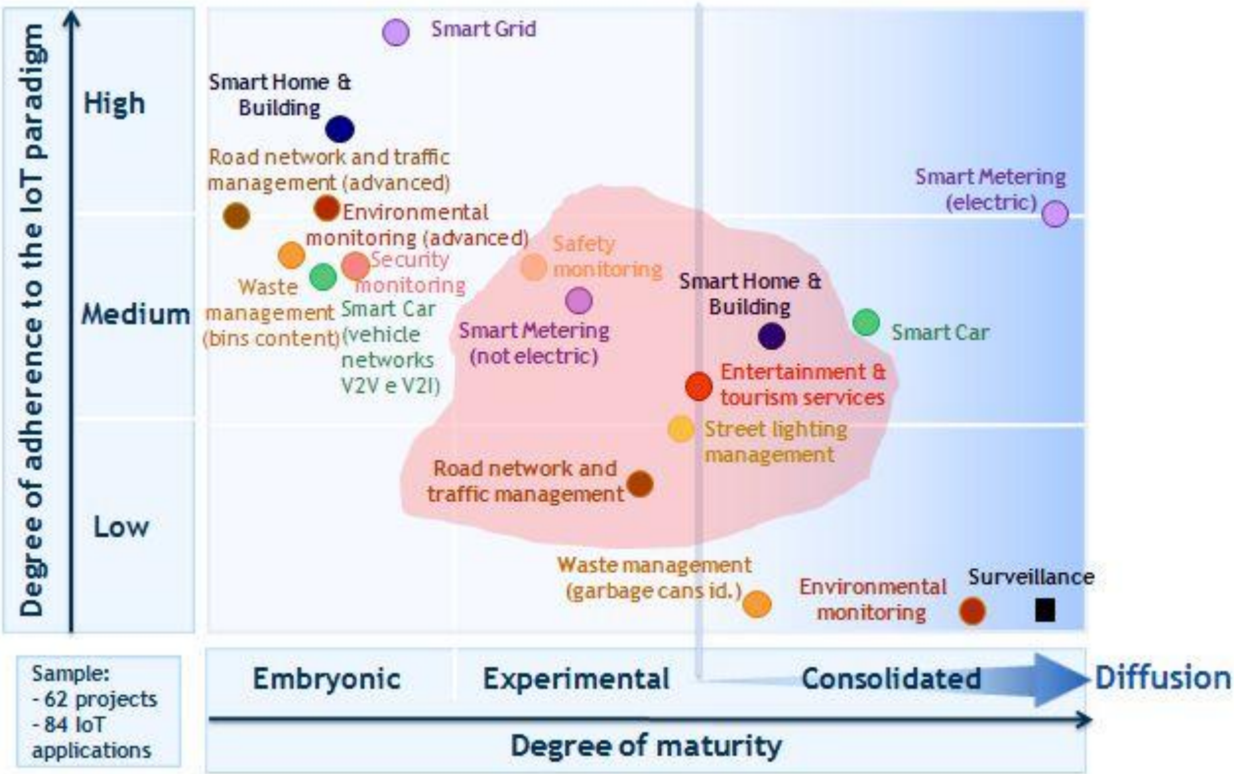

Figure 3: Smart city fields of application maturity and adherence to the IoT paradigm

The actual electric smart meters has been left out of the focus in Figure 3 as, although having a great level of adherence to the IoT paradigm, don't present the interoperability and scalability requirements to be integrated with another communication infrastructure – however the second generation smart electric meters to be deployed in 2016 will present those requirements as they are required to enable the smart grid paradigm. The "smart car" field of application, although diffused, doesn't appear in the red area of Figure 3 as is often based on custom solution, and intrinsically doesn't present any synergies with the smart metering infrastructure (i.e. the communication network can't be shared).

Based on these fields of application, three service architectures have been studied characterized by increasing levels of integration but lower feasibility rates (considering the current infrastructural development):

- integration with other utilities (i.e. exploiting synergies with heating meters, water meters and electric meters);
- integration with other smart city infrastructural components (i.e. adding to the communication infrastructure lampposts, safety and environmental monitoring devices, security cameras or cameras for traffic management, etc.);
- integration with other smart city infrastructural components and smart homes (i.e. adding also home devices on the same communication infrastructure; cf. Figure 4).

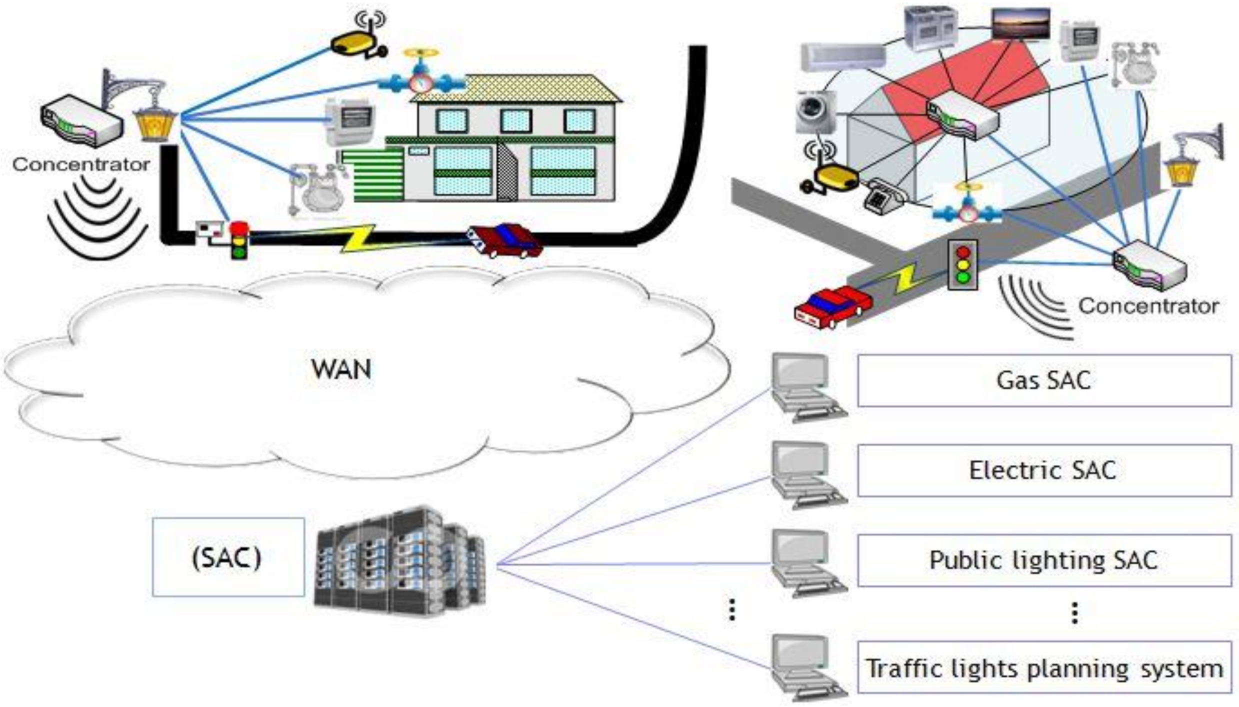

Figure 4: Integration with smart city and with smart home: architectural solution

The resulting infrastructure thus presents the following strengths:

- Coherence with European mandate M/441 and with last AEEG's resolution papers calling for pilot project proposals (DCO 40/11 and DCO 28/12)
- Scalability: a multi-service solution allows exploiting the communication infrastructure for subsequent needs. Indeed it tolerates the extension to other services to be provided through the same infrastructure with marginal incremental costs. The solution can be installed in the present exclusively for smart gas meters, but can be extended to other smart city services.
- Flexibility: the solution can be customized for different users' needs and requirements
- Effectiveness: the solution enables an effective transmission of consumption data to the customer therefore satisfying the European directives aimed at increasing customer's awareness of their energy usage
- Efficiency: a unique communication infrastructure – and in particular a single concentrator – is sufficient to implement the system. By optimizing field devices' configuration, the costs of operations and maintenance will reduce as the unitary costs of each operation will decrease. Furthermore the cost of the service for each user should decrease as the number of users increase.

- Possibility of new service creation: this solution enables the opportunity of providing value added service to customers through a simple communication with its local area network

While the main criticalities of the resulting multi-service infrastructure are:

- The investment costs (for gas distributors) is higher, particularly in the initial phases given the higher potentiality of the system
- Organizational and planning costs are also higher given the relatively higher complexity of the communication system and the different actors involved. Forecasts on the future users of the system need to be performed in all different locations to assess the value of this option in different areas
- Need of local administrations support in fostering the adoption of the system by different actors of the city (lamppost management – utilities – regulations for building access – etc.).

To pursue the work of this master thesis, future research should be addressed at the smart metering topic in the gas sector, notably concentrating on domestic consumption behaviours with the aim of assessing the real potentialities of consumption reductions or switches over time depending on the type of feedback provided to consumers. The potentiality of new service provision based on the wide set of information generated by domestic smart gas meters should also be investigated. Finally, the realization of pilot projects to test and study the resulting shared communication architectures would further shed light on the operative, technical and managerial complexities of the multiservice metering infrastructure.

Chapter 1 - Internet of Things

This chapter is aimed at introducing the concept of Internet of Things, reviewing the Literature on the main enabling technologies, their state of art picture and future trends for the development of the IoT paradigm, as well as providing a picture of its main fields of application.

1.1 Concepts and definitions

1.1.1 Literature review on the Internet of Things concept

In the last decade billions of people have connected to the internet through computers, and more recently through mobile devices capable of combining their core functions to access the network (e.g. smartphones). This communication revolution is now evolving from people to objects. Although communication between objects has repeatedly been envisaged, it was often considered an unattainable horizon; but the steady advances in microelectronics, communications and information technology that were witnessed in recent years opened the doors to the "Internet of Things" paradigm. Through this paradigm, everyday objects – from furniture, food and clothing to personal electronics, appliances, cars and houses – gain a digital identity which allows the direct link between the physical world and the digital one enabling a whole new class of applications and services.

This interconnection of physical objects will amplify the effect that the communication networks will have on our society: innovative applications will emerge from this social context, improving connectivity and accessibility. For instance, logistics processes will be more efficient, paving the way to a revolution in commerce and retail; intelligent buildings, robots and smart cities will arise and will facilitate people's daily life by increasing its quality; factories will no longer require the human presence at all; a comprehensive view of all the consequences that IoT will have in the future is impossible to provide at this stage of development although its pervasiveness and ubiquity seem undoubted.

Diverse definitions of "Internet of Things" traceable within the research community give evidence of the strong interest on IoT issues and of the vivacity of the debates on it. By browsing the literature, an interested reader might experience a real complexity in understanding what IoT really means, which basic ideas stand behind this concept, and which social, economical and technical implications the full deployment of IoT will have.

The IoT concept was first drawn into attention by Mark Weser – a researcher of Xeros Parc in Palo Alto, California – over two decades ago through his theory on ubiquitous computing:

"Specialized elements of hardware and software, connected by wires, radio waves and infrared, will be so ubiquitous that no one will notice their presence" (Weiser, 1991)

"Our preliminary approach: Activate the world. Provide hundreds of wireless computing devices per person per office, of all scales. [...] We call our work "ubiquitous computing". This is different from PDA's, dynabooks, or information at your fingertips. It is invisible, everywhere computing that does not live on a personal device of any sort, but is in the woodwork everywhere." (Weiser, 1988)

He believed that computers were to become invisible, disappearing into the environment so that people would use them in a natural way. As a result, computers shouldn't create an artificial world, but simply enhance and support the existing one: technological research should be focused on human beings and their needs. Ubiquity, according to Weiser was not simply related to the shift from fixed computers to laptops or mobile devices, conversely it rather referred to the necessity of integrating technology into the human context to enhance people's attitude towards exploiting its full potentiality.

"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it. […] the idea of a "personal" computer itself is misplaced, and that the vision of laptop machines, dynabooks and "knowledge navigators" is only a transitional step toward achieving the real potential of information technology. […] Ubiquitous computing in this context does not just mean computers that can be carried to the beach, jungle or airport." (Weiser, 1991)

In this quote emerges Weiser's definition of what will later be called IoT. He had the vision of a hidden technology (from users perspective), able to interconnect machines and facilitate people's work through information sharing. The expressed level of detail regarding implications and potentials of the gleaned technology results astonishing and particularly apt over twenty years after his intuition.

A decade after Weiser's intuition, the ubiquitous computing topic was again brought into attention at the Massachusetts Institute of Technology (MIT), from work at the Auto-ID Center. Founded in 1999, this group was working in the field of networked radio frequency identification and emerging sensing technologies. David L. Brock, researcher and co-director at the MIT Auto-ID centre coined the term Internet of things:

"Our vision is to create a "Smart World" that is, an intelligent infrastructure linking objects, information and people through the computer network. This new infrastructure will allow universal coordination of physical resources through remote monitoring and control by humans and machines. Our objective is to create open standards, protocols and languages to facilitate worldwide adoption of this network – forming the basis for a new "Internet of Things. […] We envision an intelligent infrastructure which automatically and seamlessly links physical objects to the global Internet." (Brock, 2001)

The goal of the Auto-ID Centre was to architect the IoT together with the EPC Global[1] to support the spread use of RFId in worldwide modern trading networks by consolidating the underlying standards required. These standards are mainly designed to improve object's visibility: traceability of an object, awareness of its status, current location, etc. The above definition therefore derives from a "Things oriented" perspective; the considered things are very simple items: Radio-Frequency Identification (RFId) tags. However, although representing a major pillar for the development of the IoT, RFId is not the unique enabling technology; Near Field Communication (NFC) and Wireless Sensors and Actuators Network (WSAN) also stand at the forefront of the technologies driving this vision. This issue has been clearly pointed out by

[1] The EPCglobal Architecture Framework, EPCglobal Final Version 1.3, Approved 19 March 2009, <www.epcglobalinc.org>.

the definition the US-National Intelligence Council provided on the report on disruptive technologies; here a detailed definition of smart things is argued:

"The term Internet of Things appears to have been coined by a member of the RFId development community circa 2000, who referred to the possibility of discovering information about a tagged object by browsing an Internet address or database entry that corresponds to a particular RFId.[…] Since that time, visionaries have seized on the phrase "Internet of Things" to refer to the general idea of things, especially everyday objects, that are readable, recognizable, locatable, addressable, and/or controllable via the Internet — whether via RFId, wireless LAN, wide-area network, or other means"(US-NIC, 2009)

In 2005 the International Telecommunication Union (ITU) also provided a definition of the IoT which foresees the augmentation of "everyday objects" capabilities (coherently with the "things oriented vision"), but underlies as well the need of a network able to seamlessly include every object:

"Today, developments are rapidly under way to take this phenomenon an important step further, by embedding short-range mobile transceivers into a wide array of additional gadgets and everyday items, enabling new forms of communication between people and things, and between things themselves. A new dimension has been added to the world of information and communication technologies (ICTs): from anytime, anyplace connectivity for anyone, we will now have connectivity for anything. […] The Internet of Things is neither science fiction nor industry hype, but is based on solid technological advances and visions of network ubiquity that are zealously being realized." (ITU, 2005)

This quote emphasizes the conceptual and social breakthrough emerging by the realization of this paradigm, introducing the relevance of communication between objects. Conversely to the "Things oriented vision", the "Internet oriented vision" identifies the communication as the development direction, focusing on what enables the interactions through the network. Indeed, both the IPSO (IP for Smart Objects) Alliance – leading organization in the promotion of the use of the Internet Protocol for the communication between small objects – and the Internet Ø (defined as a low speed physical layer designed to route the "IP over anything"), focus their efforts on the research of protocols enabling the connection of disparate objects to a same network. Their aim is to simplify the current IP in order to fit it to every type of object and make it identifiable and accessible independently from the location and time: enabling a platform for pervasive computing. This research, based on the study of the Internet Protocol, which is called "IP over anything" from the Internet Ø (N.Gershenfeld et al., 2004) is widely regarded "as the wisest way to go from the Internet of Devices to the Internet of Things" (Atzori et al., 2010).

A further definition, acting as *trait d'union* between those two visions is the one provided by the CASAGRAS consortium (Coordination and support action for global RFId-related activities and standardization):

"A global network infrastructure, linking physical and virtual objects through the exploitation of data capture and communications capabilities. This infrastructure includes existing and evolving Internet and network developments. It will offer specific object-identification, sensor and

connection capability as the basis for the development of independent federated services and applications. These will be characterised by a high degree of autonomous data capture, event transfer, network connectivity and interoperability." (CASAGRAS, 2009)

This definition is focused on connection, automatic identification and data collection technologies that will be leveraged for integrating the objects in the Internet of Things and assumes that this paradigm will be built upon the existing Internet communication infrastructure. Besides providing a definition for the IoT, CASAGRAS recalls the semantic meaning of the term "Internet of Things"; in fact, Internet stands for a global system of interconnected computer networks that use the standard Internet protocol suite (TCP/IP) to serve billions of users worldwide, while *Things* stand for objects non precisely identifiable. Combining these two elements, IoT would mean *"a global network of interconnected objects uniquely addressable, based on standard protocols."* (Bassi and Horn, 2008)

This definition is particularly in line with the recent explanation provided by the EPoSS (European Technology Platform on Smart Systems Integration) and the DG INFSO (Information Society and Media Directorate general of the European Commission) on the report published in 2008:

"Things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts. A different definition, that puts the focus on the seamless integration, could be formulated as interconnected objects having an active role in what might be called the Future Internet". (Bassi and Horn, 2008)

This quote expresses a comprehensive explanation of the IoT underlying the difficulty in providing a unique explanation to such a wide paradigm. Indeed the first perspective it discloses focuses on the functionalities and identity of the objects inserted in intelligent contexts, while the second one centers the attention on the broader interconnection of everyday object.

The various definitions provided tackle the IoT concept by using different perspective and focuses, among which have been identified the:

- Unique identification of objects
- Communication between objects
- Connection between the real world and virtual one
- Connecting to the Internet (no proximity constraints)
- Systems' autonomy (reduced need of humans)
- Information generation (knowledge creation through the greater amount of data generated by the interconnection of objects)

The following table summarizes the various definitions provided according to their focus with the aim of analyzing the relative importance of the aspects tackled by the manifold definitions provided according to their recurrence:

	Unique identification of objects	Communication between objects	Connection between the real world and virtual one	Connecting to the Internet	Systems' autonomy	Information generation
Weiser, 1991			X		X	X
Auto-ID Center, 2001	X		X			
ITU, 2005	X	X	X			X
IPSO Alliance & Internet Ø	X	X		X		X
EPoSS & DG INFSO, 2008		X	X	X	X	X
CASAGRAS, 2009	X	X	X	X	X	X
US-NIC, 2009	X	X	X	X		X
Number of citations	**5**	**5**	**6**	**4**	**3**	**6**

Table 1: Focus of the various definitions of the IoT paradigm

1.1.2 Conclusions

The term Internet of Things describes an already initiated process in the technological development, whereby through the Internet, potentially every object of our daily experience acquires its own identity in the digital world.

The essence of the IoT relies on smart objects. An object is defined as smart whether it possesses one or more features of self-awareness, interaction with the surrounding environment and data processing, as well as the ability to connect and communicate information owned, collected or processed.

Indeed, the intelligence embedded in smart objects can be developed through three main axes:

- **Self-awareness functionalities:**
    - *Identification:* the possession of a unique digital identifier. This characteristics lays at the basis of each IoT application
    - *Localization:* the ability of objects to know their position. The localization can be implemented in real time, or through the elaboration of information collected through the production and logistics processes (tracing)
    - *Asset Management:* the ability of monitoring the object's internal parameters aimed at ensuring its proper functioning and perhaps request for assistance
- **Interactions with the surrounding environment:**
    - *Data Acquisition:* which can be accomplished through Sensing (measurement of state variables such as temperature, humidity, noise, pressure, etc) and Metering (measurement of flow variables such as electricity, water, heat or gas consumption)
    - *Actuation:* the ability of executing remotely assigned commands or actions derived by objects' processing capabilities
- **Data processing capabilities:**
    - *Basic processing:* elaboration of the primitive data collected, perhaps through filtering, correction, algebraic combinations, conversions, encriptions, etc.
    - *Advanced processing:* extraction of information from the primitive data collected, perhaps through statistical analysis, inferences, forecasts, etc.

The intelligence underlying IoT application is not limited to the one embedded in smart objects, conversely it penetrates into the essence of the network interconnecting them. Standardization and openness, reachability and accessibility are the network evolutionary lines enhancing the development of the IoT paradigm.

Indeed, there are manifold applications where objects possess a certain degree of intelligence enabling the communication on the network of information they collected or processed. However, in most cases those applications make use of proprietary protocols or "closed" technologies. Instead, by focusing on the factors that enabled the worldwide Internet success, some properties embedded in IoT applications can be defined:

- **The use of open standards** for all application layers interfacing with the physical world (i.e. tags and sensors) both for data acquisition, for the communication between nodes and for the communication between nodes and the network. Besides the economic benefits derived by the interoperability of distinctive devices, the use of open standard is essential to simplify and accelerate the development of the application layer above.
- **Data accessibility and object reachability:** as a significant portion of the internet value is enhanced by the public availability of information contained in it, in parallel an enabling factor of the IoT is represented by the openness of the data collected by tags and sensors to the widest number of users, stakeholders and developers. However, the data availability represents only a portion of the required accessibility for the full deployment of the IoT paradigm, in fact as it happens in the Internet, where each resource is directly reachable through its IP address, to enhance the full capabilities of IoT every object

should become directly reachable and addressable, not requiring the mediation of a dedicated service.

Finally, the intelligence of the IoT paradigm is enhanced in the application layer through the multi-functionality of the manifold nodes composing the network. Indeed, this characteristic exhibits the full capabilities of the IoT as an application built for a specific objective can be leveraged on for transversal purposes: a tag and sensors infrastructure erected for traffic monitoring can be used for monitoring the crowds during major events.

1.2 Technological overview

1.2.1 Enabling technologies

The IoT paradigm can't be traced to a single novel technology; conversely several complementary technical developments provide capabilities that taken together help to bridge the gap between the physical realm and the virtual world.

it includes manifold technologies to enable the identification of objects, the collection, storage, processing and transferring of information from the physical realm to the digital world. Although the appearance of the IoT is related to the progress in a widespread set of technologies, by reviewing the literature, it can be stated that researchers agree on the fact that the backbone of all the devices lies behind Radio Frequency Identifiers (RFIds) technology followed by sensor networks (Wang, 2010) (Iera, 2010) (Atzori, 2010) (Ferreira, 2010). Moreover, it is generally recognized that the full IoT potential is enhanced by the integration of these two technologies (WSN and RFId) (Jedermann and Lang, 2006).

Following, the major enabling technologies will be introduced and discussed.

1.2.1.1 *RFId*

Although the Radio Frequency Identification technology is often referred to as the technology of the future, its origins can be traced to the Second World War. Indeed, it appeared as a tool used by British forces to identify their own planes, and distinguish them from their enemies' – at that time radars were only able to identify the presence of nearby airplane, without any distinction. They therefore equipped their aircrafts with a transponder which, when interrogated by a reader would issue a cryptic sign enabling its unique identification.

More recently, a key role for its worldwide diffusion was played by the Auto-ID Center, a research project directed and coordinated by the Massachusetts Institute of Technology (MIT) aimed at studying new standards for RFID technologies and methods for the unique identification, on a global scale of individual objects, in order to facilitate trade, transfer of information and activities along the supply chain.

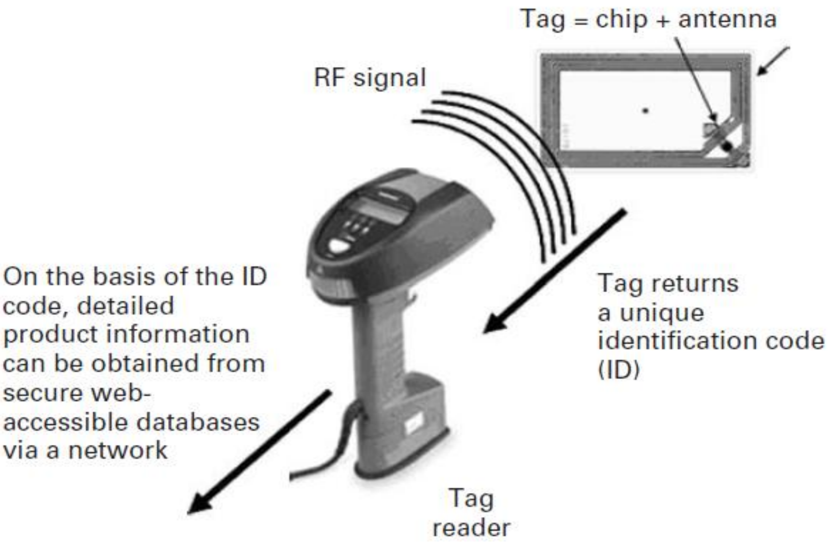

Figure 5: RFId system representation (Miles et al., 2008)

From the constructive point of view, an RFId system presents three major components (Talone et al., 2008):

- A ‘Tag’, or transponder whose main function is to store data and transmit it to the reader; it consists in a chip and an antenna, protected and connected by a special structure in plastic or paper. Generally, the chip contains the memory in which information is written and read, and depending on the type of tag batteries may be present or not.
- The ‘Reader’, or transceiver is the device that reads the information contained in RFID tags. It transmits an interrogation signal via an antenna and is capable of receiving the response of the tag. It then communicates the received information to the management system. The reader may also be capable of writing information into the tag.
- The ‘Middleware’, which collects the information contained in the tags and makes it available to the application that makes use of the RFID system.

Depending on power supply sources, tags can be distinguished into different classes (Hunt et al., 2007) (Williams et al., 2008) (Finkenzeller,2003):

- **Active:** they include power supply (battery), which allows them to communicate with less powerful readers and transmit information over long distances, up to hundreds of meters. Moreover, they are also equipped with a significant memory (up to 128 kBytes). However, the larger dimensions and the constructive complexity make them quite expensive.
- **Passive:** they do not incorporate any internal power supply, but pick up from the radio signal sent from the reader the energy required to transmit data. As a result, passive tags result smaller and require lower manufacturing costs than active tags, but can cover only short distances, they contain small memories and, depending on the application, may require very powerful readers.

- Battery-assisted passive: they have a miniature battery, used to supply only some parts of the tag. They can further be subdivided into semi-active – where the battery is used to power the microchip, or electronic components such as sensors, embedded in the tag – and semi-passive – although the battery is used to power the transmitter and the chips, these are deactivated to save energy until they are interrogated by the reader: they use the reader's power to transmit a message back to the RFId reader using a technique known as backscatter (Simson Garfinkel, 2005).

Compared to the bar code and other identification technologies, RFID systems have many advantages, including reading without the need of direct contact, the ability to simultaneously read various tags, the high strength of the latter in harsh environments, the bigger information contained, the possibility of updating it continually, etc. In conclusion, although the RFID tags imply significant higher costs than bar codes, the cost/benefit analysis is absolutely in favor of the former one.

1.2.1.2 *Near Field Communication*

The acronym NFC technology defines a short-range wireless communication, which allows the exchange of data between neighboring devices. The Near Field Communication is not a completely new technology, but represents the evolution of the RFID technology. It was jointly developed by Philips and Sony in 2004. It is the result of the combination of two technologies: Contactless ISO 1443 (RFID read/write high-security cards used for banking, cards, electronic identity documents ...) and Mobile GSM (Medaglia, 2010).

The NFC standard, which encompasses codes, transmission speed, transfer protocol and interfaces of the involved devices, was approved in 2003 by EMCA (European Computer Manufacturers Association), ISO and IEC (International Electrotechnical Commission).

Unlike RFId, the NFC communication is enabled through a two-way communication: if two NFC devices are put together they create a peer to peer connection between the two and both can send and receive data at a maximum distance of 10cm. NFC operates at a frequency of 13.56 MHz and has a maximum transmission rate of 424 kbit/s (Talone et al., 2008). This technology, which has been integrated in some new models of smartphones, can be used to emulate a contactless card (for example for services electronic ticketing), for exchanging data in a peer to peer (for example for reading smart posters) or in read mode (acting as a passive tag RFID).

The diffusion process of the NFC technology, conversely to what were the forecasts, is growing at a contained rate. The major limit to its diffusion is represented by the standardization; in particular a strong debate has arisen for what concerns the location of the secure element (a chip which allows the secure storage of user's data such as PIN and credit card credentials) to be placed in the SIM cards or in terminals' hardware.

1.2.1.3 *Bluetooth*

The Bluetooth term derives from the nickname of the Danish king Harold Gormsson, who lived in the first century AD and was called Blatand (blue tooth) as he often had a smile bluish because of his passion for blue berries. He had the merit of linking Denmark, Sweden and Norway, land divided not only by sea, but also from different traditions and secular disagreements: similarly, the Bluetooth technology had the target of connecting different objects, such as phones, notebook computers, stereos, etc.., without any cable connections, using radio frequency. (Labiod et al., 2007)

The Bluetooth standard was developed jointly by 3 Com, Ericsson, Intel, IBM, Lucent, Microsoft, Motorola, Nokia, and Toshiba, and was subsequently adopted by more than 1,300 of the largest IT companies and telecommunications. It uses a transceiver contained in a single chip and can operate within a distance of 10 m, extendable up to 100m by integrating the system with an amplifier. All Bluetooth equipment can generate small wireless networks. The wireless link is performed using a transceiver that operates in the frequency band of 2.45 GHz (assigned for industrial uses). The frequencies used vary from country to country, depending on national regulations, for example, in Europe using frequencies between 2.402 and 2.480 GHz (Goldsmith, A., 2005).

Bluetooth handles both data and voice, using a transmission of a packet radio network for data and a connection-oriented mode for voice. In addition, Bluetooth can enable a communication broadcast (the broadcaster transmits a signal to every other node and recipients can decide whether to accept it or not). Each Bluetooth device can simultaneously communicate with up to seven devices. There is no need of user's intervention to create a Bluetooth network; the detection of a Bluetooth device by an analogous device (called the "discovery" process) is sufficient in order to establish a connection.

Compared with the Wi-Fi technology, Bluetooth provides much lower performance in terms of transmission speed and distance reached by the signal. The latter, however, has a lower cost in terms of hardware, and energy demand. The lower power dissipation makes Bluetooth a standard suitable particularly to the battery-powered devices, i.e. not connected to the electric grid. There are devices, such as some new smartphone models that allow the integration between the two technologies: when the device requires a high speed connection (e.g. for playback of streaming content) the communication protocol will be passed automatically to the 802.11 (Wi-Fi protocol), which can transfer data at much higher speeds. Once the high speed connection is not required anymore, the Wi-Fi will be disconnected and the control returns to the Bluetooth (Ian, P., 2009).

1.2.1.4 *Internet Protocol (IP)*

IP is the primary protocol in the Internet Layer of the Internet Protocol Suite and has the task of delivering datagrams from the source host to the destination host solely based on the addresses. Its main task is therefore to ensure communication between different computers with different operating systems allowing the unique identification of the single computer or device connected to the internet.

The first and current major version of the IP protocol is IPv4 and can guarantee a maximum of 4.3 billion IP addresses; saturation problems have led to the development of a new protocol version, IPv6, capable of offering larger address spaces. The emerging need of connecting billions of smart objects via IP makes the IPv6 essential for the development of IoT networks. However, the transition from IPv4 to IPv6 is happening gradually mainly due to high switching costs. Its development is fostered by the "IP for Smart Objects Alliance" (IPSO) which is the world's industrial alliance established in September 2008 with the aim of promoting through research, publications and analysis of use cases, the use of IP as the standard for smart objects. In the literature, many researchers agree that the IP will be the future of smart objects networks; its suitability for IoT application development is mainly related to three features characterizing the IP (Vasseur and Dunkels, 2010):

- **Interoperability:** Interoperability is one of the main features of the Internet Protocol; indeed it was designed on a set of different layers suitably to enable this characteristic. In parallel it represents an essential requirement for smart objects, whose networks are composed of a variety of nodes and transmission mechanisms. Thanks to its architecture structured in layers, IP ensures interoperability between different devices, without resorting to special servers, gateways or special software to connect systems. Another strength of the IP is related to its widespread use: it is no longer only the standard protocol of Internet but has been established also outside the Internet to connect computers. The IP-enabled smart object can then seamlessly interact with a wide range of systems and devices.
- **Development and versatility:** the application versatility and ability to evolve has always characterized the IP architecture: these features were made possible thanks to the principle of "end-to-end", one of the central principles of the IP protocol which provides the basis for the Internet. According to this principle, operations relative to communication protocols must take place on the endpoints of a communication system.
- **Stability and universality:** in addition to flexibility, another important aspect of IP in the IoT perspective is its stability. In fact, since the systems of smart object are designed to have a long useful life, it is essential to ensure stability. The IP, although it has evolved considerably over the years, has always provided great stability in the network. Moreover, since the IP is the foundation of the Internet, it will continue to exist in the future, consequently, there will always be software, hardware and infrastructure supporting it.

Despite the aforementioned advantages, the IP was initially overlooked in studies for the realization of wireless networks, because it was assumed that it would not be able to meet the challenges of this field. In fact, some believe that the IP architecture is too heavy to be used in short-haul and low power consumption networks (typical of the smart object). However, after a few years, attention has turned back on IP, mainly thanks to its modularity and interoperability with existing systems.

1.2.1.5 *WSN and WSAN technologies*

Most IoT applications require the detection of field parameters which is enabled by the use of sensors. The information collected by these devices can then be shared through communication technologies and eventually generates responses from the system. The sensors are devices that have the function of detecting a physical quantity and to convert the entity detected in a signal of a different nature, typically electrical. The parameter that sensors can detect are manifold, including concentrations of chemical species present in air or water, the temperature, pressure, noise... Depending on sensor's characteristics, the parameters measured can be read directly (such as, for instance mercury thermometers), or read through a display connected to it which converts the sensor signal, or just register the collected data in a dedicated storage memory for subsequent processing – this latter alternative often implies the conversion of the data into a digital format. Sensors can be classified using different rationales, perhaps according to their operating principles, or to the type of output emitted; however the most common classification sorts them according to the measured parameter – light sensors, noise, temperature, pressure, motion, humidity, acceleration, biometric...

Sensors are typically connected to each other forming sensors networks, the connection can either be wired or wireless. Both constitute an enabling technology for the IoT, but the ubiquity of the nodes required by many applications often implies the impossibility of connecting them using wired solution. The WSN is built of "nodes" – from a few to several hundreds or even thousands, where each node is connected to one (or sometimes several) sensors. Each such sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting. Sensor networks can provide highly reliable information, providing real-time data, allow a reduction of the costs of generation and transmission of information and can operate in hostile environments. In a WSN, communication can occur between different nodes (or sensors) or between nodes and the gateway, which receives data and can optionally be connected to other networks (such as corporate networks or the Internet). The individual nodes of the WSN can generate information or simply send those generated by other nodes therefore allowing the multi-hop network architecture (cf. Figure 6). This characteristic enhances the ability of WSNs to tolerate failures or malfunctions. In fact, the network is self-configured; therefore, if a node stops working (failure, low battery ...) the communication will automatically switch from another node. The data from the various sensors are then collected and further processed by an application. Who uses the results, therefore, does not access the raw data, but those already developed and significant (Sisinni, E., 2005).

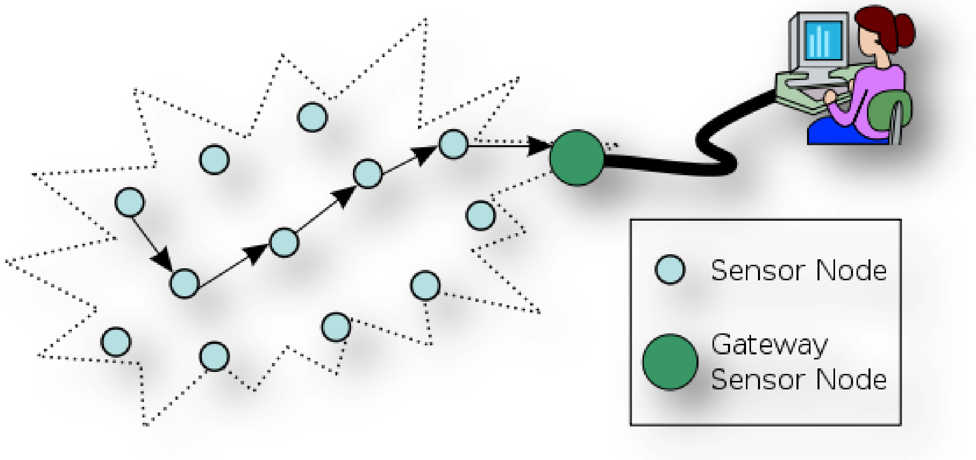

Figure 6: The typical multi-hop wireless sensors network architecture

Alongside WSNs, WSAN (Wireless Sensor & Actuator Networks) are developing, therefore creating, through the use of actuators flanked to sensors, the possibility of autonomously reacting to environmental stimuli and/or executing orders from the network. Thus WSAN allow a bi-directional link between the physical realm and the virtual world; sensors allow the real time connection of events in the real world into processes of the virtual one through the use of communication technologies and Internet, while actuators conversely, allow the intervention of the virtual world into the real one. (Xia et al., 2007).

The communication can be initiated when a sensor detects an event, or following a request of another node of the network (typically the gateway). However, the nodes being characterized by autonomous energy systems require a communication system able to minimize their energy consumption. Many deployed devices are expected to last years without requiring replacement batteries; some of them use energy harvesting techniques to allow them to operate indefinitely without any power source (Starsinic, 2010) (Inhyok et al., 2009).

The various communication vectors enabling the communication between different nodes will later be analyzed in details with reference to their transfer rate, reliability, bandwidth, energy consumption, and network requirements; in particular, the strengths and weaknesses of Wi-Fi, WiMax, ZigBee, Z-Wave and mobile communication technologies GSM and GPRS will be analyzed in details in section 4.3. The state of art picture of existing WSN seem to entrust the ZigBee standard technology for its low energy consumption, although it must be said that the progresses in different standardization groups (e.g. 6LowPan, IP over anything) enlighten a difficulty in predicting the ideal communication standard facilitating the connection between objects at field level.

1.2.1.6 *Satellite communication*

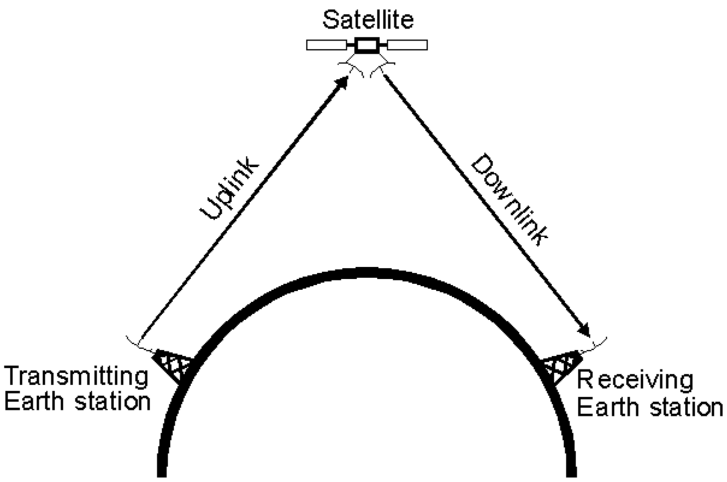

Figure 7: Satellite communication scheme

The satellite communication is used for the wireless transmission of data over long distances. It is based on transmitters and receivers that communicate with satellites in orbit around the Earth. Usually the downlink communication (i.e. from satellite to earth) is done directly between the satellite and the system that should receive data through an antenna. Instead, in the uplink communication, the request is usually sent via wired or wireless telephone lines to a transmitter station, which forwards it to the satellite (cf. Figure 7). (Evans, 1998)

Some of the main applications involve geolocation (GPS), satellite television, telephony and broadband Internet services

1.2.2 Reference architecture

Current Internet has a five-layered architecture, running with TCP/IP protocols, and as mentioned above has proved to provide great stability and capacity of evolving in response to new challenges (Wang and Tan, 2010). However, the original design of the Internet architecture couldn't foresee the breakthrough emergence of the IoT paradigm and its consequences on the network design, requirements and performances. It is therefore essential to design a new architecture that best suits the requirements of the Internet of Things. Although some researchers provide detailed multi-layered communication architectures suitable for the IoT, it is generally accepted in the literature, that the manifold components of an IoT system can be structured into a three-layered network architecture – which can then be broken down into further layers. (Gong Guo et al., 2011) (Haller et al., 2010) (Atzori, 2010) (Gama, 2011)

RFID tags and readers, sensor and actuator nodes, gateways and control centers are just some of the functional elements that make up the Internet of Things. These devices, which differ in processing and sensing capabilities, size, costs and autonomy, are generally structured in a network architecture composed of three subsequent levels (cf. Figure 8):

- ***Interface with the physical world:*** this first layer is composed by a large number of nodes (tags or sensing units) which interact with the environment by providing an identification code, acquiring information or by controlling an actuator. In general, these nodes are not provided with power supply (passive tags) or are just powered by battery (sensor units and actuators). They are generally characterized by reduced processing power and memory, although they are endowed with communication mechanisms (wired or wireless) to communicate with the units of the second layer. The operational life ranges from a few years for battery powered devices (strongly dependent on the type of application), to over ten years for tags Passive RFID.

- ***Middleware:*** the units of the second level, which include RFID tag readers and gateways, have the task of collecting information from the underlying level nodes and conveying them to control centers. They are characterized by a greater processing capacity and memory, by multiple communication interfaces, and are generally fed by the electric distribution network. They allow the ubiquitous integration of heterogeneous communication networks, including the existing Internet, communications networks, extensive networks and a variety of access and private networks, realizing the information transmission and processing.

- ***Control Center:*** the units of the third level, which include the acquisition systems control units (SAC), operating rooms and enterprise backend information systems, have the task of receiving the information from units of the second layer for the subsequent stages of analysis, processing, storage and provision to the various application users. They manage and supervise the network architecture.

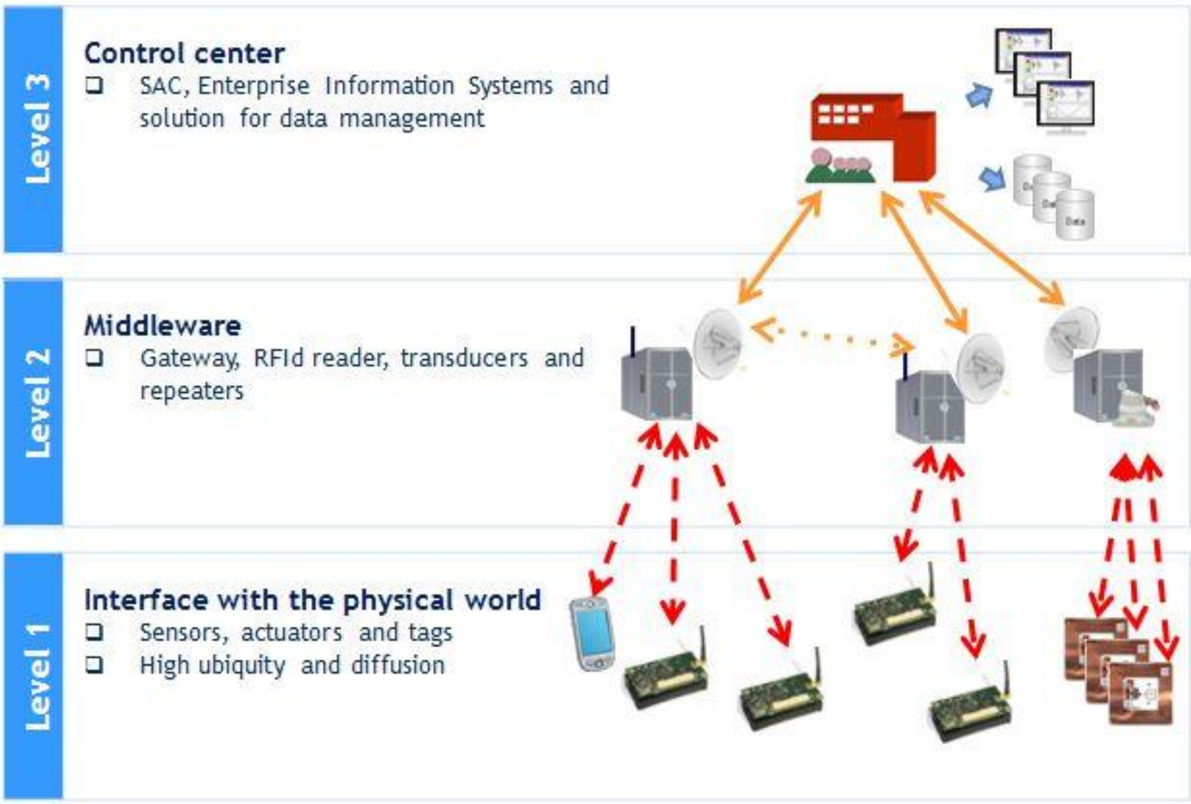

Figure 8: IoT reference architecture

1.2.3 Technological state of art picture and ways forward

To reach the full potential of IoT a number of issues and criticalities characterizing nowadays implementations need to be overcome. These are relative to:

- **Heterogeneity of devices**

The ecosystem constituting the Internet of Things is currently characterized by solutions highly heterogeneous in hardware, software and communication protocols between the physical realm of things and the digital world of Internet. In particular, the different components of the IoT architecture enjoy different degrees of standardization and maturity, leading to noteworthy architectural issues in the realization of IoT networks. (Michele Zorzi, 2010)

While the RFId technology can be deemed consolidated, reflected by established commercial offers of RFId tags and readers in the market; the same does not apply to sensor networks. Indeed sensor nodes and gateways (i.e. devices of the first and second layer) are not yet characterized by standardized solutions either in terms of hardware (Mica Motes, Sunspot, Jennic, etc..), or software (Tiny OS, SOS, Mantis, Contiki, FreeRTOS, etc..) or middleware

(Tiny DB, GSN, DNS, SWORD, etc..). Contrariwise, the units of the third level enjoy greater technological maturity as they are supported by consolidated architectures for servers, client-server interactions and databases. (Tumino, A., Miragliotta, G., 2012)

- **Lack of standardization**

The lack of standardization in units of the first two levels has led to the consolidation of an ad-hoc approach for the design of customized network architecture, aimed at optimizing the single application (perhaps in terms of energy) rather than abstracting from the specific application problem and developing infrastructures which might result useful to a wider class of applications. This heterogeneity of solutions appears to be even more evident when considering communication vectors used between devices. Indeed, specific and dedicated solutions are often designed and implemented ad-hoc for each field of application. In particular, this is true for the communication between field devices (i.e. between components of the first and second layer) as the set of substitutive technologies is wide (even though presenting different characteristics) and their level of standardization often pre-mature (e.g. considering Wireless M-Bus, ZigBee, IEEE 802.15.4, ZWave, Bluetooth, etc.).

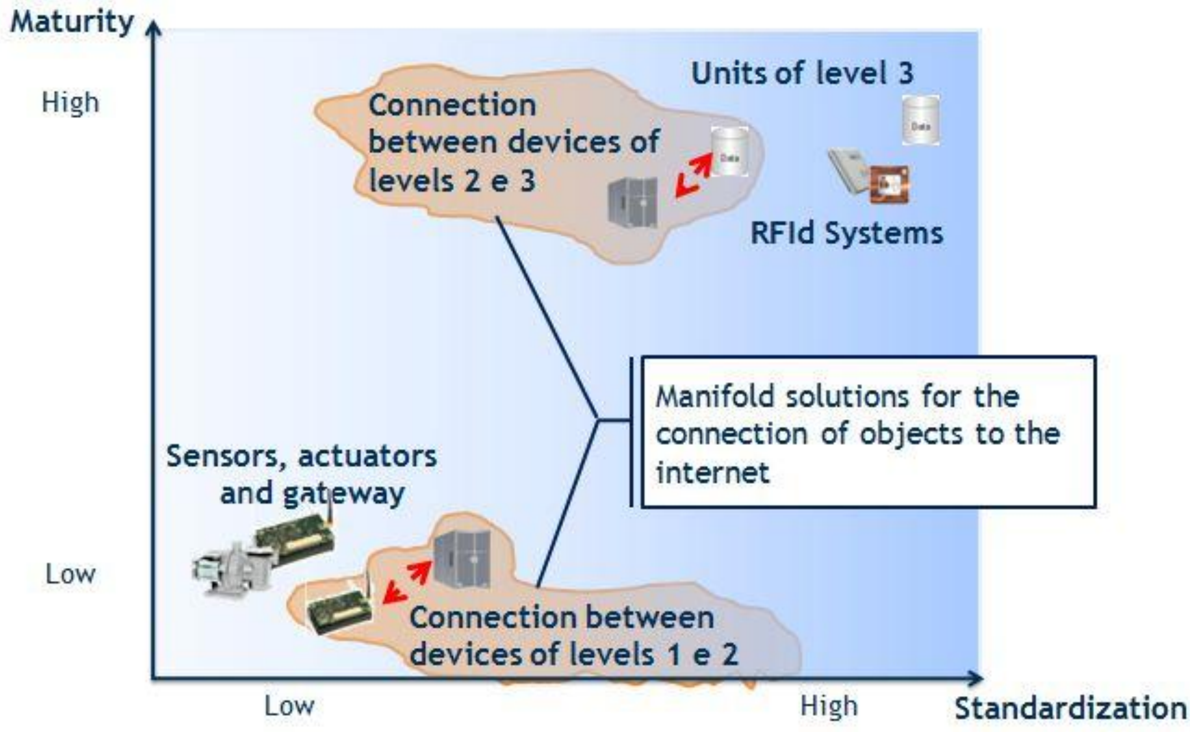

Figure 9: Maturity and Standardization of the different IoT components

Conversely, the communication between second and third layer devices is characterized by a greater level of maturity as it typically relies on cellular technologies such as 2G, 2G+, 3G, or on other mature technologies such as Wireless Mesh or Power Line Communication.

Figure 9 expresses the level of maturity and standardization of the different components of the IoT architecture.

- **Interoperability**

These aspects explain the partial level of interoperability embedded in current IoT applications. Indeed, the majority of existing IoT applications enables interoperability uniquely at data level. The information retrieved by field devices (i.e. level 1) belonging to different networks can be exchanged and shared only after they have been collected, translated and then eventually made available by the respective control centers. Thus, objects pertaining to different networks can't communicate directly, but need the mediation of the respective network architectures (devices from levels 2 and 3). This aspect creates a clear boundary between the physical world of objects and the internet which is the result of a vertical design approach (i.e. ad-hoc design of the hardware, software, communication and application layers).

Conversely, the full IoT potential can be obtained only by bringing the interoperability at object level, i.e. enabling the direct access to a node (object) of the system as it happens in the internet with a given IP address; and therefore enabling the direct communication between objects. This would enable a revolution in the architectural design process, passing from a vertical approach to a horizontal one. This approach would allow to reduce the entry barriers related to the requirement of knowing the technology in all its aspects (hardware, software, network architectures and communication); the design phase would result simplified, and the level of customization of the technological solution, increased.

- **Energy issues**

However, bringing interoperability at object level would require augmented performances embedded in end nodes (tags and sensors) in terms of storage, communication and processing capabilities. Indeed, part of the task which is now carried out by the devices at layer 2 (gateway) will have to be managed at object level therefore implying higher hardware and software complexity and performances. This is translated into higher energy requirements at object level. The development of the IoT is therefore strictly linked to the progress in energy efficiency (i.e. decreasing the amount of energy required to operate), energy storage (i.e. increasing batteries capacity), and energy harvesting (i.e. enhancing object's capacity of retrieving energy from their surrounding environment; for instance through small solar panels or through radio waves).

Finally, it has to be mentioned that progresses in the standardization activity are being pursued essentially by two competing bodies, the IPSO Alliance (for the development of the 6LoWPAN standard) and ZigBee alliance. Although using different substantial approaches, these two bodies share the same goal: guarantee interoperability at object level. Currently, the ZigBee approach has a greater maturity and a greater diffusion; this is also due to the fact that the work of the IPSO Alliance has begun recently. However, hybrid solutions are emerging in which the ZigBee approach exploits 6LoWPAN communication principles.

1.3 Application fields

The fields of application of the Internet of Things are manifold as this paradigm is aimed at integrating into all areas of the people existence. The technologies and business models offered by the Internet of Things will offer massive opportunity right across business, society and government. This section is aimed at providing an illustrative picture of the different domains where IoT infrastructures are implemented. Indeed the detailed analysis of the major fields of application relevant for this research work will be pursued in section 8.3.

1.3.1 Smart city

Smart City is a concept that is increasingly spreading all over the world, and indicates a city offering a high quality of life. A Smart City is characterized by a high level of performance in the following areas: economics, government capacity, mobility, environment, lifestyle and "intelligence" of the population (social and human capital). Figure 10 illustrates the main characteristics distinguishing a smart city.

A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rail/subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens. Emergency response management to both natural as well as man-made challenges to the system can be focused and rapid. With advanced monitoring systems and built-in smart sensors, data can be collected and evaluated in real time, enhancing city management's decision-making.

Although there isn't a full overlap between Smart City initiatives and the IoT paradigm, contact points are numerous and very deep as the uses of Internet of Things solutions within urban areas are very varied. These vary from the road network and traffic management (management of parking, updated information traffic management, traffic lights, street lights.) to public transport (location of vehicles, real-time monitoring of the flow of passengers), from the collection of waste (bins' identification, bins' fulfillment level control) to security and territorial control (surveillance, danger detection), from monitoring the environment (measuring of air or water pollution) to the monitoring of the territory (prevention and monitoring of floods, fires, landslides) and up to entertainment and tourist services (information to tourists, Smart Poster, cultural routes). All these fields of application will be discussed in details all along section 8.3.

SMART ECONOMY (Competitiveness)	SMART PEOPLE (Social and Human Capital)
▪ Innovative spirit ▪ Entrepreneurship ▪ Economic image & trademarks ▪ Productivity ▪ Flexibility of labour market ▪ International embeddedness ▪ *Ability to transform*	▪ Level of qualification ▪ Affinity to life long learning ▪ Social and ethnic plurality ▪ Flexibility ▪ Creativity ▪ Cosmopolitanism/Open-mindedness ▪ Participation in public life

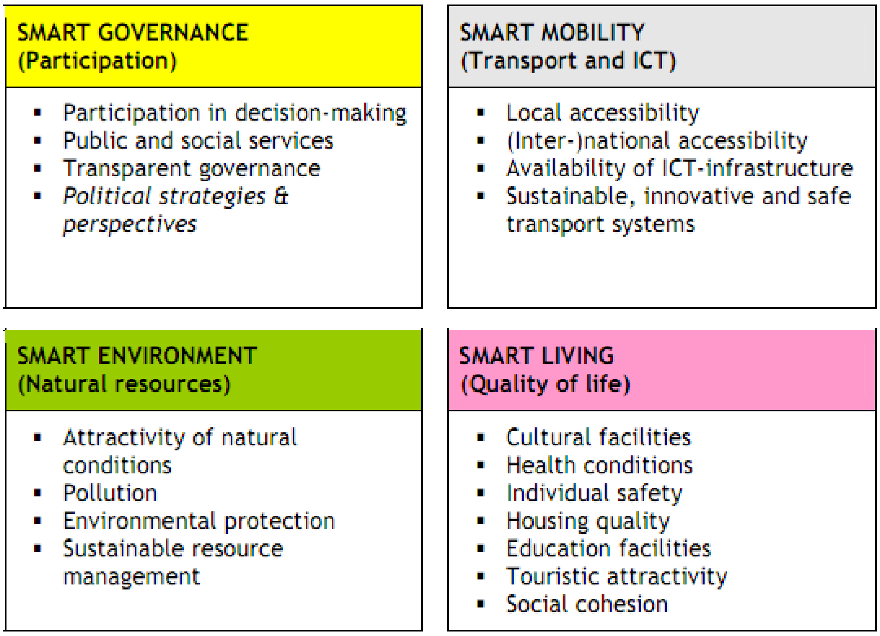

Figure 10: Characteristics and factors of a Smart City (Centre of Regional Science, 2007)

1.3.2 Smart metering and smart grid

The smart grid paradigm is a technological development path which involves the evolution from a system characterized by a unidirectional flow of electrical energy, which streams from its generation sources to the points where it is consumed, to a system where a bi-directional flow of electricity and information is produced and managed in an “intelligent” manner. The smart grid paradigm therefore enables a new set of functionalities in the stages of generation, transmission, distribution and consumption of energy, with clear benefits in terms of efficiency, effectiveness, safety and independence of the power system itself.

The impressive growth in production of electricity from renewable sources, strongly supported by the European Union through the adoption of the Climate-Energy Package, also known as "Packet 20-20-20" and, consequently, lavishly promoted and encouraged in Italy, is having major consequences and is leading to significant problems for the electrical system. In fact, although having a lower impact on the environment, renewable sources are not predictable in nature and therefore can’t be scheduled (especially the photovoltaic and wind energy technologies). This causes imbalances on the network and increases the complexity of managing an electrical system that was designed and made consistent with the characteristics and requirements of a model of centralized generation. To solve these issues, the evolution of the electrical system into a system which allows the integration of the actions of all the users connected to the network becomes essential, in order to allow the use of electricity in an efficient, sustainable and secure manner. To emphasize the magnitude of this paradigm, it must be mentioned that analysts predict that a total of $200 billion will be invested globally in smart grid technologies before 2015 (Yu and Yang, 2011)

The importance of IoT for the realization of smart grids is therefore straightforward as each node of the system must communicate its energy production and/or consumption to the grid. This, in particular, is enabled by smart metering systems which are the infrastructural components of smart grids aimed at monitoring energy consumption. Smart meters, indeed, allow the real time remote read of customer's energy consumption, hence invoicing them on real consumptions and enabling dynamic electricity pricing strategies. Furthermore, advanced metering infrastructure offers the possibility for additional smart grid services such as demand side management and the realization of virtual power plants (clusters of distributed generation installations collectively run by a central control unit).

Smart Grids enhance the flexibility of the distribution grid and allow a better response to unforeseen events. Perhaps, at present if a blackout occurs many services, such as banks, traffic management and communications and security might be greatly affected. A Smart Grid could enable the automatic and strategic redirection of energy supply in case of problems, ensuring the selective energy provision only to most needed public services. Also, prosumers (the so called "producers-and-consumers" of energy) can provide energy when not available from the public service, allowing the active provision of basic services to the community in emergency situations. Finally, extended blackout can be prevented: in case of failures in the system sensors along the distribution grid will be able to detect the problem and to isolate it before it turns in a blackout on a large scale. Smart grids will thus provide a huge quantity of data that can then be used by different systems in order to optimize them. Similarly, a prediction for sunny and windy weather will be translated into a forecast of high renewable energies production. This information results useful for power plants in order to update their energy production plans (i.e. reducing their energy production); in parallel factories can plan to schedule high energy consuming tasks during daily hours as electricity will be available from local generators (e.g. photovoltaic panels); and electric car drivers can fully charge their battery leveraging on lower electricity prices.

1.3.3 Smart home and building

This field of application involves the transformation of current homes and buildings into intelligent infrastructural component able to sense the presence and needs of their inhabitants, therefore automating various functionalities of the home, and enhancing the creation and provision of additional services.

Sensors and actuators distributed in houses can make life more comfortable in several aspects: rooms heating can be tailored to inhabitants preferences and to weather conditions; the room lighting can change according to the time of the day; domestic incidents can be avoided with customized monitoring and alarm systems; and domestic energy consumption can be reduced by automatically switching off electrical appliances when not in use.

Over 40%[2] of the energy consumption in the EU and US is consumed by buildings. Buildings therefore constitute a noteworthy opportunity for meeting the 20/20/20 targets set by the EU[3].

[2] source: Building Energy Data Book, US Department of energy, 2011, (http://buildingsdatabook.eren.doe.gov)

[3] In March 2007 the EU Heads of State and Government endorsed an integrated approach to climate and energy policy, and set a series of demanding climate and energy targets to be met by 2020, known as the "20-20-20" targets. These are: a reduction in EU greenhouse gas emissions of at least 20% below 1990 levels; a 20% of EU energy consumption to come

Their ubiquity and omnipresence in every sector fostered the international community and governments to foresee appropriate plans for the implementation of sensing, actuating and metering technologies for the efficient use of energy. Building and home automation are not novel fields of application, technologies and applications appear to be consolidated although this business sector struggles to take off. This is also due to the predominance of customized and dedicated network solutions which rarely allow interoperability with objects not pertaining to the same network. Interoperability at object level would, in this field of application, in one hand allow developers to design customized solutions with a lower cost, and in the other enable a set of applications derived by the interaction between homes and buildings and distribution grids. For instance, they would enable the demand-response paradigm. Indeed smart appliances can communicate with the energy grid and therefore schedule to take advantage of lower energy prices during off-peak hours, and consumers can be real time informed about their energy consumption and its costs. (Makaer, 2010)

This field of application can further be subdivided into six subfields which will be analyzed in details in section 8.3.5; these are: energy management; management of scenarios; security; safety; maintenance facilities and personal assistance.

1.3.4 Smart factory

The smart factory field of application allows, through IoT technologies the real time monitoring of all the processes inside a factory. The widespread use of sensors in the factories allows machines to act context-aware, meaning that they result aware of their environment, and whether a problem (e.g. broken component) occurs, through their communication, processing and actuating capabilities, it can be solved locally without the need of any human intervention. This is only the operative perspective of enabled benefits, as this system allows to optimize the use and capacity utilization of machines and lines but also to be able to respond rapidly to wrong developments in production and thus minimizing adverse impacts on the business while increasing operators' security. (Lucke et al., 2008)

Future scenario of the "smart factory" will be enabled once IoT will be fully deployed both inside and outside the factory. The factory will be able to be modified and expanded at will, combining all components from different manufacturers and enabling them to take on context-related tasks autonomously. (Bosscha et al., 2006)

1.3.5 Smart logistics

In the field of logistics and distribution processes, the use of ubiquitous computing can facilitate the exchange of information and increase the overall efficiency of supply chain management. Particularly relevant in this field of application are the use of RFId and NFC technologies as they allow the real-time monitoring of the entire supply chain. By equipping products with RFId tags it is possible to ensure the real-time availability of goods on the shelf of points of sale. Moreover, the merchant can automatically check the reception of goods, track stock outs and prevent thefts.

from renewable resources; and a 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency.

The data collected from points of sale can then be shared with suppliers, enabling their real time visibility on the quantities sold and on remaining stocks in stores, therefore consenting suppliers to perform better production plans and shipping the right quantity of goods needed to meet demand.

The benefits enabled by IoT solutions in logistics show their impacts all along the supply chain, not letting aside the end customer. Indeed, NFC enabled points of sale permit the automatic payment, avoiding the lost of time consumers face along the long lines to pay their shopping. Stores allow tracking the history of products, which would bring more security (supply chain transparency, monitoring the cold chain, anti-counterfeiting, etc.), and provide guidance to consumers in the store. As for the transportation of goods, IoT allows monitoring the effective delivery of products and their integrity (Makaer, 2010).

These applications mainly rely on the extensive use of RFId technology and therefore are characterized by a great level of maturity as their diffusion results considerable.

1.3.6 Smart agriculture

This field of application ranges from monitoring activities aimed at increasing the yield of greenhouses and fields, to the track and trace of animal's behaviors aimed at ensuring their good health conditions. This field of application has attracted much attention especially in relation to the quality and security of foods reaching end consumers.

Applying ubiquitous computing systems in vineyards perhaps enables the punctual monitoring of the temperature, humidity and light allowing farmers to optimize timings of the collection process through insights on the actual maturity of grapes. Similarly, through the application of identification systems, animal diseases can be controlled and prevented. IoT can also impact on the supply chain distribution system from farmers to consumers. Indeed, embedding information on foods leaving the farm paves the way for more direct and shorter chains between producers and consumers. (Bandyopadhyay and Jaydip, 2011)

1.3.7 Smart asset management

Smart asset management is a transversal field of application which is present in many different sectors as it allows the accurate monitoring of the well functioning (i.e. identification, localization and knowledge on its status) of an entity's assets. Thus, wheelchairs, stretchers and other medical equipment can be traced within the hospital, allowing a quick identification, localization and status recognition; perhaps, a stretcher that came with an ambulance, but pertaining to a different hospital can be identified immediately, and sent back to its owner. Lamps of public lampposts can be change as they reach their end of life; elevators can communicate to the maintenance company when a safeguarding activity is needed, or signal failures; and public buses signal their position and status to optimize maintenance activities.

1.3.8 Smart car

This field of application encompasses public and private transportation applications; indeed these often share the same infrastructure (i.e. road networks) and therefore applications aimed at optimizing one of these fields can often be leveraged to optimize the other. In the field of public transports IoT enables benefits that range from the optimization of transportation processes (i.e. asset management, routes optimization, better emergency management, real time tracking, etc.) to the improvement of the services to citizens (i.e. electronic ticketing, infomobility). Indeed providing transportation infrastructures (e.g. roads, bridges, tunnels, traffic lights, lampposts, etc.) with ubiquitous sensing technologies allows the real time monitoring of traffic conditions, a better management of daily operating activities and an improved planning of long term infrastructural requirements. Other applications are enhanced by the NFC technology which allows the purchase and validation of electronic tickets for public transportation directly through the user's mobile phone. Besides increasing the service level, this allows the punctual tracking of passengers, therefore implying a better knowledge on customers behaviors, the better planning of infrastructural resources and perhaps the provision of information relative to the number and identity of the passengers to rescuers in case of accidents (Makaer, 2010).

The ubiquitous monitoring of transportation infrastructure enables a diversified set of benefits both for public and private transport systems. Some examples are the traffic light management – to reduce congestion or facilitate the mobility of particular vehicles categories (e.g. police, ambulance) perhaps through a dynamic change of the duration of traffic lights based on the actual level of traffic; the parking management – thanks to ad-hoc sensors embedded in the asphalt or conceivably positioned on a lamppost, clear indication to car drivers can be provided on the status and location of a free parking; the management of street lighting – by fitting sensors on the lampposts to monitor, control and adjust the light power according to real visibility conditions.

The provision of timely – possibly real-time – geo-referenced information on traffic situation and road conditions also represents a major improvement enabled by the IoT in the private transportation field as it represents a powerful tool for reducing congestion levels.

Finally, a great set of benefits is enabled by the connected vehicles subfield of application; indeed, modern cars are already equipped with a large quantity of electronic components and sensors, but have until now been regarded as independent entities. Connecting cars to the Internet enhances the opportunity of new service provision such as new insurance models (based on car driver's behaviors) or vehicle's assistance and diagnosis services, perhaps enabling the remote equipment repair or automatic message transmission whether an accident occurs. Moreover, it would be possible to increase passenger safety by ensuring that the vehicle prevents the driver from undertaking dangerous actions (e.g. impeding high speed driving in adverse weather conditions). (Atzori, L. et al., 2010).

1.3.9 E-health

Although the research interests in the medical sector characterize it by a constant and stable evolution, our society still pays a high price in terms of human lives due to errors in healthcare: thousands of people die in EU and US hospitals each year. The healthcare logistics, the flow of drugs and patients require a management that does not differ in substance from that of traditional manufacturing and logistics systems. The challenge is to design systems that can ensure the health of people by optimizing the entire process, from the supply of medicines to the patient service (Bassi and Horn, 2008).

In the field of healthcare IoT finds many applications to improve the quality of service, reduce costs and deal with social problems, such as, for instance, the increase in elderly population due to the elongation of life expectancy. Telemedicine is aimed at performing remote clinical care using electronic communications and information technology (Meystre, S., 2005). The Internet of Things, in this context, provides remote control devices (internal or external to the human body) that allow through the use of sensors the remote detection of vital signs (heart rate, temperature, cholesterol and glucose, blood pressure, etc.) while the patient remains in his household, without any need of intervention by the health personnel. These data detected by the device are then transmitted automatically via the Internet to the hospital or medical center, enhancing the possibility of diagnosing and detecting any danger for the patient. These applications can be implemented not only to facilitate older population home living, but can be applied to a diversified set of chronicle patients. The applications are manifold; perhaps in nursing homes, specific software allow the analysis of patients' daily routine movements and realize whether an abnormal situations emerges, therefore alerting the medical staff (Makaer, 2010).

A further feature enabled in this field of application is the monitoring of patients', personnel and medical equipment position, by the use of embedded RFId tags. This allows, for instance, to improve the work flows in hospitals, to facilitate the tracking of patients, and perhaps make real time inventories (Atzori, L. et al., 2009).

The use of RFId to electronically identify patients allows the direct provision of real time medical history to medical personnel as the patient enters the hospital while presenting significant benefits when it comes to patients who need special treatments – i.e. patients with specific diseases (like diabetes, cancer, coronary inconvenience ...) or implanted medical devices (like pacemakers) can directly be identified, and contraindicated measures can be avoided (Makaer, 2010).

1.3.10 Conclusions

The following Figure 11 summarizes the different fields of application discussed above into a matrix crossing the functionalities levied by IoT applications with the sectors impacted by the specific field of application.

This figure emphasizes the benefits which may be obtained by enhancing the multi-functionality on different fields of application. Indeed the figure shows how different sectors and fields of applications rely on the same functionalities suggesting the implementation of cross-sector and cross-application infrastructure which might be levied by different actors. This is particularly highlighted by the intersections of the different fields of applications. Indeed a smart building infrastructure can be leveraged on for smart grid, smart home or smart factory applications. Finally, the above scheme suggests the centrality of the smart city field of application crossing over with many fields of application and encompassing three ubiquitous sectors: public administrations (therefore encompassing all city infrastructures), utilities (whose infrastructure result ubiquitous in nature) and the consumers.

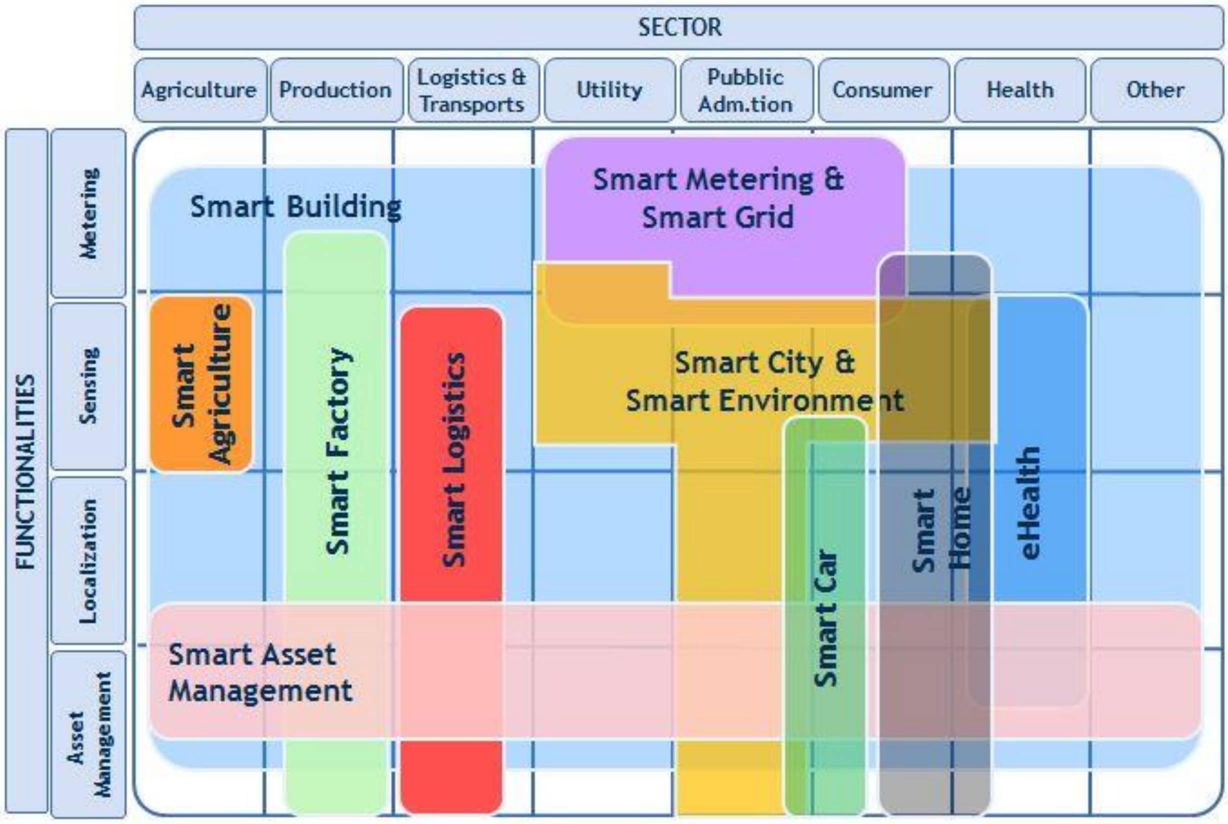

Figure 11 Matrix of IoT fields of application by sectors and functionalities

Chapter 2 - Smart Gas Metering: The Italian Roll-out Case

This chapter describes the Italian gas supply chain, analysing the role of each different actor and their interfaces. Following, the impact on the different actors of the supply chain as well as the entrance of new players for enabling the smart metering roll-out is evaluated.

2.1 Premise

Until the early 90's the gas sector in Italy was characterized by a situation of monopoly exercised by Eni which, also through its subsidiaries, managed all the phases of the gas lifecycle from extraction until delivery to end customers. The impulse to the process of liberalization was first given by EU laws in a perspective of overcoming the existing monopolistic system and with the aim of creating an internal market for energy. The process of liberalization isn't yet completed as recently the Monti Government enacted a decree[4] requiring the complete separation of SNAM S.p.a – the biggest gas transportation company in Italy (managing over 90% of the infrastructure in place) which was firstly owned by ENI, then since 2002 controlled[5], and now completely separated. The introduction of smart gas meters as well represents a step towards liberalisation as it facilitates customer's switch between different suppliers, therefore increasing the competitiveness of the whole market.

2.2 The current supply chain

In the present situation, the Italian gas supply chain presents a mixture between regulated markets and free markets. The structure of the supply chain can be subdivided into four main areas characterized by the presence of different actors: the provision, the infrastructures, the sales and the consumption (as depicted in the below Table 12).

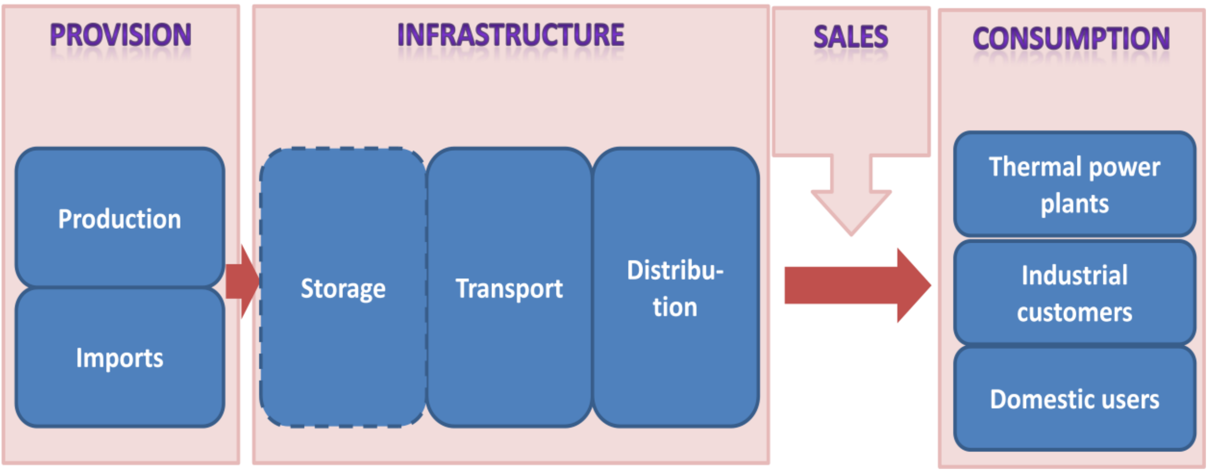

Figure 12 The Italian gas supply chain

2.2.1 Provision

The provision or supply of natural gas in Italy comes from two sources: production, or extraction, which accounts just for the 7.5% of the provisioned gas, and imports. The vast

[4] 25/05/2012 - Decree of the President of the Council of Ministers, which requires the full impartiality of the company SNAM SpA against vertically integrated companies in the production and supply of natural gas. Eni will therefore have to reduce its share in SNAM SpA from 50.1% to 25% within 18 months for subsequently ceding the residual share capital.

[5] The Legislative Decree n. 164/2000 of 23 may 2000, known as "Decreto Letta", and implemented to incorporate the European Directive 98/30/EC rearranged the natural gas sector and gave guidelines relative to competition and unbundling.

majority of the Italian gas reserve is located in the Mediterranean Sea, where most of the extraction activities take place. Eni represents the biggest extraction company in Italy in a market which remains very concentrated (7 gas producer covering over 83%[6] of the extracted gas). Also the import market is highly concentrated having over the 72% of the imported gas managed by the first three companies in the market (in total there are 88 import companies),. With over 92% of the consumed gas coming from imports it can be noticed how Italy depends on other countries for its energy sector. In fact most of the imported gas, which arrives in Italy through pipelines, is imported from extra EU countries (90% of it). Some of this gas arrives through ships and therefore travels in a liquid form. Once arrived in Italian depots, it is subsequently regasified. (AEEG, 2011a)

2.2.2 Infrastructure

The infrastructural segment of the supply chain involves the storage and transmission of gas from its provision sources until end customer. The actors of this segment of the supply chain operate in regulated markets (by the "Autorità per l'Energia Elettrica ed il Gas" AEEG) as they often represent de facto monopolists (as they are the owners of the infrastructure).

2.2.2.1 *Storage*

The storage capacity is divided between the space for strategic storage (determined by the Ministry of Economic Development) and space for services such as modulation, mining storage and operational balancing of the transport network. Out of the 10 storage fields present in the Italian territory, 8 are managed by Stogit (a company controlled by the group SNAM S.p.a) and 2 from the company Edison Stoccaggio.

The overall storage capacity represents approximately 18% of the yearly consumption. (AEEG, 2011a)

2.2.2.2 *Transport*

The transport network is the one in charge of the connection between gas producers or importers and the distribution network of high pressure gas. It is an activity regulated by the Italian Authority AEEG with multiannual contributions. The overall gas transport market is composed by ten companies, including three of them operating at a national level. Once again the group SNAM S.p.a manages the biggest stake of the market controlling the 93.8% of the national grid. (AEEG, 2011b)

2.2.2.3 *Distribution*

Distributors (DSOs) deal with the physical distribution of energy from the transport network – in high pressure – to the end-user through various stages of gas transformation. They own the distribution infrastructure from the delivery points (from the transport network) to the end-user's gas meter. The distribution market is composed by 245 companies and the vast majority of those are of little dimensions: 60% of distribution companies employ less then 10 workers (cf. Figure 13). Furthermore, the market is characterized by an impressive diversity in terms of dimensions

[6] Source: AEEG, Relazione annual sullo stato dei servizi e sull'attività svolta, 2011

of the company as 80% of clients are served by 15% of the companies. Once again, the market leader is Italgas, a subsidiary of SNAM S.p.a. (AEEG, 2011a)

Distribution companies bill the gas to vendors based on estimates of end-users' consumptions although they are required – by the regulator – to perform at least an effective reading of end-users' meter per year, which then has to be transmitted to the supplier. Distributors are also responsible for the gas measuring service and for interventions on clients' meters. Finally they are in charge of the quality of the service and of security issues all the way from the distribution grid to the final consumers' meter.

DSOs main retribution tariffs are based on the activities carried out for the provision of three services: physical distribution service; meter reading service; development of commercial services

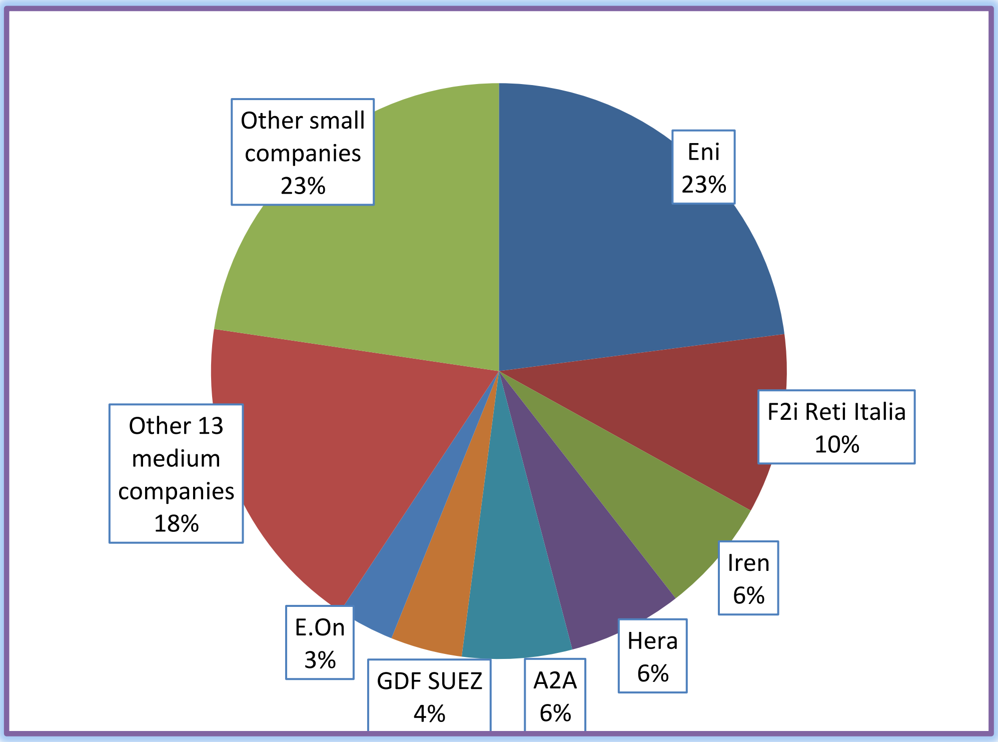

Figure 13 Italian gas distributors per shares of distributed volumes (245 companies in total) ***(AEEG, 2011a)***

2.2.3 Sales

Suppliers, or vendors (VSOs) were constituted following the liberalization of energy markets for the sale to end customers, they purchase the gas at wholesale, stipulate supply contracts with end consumers and transmission contracts with local distributors (with rates adjusted by the Authority). The sales market is composed by 390 companies, three quarters of which employ less then 9 workers. The first three market leaders cover over the 48% of the total sales (cf. Figure 14 Italian gas suppliers per sales share).

Suppliers are responsible for the commercial offer and for all communications with end customers (customer service, handling of complaints, etc.). The billing is based on estimates of consumption and subsequent adjustments (a yearly invoice adjustment is required by the regulation Authority). The end-user's consumption estimates are provided by distribution companies, but often sales companies also have their own estimation process. (AEEG, 2011c)

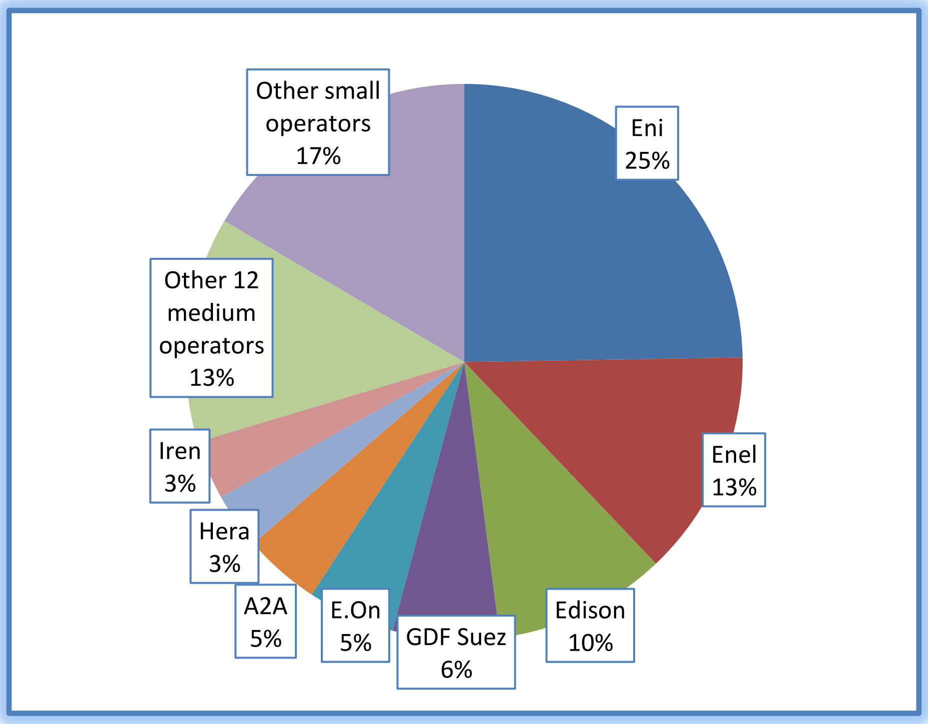

Figure 14 Italian gas suppliers per sales share (390 companies in total) ***(AEEG, 2011a)***

2.2.4 Consumption

The gas consumer market is composed by three sectors of consumption which differ significantly in terms of number of clients and volumes consumed. The domestic consumers represent the 98% of total clients, accounting for 33% of yearly volumes; the industrial consumers represent the 1.2% of total clients and 25.5% of total volumes. Finally the category which consumes the biggest quantities of gas is thermal power plants which represent 0.8% of total clients and the 41.5% of total consumption.

The analysis is centred on the domestic market, therefore focusing our attention on 33% of the total gas consumption. For these customers the billing is undertaken on the basis of estimates of consumption, with a mandatory yearly invoice adjustment. In case the meter is not accessible by the distributor once he commissioned an effective reading – because the meter is placed inside the client's apartment and the client is not present during the visit – the yearly invoice adjustment is performed on the basis of estimate once again, running the risk of significantly diverging from real consumption rates. (AEEG, 2011b)

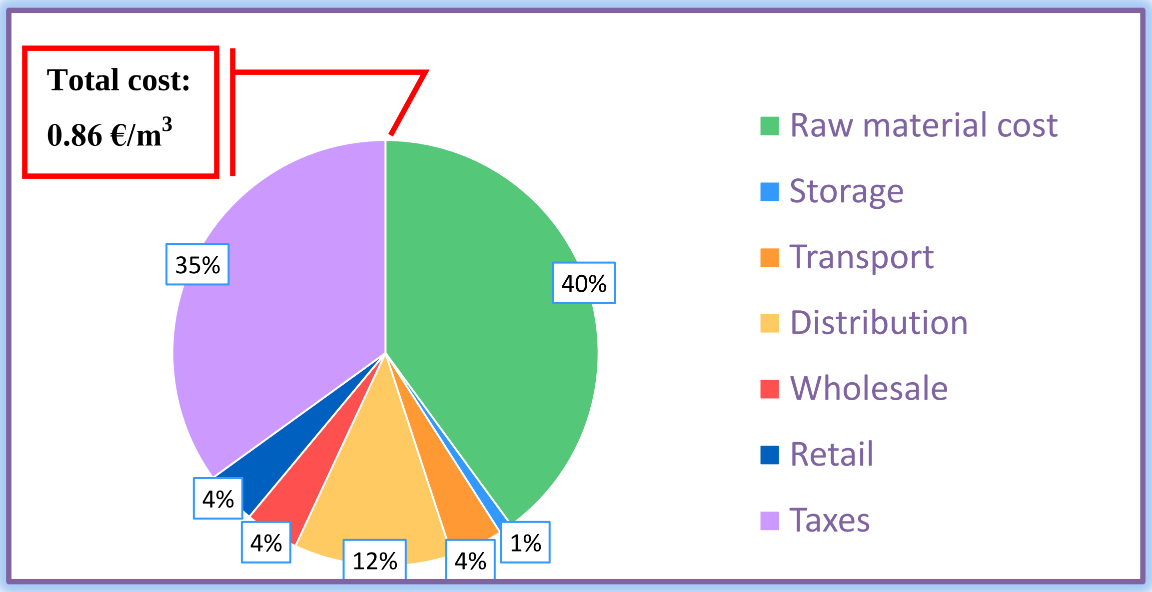

Figure 15 Components of the average final price of natural gas *(AEEG, 2011a)*

The above Figure 15 breaks down the cost of gas for the final customer considering the entire supply chain, the figure depicts clearly how 75% of the final cost for customer is represented by the raw material cost and by taxes. Still, the 25% remaining is the cost of buying and selling the gas from wholesalers to final customers, and the storage and transmission of gas through pipelines to the final customer. The figure also highlights the weight of the distribution service in the final cost of gas for end-customers, which – as seen previously – is composed by the physical distribution from delivery points to end-customers, and of the metering service (whose burden is targeted to reduce following the smart metering obligation). (AEEG, 2011b)

2.3 Impacts of the metering solution

As a clear picture of the Italian gas supply chain has been provided, the analysis can follow considering how the figure is modified by the fulfilment of the smart metering obligation. In fact, as seen, most of the actors of the supply chain operate in regulated contexts which are driven by regulatory initiatives and therefore are characterized by a low level of innovation and flexibility. The introduction of the smart metering obligation upsets the overall supply chain given the complexity of the requirement for such a stable market. Indeed smart metering requires the roll-out of a pervasive communication system able to transmit consumption data – along with other parameters which will further be elucidated – from each customer’s household until utilities’ control centres. Consequently, the present regulatory requirement involves the entry on the gas supply chain of new actors and new business segments. New and diverse skills are required: there isn’t a unique actor capable of independently providing a "plug & play" solution of smart metering ready for use, and therefore the different actors must build strategic alliances to leverage on each actor’s core competencies and offer integrated solutions

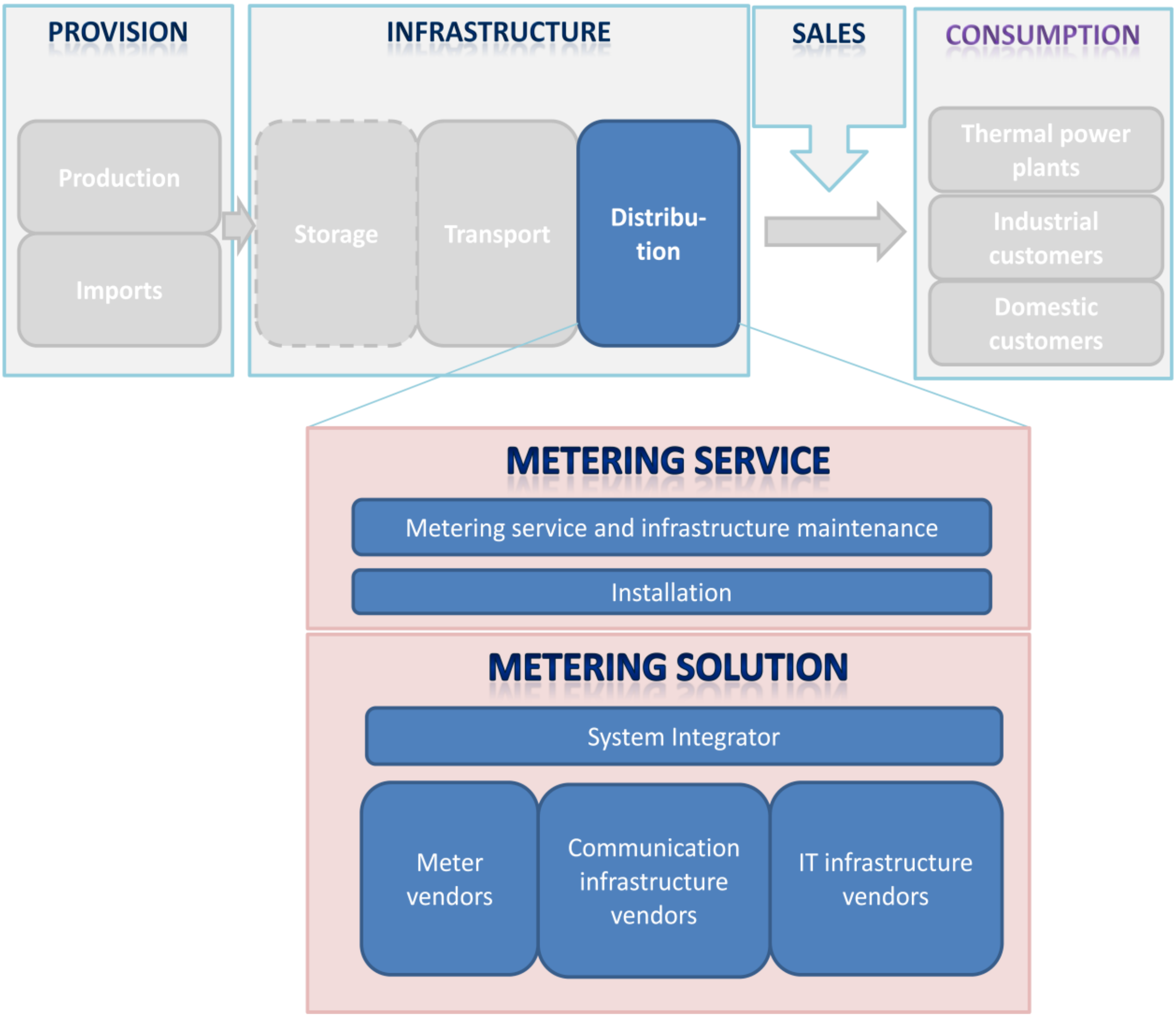

Figure 16 The smart gas metering supply chain

Figure 16 portrays how the new actors are all initially interfaced with the distributor. In fact the distributor is the one responsible for the metering service, and therefore, following the norm ArgGas 155/08, he is in charge of the investment for smart meters and the relative communication and information infrastructure.

As depicted by Figure 16, the metering solution is supplied through the integration of three main suppliers: smart gas meter producers, communication infrastructure suppliers and IT infrastructure supplier for data management. Other actors could also be involved to deliver installation or metering services.

2.3.1 Smart gas meter producers

Worldwide various companies entered the smart electric meter production market, given the actual commitment of governments towards enabling the development of smart grids (the smart meter being a fundamental requirement to enable that progress). The situation is different when we consider smart gas meters; indeed the actual diffusion of smart gas meters is restricted to the deployment in some isolated pilot project. Furthermore, being the smart meter introduction a lever to foster the competitiveness of the market at a EU level, the completion of the standardization work undertaken by EU bodies: CEN, CENELEC, and ETSI are crucial to foster the massive production of smart gas meters by producers at an international level.

At national level, although the body entitled for the standardization of smart meters CIG (Comitato Italiano Gas) – whose work began in 2008 after the publication of the regulatory requirement – had envisioned to conclude its work within 2010, the body's worktables and process didn't yet come up with a standard for domestic clients (standards for industrial clients was achieved in 2010). This was also due to an EU pressure to the Italian regulator to be aligned, in terms of standards, with EU entitled bodies in order to avoid the risk of incongruence between the Italian initiative and EU's.

Currently the smart gas meter production market is represented by 5 companies in Italy, with two prototypes which already obtained the MID certification (Measuring Instruments Directive 2004/22/CE). This said, it is important to point out that the production process is still in the phase of pre-industrialization. From the interviews with the two leading distributors it became clear how producers, although they seem to have achieved remarkable progress in the past two years, are still characterized by a high level of immaturity (which is then reflected on the price of smart meters).

2.3.2 Communication infrastructure supplier

The main actors for the provision of the communication infrastructure are represented by TELCOS. Their solution consists in providing Sim M2M (machine to machine) to be installed in concentrators (gateways which collect the information from different meters and transmit it to the central data systems) or directly on the meters. The peculiarity of those Sim is the low transmission rates (just little data to be transmitted every day), combined with the crucial necessity to be covered by the communication network at anytime. Furthermore, in case the Sim is installed directly on the meter, the TELCO must ensure the coverage of the meter even if installed in a place not covered by that operator, therefore must ensure the roaming. These peculiarities led some telcos to design ad-hoc Sim M2M to fulfil those requirements.

Another supplier of communication infrastructure, depending on the solution adopted by gas distributors, could be electric distributors which can aggregate data from gas meters on the electric meter and transmit it to central acquisition systems through power line carrier (PLC).

2.3.3 IT infrastructure supplier for data management

This segment of the metering supply chain is characterized by a multitude of different providers which compete in a mature market. The technologies and solutions are widely consolidated; the competition is based on the ability of different ICT companies to differentiate their offer, designing a solution that best fits utilities needs.

2.3.4 System integrator

Given the complexity of the metering solution and the many actors involved for the construction of the solution to be offered to distributors, the need of a system integrator emerges. This actor is the one dealing directly with the distributor and translating its needs into requirements for the underneath actors composing the metering supply chain. He is the one coordinating the efforts, setting time plans and deadlines and stipulating contracts with subcontractors. His role can be extended to the provision of the metering service, therefore managing as well the installation process, the metering service (managing the communication infrastructure and transmitting the acquired data to distributors' management systems) and the maintenance of the entire system. These actors are likely to be ICT providers or Telcos, although some major meter vendor also entered into the metering service market.

2.3.5 Installation

The installation process, depending on the metering architecture chosen by the distributor, could require the contextual installation of the smart meters and of the communication infrastructure (to ensure each meter is effectively reached by the signal of the concentrator). The intricacy of this activity, requiring a high degree of expertise in the telecommunications, network design and information technology implies a distributor inclination towards outsourcing this activity. The most desirable actors for the realization of the installation process are therefore Telcos and communication system vendors.

2.3.6 Metering service and maintenance of the infrastructure

This activity is actually covered by the distributor, but could be outsourced to a third actor which could leverage on more adequate resources. The drivers which could lead distributors towards outsourcing this activity will be discussed in details in chapter 5 and encompasses the dimension of the distributor, its organizational structure, the reimbursement mechanisms foreseen by the regulator, the communication architecture chosen (standards, requirements, costs), the rates applied by Telcos, etc.

Chapter 3 - Smart gas metering: Regulation and current initiatives

This section is aimed at analysing and reviewing the main regulations emitted for the introduction of smart gas meters in the domestic market. The analysis first considers the European regulatory framework for subsequently focusing on the Italian regulation, investigating on norms and resolution designing the current mandatory roll-out plan. Finally an examination of the current initiatives in the field of smart gas metering undertaken in Europe will be pursued.

3.1 Premise

This section is aimed at analysing and reviewing the main regulations emitted for the introduction of smart gas meters in the domestic market. The analysis first considers the European regulatory framework, which – as will be discussed – deems the introduction of smart meters – for all energy fields including electricity, gas, water, heat – a crucial step towards reaching the Energy-Climate Package goals.

In the second step the study is focused on the Italian regulation, investigating on norms and resolution designing the current mandatory roll-out plan and finally an examination of the current initiatives in the field of smart gas metering undertaken in Europe will be pursued.

As the need of smart metering for electricity is widely acknowledged in the international community, in the gas sector, smart metering still represents a topic of discussion and controversies. Italy is the first mover among Member States towards the introduction of smart gas meters with an ambitious plan requiring the installation of 17.5 million smart meters (initially by 2016 then postponed to 2018). This represents an opportunity for the Italian energy system, but as it often occurs in the innovation process being first movers represents a significant risk especially when fostering the acceleration of the diffusion process of the technological innovation. In fact the menace of remaining “locked in” to wrong technological solutions may cause catastrophic economic returns particularly when the decision has such long term repercussions.

3.2 The European Regulation

Various directives from the European Commission highlight the necessity of introducing smart meters to reach the target goals in terms of environmental sustainability and of market competitiveness.

Already since early 2006 when the directive 2006/32/EC on energy efficiency was emitted, the European Commission drew attention to the importance that smart metering has for fostering awareness and responsible energy consumption by all citizens. This said, the need of planning the introduction of smart meters, both for electricity and gas, became mandatory with the emission of the third Energy Package published in June 2009 (EC, 2009a) (EC, 2009b). As a single European scope is not suitable for all Member States given the differences among countries in the gas market industry, the meter infrastructure in place, national regulations, climatology and environmental reasons, EU doesn’t aim at providing detailed and stringent directives for the introduction of smart meters. Conversely, the third Energy Package requests Member States to perform a comprehensive cost benefit analysis for the implementation of the roll-out considering all actors involved, and whether it produces positive results, to plan the implementation. As for electric smart meters a clear target is defined in terms of penetration, for gas meters any clear target has been stated. In fact, EU targets 80% of European households to be equipped with an electric smart meter by 2020 to facilitate the emergence of smart grids. Such targets seem ambitious as at present the diffusion of smart meters in Europe doesn’t exceed 10%

of households (Cervigni et al., 2011), and as Member States appear not to take appropriate actions towards meeting the objective, EU menaced to come out with more stringent directives and regulations.

Lately, through the E10-RMF-29-05 published in February 2011, ERGEG (Regulators Group for Electricity and Gas) provided concrete guidelines of good practice on smart metering systems for Member States, National Regulatory Authorities and industry (both for electricity and gas). The document contains a set of services for retail market customers which should be considered as essential for the design of the metering solution at national level, and some other services which could be encompassed by the solution, but for which single Member States should value the appropriateness. The recommendations are based on the services that could be offered through a smart metering system, leaving to Member States degrees of freedom for the design of technical specifications (as their adequateness may vary from state to state). Furthermore, a set of recommendations are directed towards Member States regarding roll-outs, cost benefit analyses and data security and integrity.

Finally, through the Directive of the European Parliament and of the Council on energy efficiency 2011/0172 (COD) it was requested to Member States to come with a clear plan by September 2012 on how and when to do the implementations.

In parallel, Mandate M/441 is an initiative of the European Commission’s Directorate General Enterprise, based on an official Commission mandate of March 2009 to CEN, CENELEC and ETSI for the development of an open architecture for utility meters involving communication protocols and functionalities enabling interoperability. The Mandate has the general objective to highlight or to harmonize European standards that will enable interoperability of utility meters (water, gas, electricity, heat), which can then improve the means by which customers’ awareness of actual consumption can be raised in order to allow timely adaptation to their demands.

European guidelines can be structure into four main areas which will be elucidated in the following paragraphs.

3.2.1 Data security and privacy

In relation to the concept of smart metering systems, concerns might be raised regarding the security of the metering data that is stored, transmitted and retrieved; and the privacy of the customer.

For ERGEG it is of the utmost importance that the privacy of customers is protected. All reasonable endeavours have to be undertaken to address data security and privacy issues before implementing a smart meter roll-out. This said, ERGEG does not intend to make detailed recommendations on security and integrity regarding meter value management since it is always the customer that chooses in which way metering data shall be used and by whom, with the exception of metering data required to fulfil regulated duties and within the national market model. Different countries have dissimilar concerns about privacy issues, and therefore the dilemma must be solved at national level (for example in the Netherlands and Belgium many critics were raised to governments from citizens regarding the daily transmission of consumption data which ended up by postponing the implementation plan). The principle should be that the party requesting information shall state what information is needed, with what frequency and will then obtain the customer's approval for this.

3.2.2 Customer services

By customer services for gas, ERGEG means the outcome which the customer can expect through the functions of the smart metering systems. ERGEG recognises that installation of smart meters will not in itself reduce consumption, or provide lower bills. However, information on actual gas consumption may trigger changes in customer behaviours and thus reduce the overall gas consumption. Towards such a goal access to consumption information should be provided to customers at most on a monthly basis. Moreover the smart meter should be connected to an interface which provides secure communication to the final customer, enabling the meter to export private metrological data to the final customer. The interface shall provide private information enabling final customers to better control their energy consumption and use the information for further potential analysis. Such information shall at least indicate the current rate of consumption (e.g. kJ or m^3) and related costs and be communicated in a format that promotes consumer action in energy efficiency. A format that may be suited for domestic consumers is the In-Home-Display, which is a home display that would communicate to the client all its energy consumption in an integrated manner (considering gas, power, heat, water, etc.) with a user-friendly interface that would facilitate the analysis of its consumption behaviors and would supply advices for optimizing it; but the decision whether to require this device is left to Member States.

ERGEG recognizes that all the services suggested may not exist as of today, but should be seen with a forward-looking perspective. This is particularly true for the modalities for interfacing with the home and providing consumption feedbacks to consumers.

3.2.3 Cost and benefit analysis

ERGEG recommends Member States to perform an overall valuation on the sustainability of implementing a smart metering infrastructure at national level. This economic assessment should contain all long-term costs and benefits to the market and to individual customer. In addition through the Directive of the European Parliament and of the Council on energy efficiency EU requested to Member States to come with a clear plan on how and when to do the implementations by September 2012. (CE, 2011b)

Part of this assessment could be a cost-benefit analysis that takes into account the economic benefits to consumers as they, in the final instance, are called upon to bear the cost of smart meters. If assessed positively, a roll-out should be carried out.

Apart from the customer benefits, the cost-benefit analysis should also take into account an extensive value chain, covering DSOs, suppliers, metering operators, sales companies, governments, etc. considering as well the costs involved regarding metering data security.

3.2.4 Roll-out

ERGEG doesn't state a specific target date for the implementation of gas metering systems, although it strongly recommends Member State to achieve the roll-out to meet the 20/20/20 target (which involves a reduction of 20% of emissions, 20% improvement in energy efficiency and 20% increase in renewables by 2020).

The European regulator recommends that, if assessed positively and a roll-out is decided, all customers should be eligible to obtain a smart meter, and that Member States should avoid discriminatory behaviour by the party responsible for the roll-out (for example: discrimination based on distinguishing between customers served under regulated prices in relation to customers served on the free market).

Table 2 summarizes the 16 main guidelines provided by the EU regulator.

Data security & integrity	1. Customer control of metering data
Customer services	2. Information on actual consumption and cost, on a monthly basis, free of charge
	3. Access to information on consumption and cost data on customer demand
	4. Easier to switch supplier, move or change contract
	5. Bills based on actual consumption
	6. Offers reflecting actual consumption patterns
	8. Remote enabling of activation and remote de-activation of supply
	11. Alert in case of exceptional energy consumption
	12. Interface with the home
	13. Software to be upgraded remotely
Costs and benefits	14. When making a cost benefit analysis, an extensive value chain should be used
	15. All customers should benefit from smart metering
Roll-out	16. No discrimination when rolling out smart meters

Table 2 European guidelines for smart gas metering *(ERGEG, 2011a)*

3.3 The Italian regulation

3.3.1 Overview

Italy is the only country in Europe which defined – already time ago – a program for installing smart gas meters. The Italian regulator AEEG (Autorità per l'Energia Elettrica e il Gas) initiated its effort for the design of a regulatory framework which would mandate the smart metering development in early 2007 by conducting a cost-benefit analysis for the complete roll-out of smart meters for every customer laced to distribution and transmission grids. Following that analysis – in October 2008 – the regulator enacted the Arg/Gas 155/08 directive requiring all distributors to sustain the investment for providing smart meters to 80% of Italian households within 2016. After the release of this law, several worktables with all actors involved in the supply chain were launched, and more than a few consultation acts were emitted. Figure 17 portrays the tortuous path of the regulatory activity.

For sake of being complete, it is important to mention that all following acts and norms consider the entire gas consumer market – therefore taking into account industrial customers or thermal power plants – breaking down the rules and regulations according to the type of meter to be installed. These vary from domestic consumers with class meters G4 and G6, to big industrial consumers with class meters over G40. Coherently with the scope of this research project, the norms and regulations further presented will be discussed with reference exclusively to the domestic market (class meters G4 and G6).

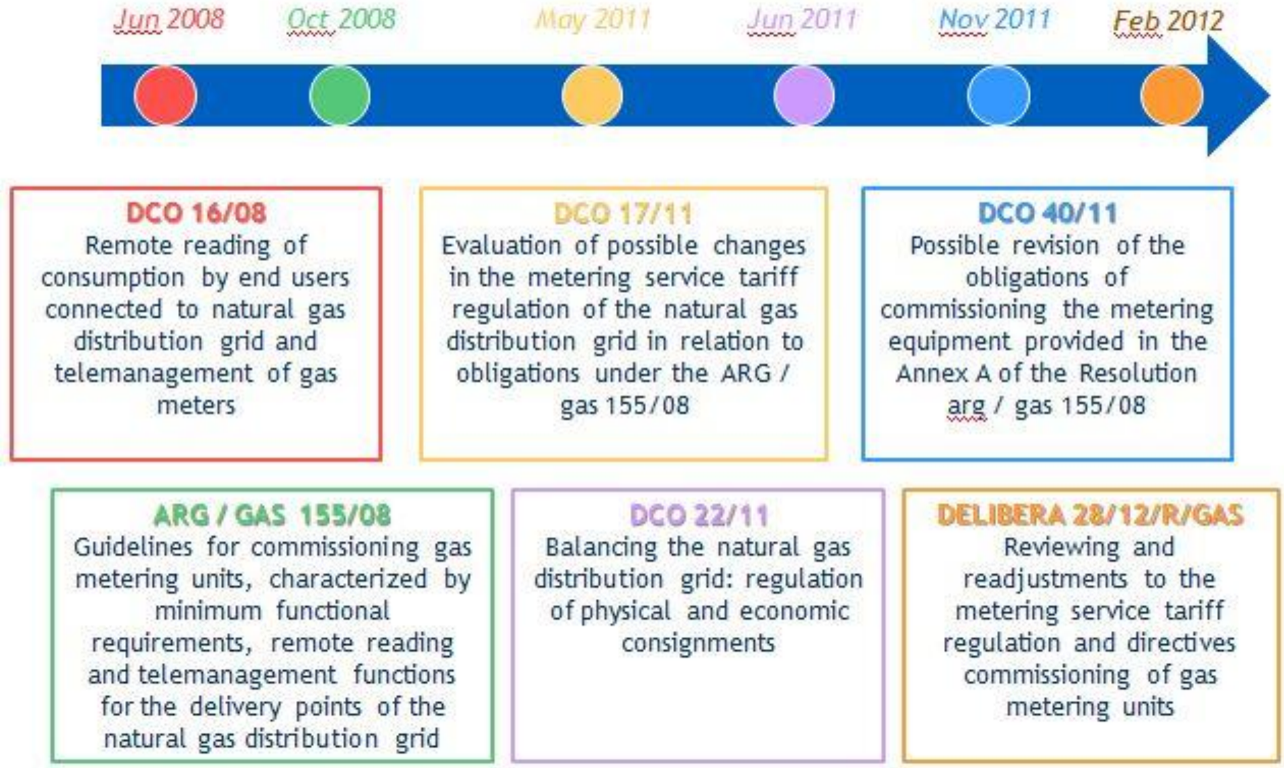

Figure 17 The Italian gas metering regulatory framework

3.3.1.1 *DCO 16/08*

The first consultation document released by the Authority reported – for discussion with all the parties involved – the outcomes of various activities aimed at verifying the technical feasibility and economic sustainability of the project, in particular:

- an exploration of technical solutions available on the market concerning smart gas meters and remote control systems/ remote reading systems, considering 2007 state of art of technologies for hardware and data communication;
- a survey at European level aimed at highlighting the degree of use of such technologies from operators of the natural gas sector;
- a quantitative analysis of costs and benefits of deploying the remote reading system in relation to the distribution firm size: the one in charge of carrying out the investments and performing the activities of reading meters

- a qualitative analysis of the benefits that the introduction of the remote reading infrastructure could cause to the entire gas system

Following the present consultation paper, a technical working table was established to develop proposals on functional requirements of gas meters to which distribution and vendor associations participated together with the CIG (Comitato Italiano Gas), meter suppliers associations, and other involved actors.

3.3.1.2 *Arg/Gas 155/08*

This regulatory order (below mentioned as 155/08) represents the transition from the initial consultative nature of the 16/08 act to the real compulsory character of the metering programme. This document sets the objectives pursued and states the minimum functionalities that smart meters should have, the deadlines for the completion of the roll-out programme, the intermediate milestones, and the fine for breaching of legislation.

According to the interviews with the responsible of AEEG's metering regulation department and from the various distributors interviewed (Snam Rete Gas – Enel Rete Gas and TEA) it clearly emerged how the present obligation represents the biggest revolution in last decades concerning the gas supply chain.

Objectives

The objectives pursued form 155/08 regulatory order involve a systemic redesign of various operations and activities to reach higher levels of effectiveness and efficiency in the entire gas supply chain (cf. Table 3). This objectives are:

- **Timely definition of reliable daily financial statements of each user of the transport network.** In fact the final balance of the transportation system (with respect to the entered and withdrawn gas on the transport network) is known reliably for a given day with a delay of a month, and is based on various estimated data.

- **Development of fair and regulated market for gas promoting the competitiveness of the market.** In fact the accurate and timely balance of the transport network allows assigning to each user of the network the effective gas ownership. This mechanism allows therefore to allocate to each user of the infrastructure the inefficiencies generated by them supporting therefore most efficient players, with obvious aftermath for the competitiveness of the market. Furthermore, the introduction of smart meters allows customer to switch between suppliers through a much easier process. Indeed, this activity is simplified by the elimination of the burden of sending an operator to customers' household to read the meter data whenever a commercial activity occurs.

- **Issue of invoices based on actual withdrawals.** This objective is mainly pursued because it allows better competitiveness of the market as the higher precision of invoices consent consumers to better differentiate between different providers, rewarding the most efficient.

- **Reduction in operating costs resulting from the elimination of manual readings and of algorithms for estimating gas consumption.**

- **Improvement of the quality of service and opportunity for new service provision.** Metering infrastructure allows to better profile customers' consumption patterns and to promptly identification of failures within metering perimeter.

- **Foster customer awareness on energy consumption.** AEEG pursue this objective by considering that whether customer are provided with more precise invoices that illustrate the actual energy consumption they might be led to modify their consumption patterns.

Minimal functional requirements (articles 4 and 6)

- **Metering units' clock.** Metering units shall be equipped with a clock function that is capable of managing seconds and of being synchronised with a frequency that entails a maximum monthly drift that shall not exceed ± 5 minutes. They shall each have a unique reference for which the gas metering service operator shall be responsible.

- **Temperature adjustment.** Metering units shall be able to measure the gas withdrawn at standard temperature conditions (standard m^3). This functionality was introduced as gas volumes are sensible to temperature and pressure environments, and therefore need to be corrected to ensure accurate customers' bills. In the present situation, the temperature adjustment is carried out by multiplying the withdrawn volumes by a factor which is set for each municipality depending on the altitude, temperature, climate, etc.

- **Withdrawal totaliser register.** Metering units shall enable the gas withdrawn to be measured and this measurement to be recorded in a single incremental totaliser register.

- **Time of use withdrawal totaliser registers.** Metering units shall enable the gas withdrawn to be measured and this measurement to be recorded in at least three separate totaliser registers. The registers shall be enabled alternatively in at most five daily time bands. This feature enables the opportunity of applying different prices for different moments of the day or days of the week. This requirement is clearly inspired by the electricity sector where time-of-use tariffs have been introduced to better shape customer's consumption behaviours. However, it has to be mentioned that real opportunities for shaping (through time-of-use pricing strategies) gas consumption behaviours are strongly uncertain (as will be discussed in details in Chapter 7 -

- **Withdrawal curve (interval metering).** Metering units shall enable withdrawal data to be recorded on a parameterisable time basis, and set at the daily minimum.

- **Saves and backups of withdrawal totaliser register and data security.** Metering units shall enable the withdrawal totaliser registers to be saved in registers that cannot be altered until the next save. Metering units shall be equipped with mechanisms to protect and monitor the withdrawal data such as alarms

- **Diagnostics.** The metering units shall be able to carry out self-diagnosis checks to verify that they are functioning properly, including a check on whether they have exceeded their maximum monthly drift. They shall record the result of these operations in a status word for transmission to the remote management centre when the centre so requests. Any anomalies recorded must be reported to the remote management centre at the first query or, if the communication system so enables, automatically and spontaneously.

- **Display.** Metering units shall be equipped with displays that visualise the following information at the customer's request on the date and time, the values of the different totalisers, any alarm showing that the metering unit has recorded an anomaly. This requirement derives from the European directives requiring the provision of consumption data feedbacks to consumers; however, setting a display on the meter has a low influence towards this objective. Indeed meters are often displaced in basements, balconies, buildings' common areas, or in sites whose access results unease for customers.

- **Up-dating of the metering unit software programme.** Metering units shall have a software programme up-date function that can be managed remotely.

- **Electrovalve.** Metering units shall be equipped with an electrovalve which allows the remote deactivation of supply, but cannot be opened remotely. During any power-supply failures the electrovalve shall remain in the state it was in immediately before the power-supply failure. As we will see this requirement is object of many controversies between DSOs associations and the regulating Authority, which established a specific working table at the UNI/CIG aimed at solving reliability issues related to its functionalities and uses. The CIG, through the commission D5 has officially requested the Authority a further period of time to deepen analyse the theme (through valuations and technical specifications) in order to eventually modify and implement the technical specification UNI/TS 11291-6:2010. The legal metrology group is also concerned by the security issue of the electrovalve and still needs to define standards and norms for its uses (which though can be emitted only after the conclusion of UNI/CIG working tables defining its functionalities and reliability)

- **Remote transactions.** Metering units shall be able to perform the following remote transactions:

  a) reading the value of the current totaliser register;

b) activating and amending the hourly schedule;
c) synchronising the clock;
d) alarm to be activated whenever the withdrawal data are unreliable, even if only in part;
e) reading the status word of the meter;
f) software programme up-dates;
g) closure of the electrovalve;
b) activation of the manual opening of the electrovalve.

Communication and interoperability

The regulatory order emphasizes the importance of interoperability for the successful competitiveness of the market both to facilitate the switch between different meter suppliers, and between different energy suppliers (sales companies). This requirement led to the constitution of working tables within the UNI/CIG (Italian Organization for Standardisation/ Italian Gas Committee) to define the standard protocols to be used by the metering infrastructure. The effort of this body has been remarkable up to date, with the emission of 7 technical norms UNI/TS 11291 (three of them still need to be approved through public inquiry), but didn’t yet come to the conclusion of the standards for the mass market (UNI/TS 11291-7). Its regulatory effort towards the definition of communication protocols for domestic consumers has been slowed down by the necessity to be aligned with the European standardization bodies CEN, CENELEC and ETSI (for the need of interoperability at international level).

Interoperability is therefore crucial for:

- Communication sub-network linking the remote management centre with metering units and with data concentrators
- Communication sub-network linking data concentrators with metering units

Deadlines for implementation

The regulatory order also identifies specific deadlines for the roll-out programme of domestic meters which are summarized in the following Table 3:

Deadline	Percentage	Unitary fine (€/metering unit not installed)
31 December 2012	5%	4
31 December 2013	20%	
31 December 2014	40%	
31 December 2015	60%	
31 December 2016	80%	

Table 3 Deadlines for implementation (*AEEG, 2011c*)

3.3.1.3 *DCO 17/11*

Following the obligation to install new meters, the Authority had provided a change in rates to cover the cost of the investment. In particular, resolution 155/08 provided that the tariff system should recognize the investments made by distributors, although the coverage is recognized "only to those responsible for metering services who actually made such investments." The resolution also requires that the costs for the roll-out plan doesn't imply any charges to be paid by end-customers. The remuneration of the investments to distributors for the implementation of the installation plan, however, presented some criticalities which were pointed out by distributors, and which led to the current consultation paper. In particular, unfairness measures were detected for what concerns:

- Costs incurred for telemetry systems, and remote transmission (SAC: "Sistemi Acquisizione Centralizzati")

- Operating costs for management of equipment, for performing metrological tests and for telecommunications

- Residual value of the meters to be replaced (which is calculated on the basis of the amortisement of meters' residual lifetime)

The measures introduced by the present consultation paper can be recapitulated as follows:

- **Capital expenditures coverage for metering units:** this rate component is computed on the basis of investments effectively sustained to cover the cost of the investment for transmission systems (concentrators, repeaters, transducers, etc.) / processing systems / recording systems / storage of metering data systems. The consultation paper 17/11 proposes that this component might be calculated on the basis of standard costs once standards will be defined.
- **Operating expenditures coverage for installation and maintenance:** this component was computed on the basis of 2006 average costs although the introduced requirement of performing metrological tests and of correcting the volumes withdrawn with actual temperature may raise operating costs. The present document (in effect from 2012) differentiates that component considering meters' class (as the functionality enabled, and thus the operating costs, may deiffer from class to class)
- **Capital expenditures coverage for substitution of traditional meters:** many distributors argued that the introduced measures couldn't be fair if they didn't take into account the residual value of traditional meters installed as their residual lifetime could reach 15 years. This measure was transposed by the current consultation paper.
- **Capital expenditures coverage for telemanagement[7] systems:** the remuneration of CAPEX is independent from actual investment and tends to reward companies that invest less than the national average.

[7] The difference between telemetering and telemanagement lays in the use of the electrovalve which in telemanagement allows the remote activation and deactivation of gas supplies.

- **Operating expenditures coverage for metering activities:** telemetering introduction should reduce operating costs for reading activities, therefore maintaining 2006 unitary costs for this activity may bring extra profits to distributors. Consequently, the present document states that those rates might be modified following the effective plan roll-out although they'll remain unvaried until 2016.
- **Capital expenditures and operating expenditure balance:** the reimbursement scheme favored distributors opting for the choice of performing metering activities in-house instead of outsourcing it as the additional operating costs deriving from the second option weren't accounted in tariffs. The current document recognizes the importance of the neutrality of the tariff system relative to DSOs organizational choices

3.3.1.4 *DCO 22/11*

This consultation paper tackles the main inefficiencies in the gas sector by redesigning the organizational mechanisms and industrial processes for allocating end customers withdrawals to different gas vendors (using the distribution network). In particular, it attempts to solve issues related to:

- **Balance of the transport network.** The balance of the transport network for a given day (or month) is set by subtracting to the sum of the gas entered on the transport network by the different sales company, the sum of the withdrawn gas by each of these companies (which then enters the distribution network). As mentioned when discussing the objectives of the 155/08 regulatory order, the actual transport balance regulation requires the balancing session to be closed within three months from the given gas day, allocating gas withdrawals to users of the infrastructure (i.e. gas vendors) with over a month of delay. Especially for domestic users for which the actual regulation requires to perform meter readings once a year, it often occurs that when the balancing session is closed for a given gas day, the sales company have to equalize their energy balance based on estimates of end customers' withdrawals as the actual data is not available.
- **Customers profiling.** Sale companies, which are the actors that should perform accurate profiles for their customer don't seem adequately incentivised to do so, and this leads to evident issues for forecasting customer's withdrawals.
- **Unaccounted gas.** Given the nature of gas distribution networks, there are always misalignments between the gas entered and withdrawn from the grid. This is mainly due to gas leakages on the grid or to errors in measures from end customers' metering units. The allocation criterions for the unaccounted gas may seem fuzzy, unfair and don't charge inefficiencies to the actors originating them, therefore creating distortions on the market.
- **Standards for data exchange.** The current consultation paper highlights the need for introducing standards to which DSOs should refer for communicating withdrawals data to transport companies as today different DSOs use different methods with manifest repercussions on the accuracy the balancing activity.

It is important to underline that all these issues can't be solved by the introduction of smart meters as these refer mainly to the transport network for which accurate metering devices are already installed at entering and withdrawals points. Smart metering introduction for end customers might although facilitate faster energy balance for sales companies.

3.3.1.5 *DCO 40/11*

This consultation paper introduces overwhelming proposals to modify the 155/08 regulatory framework both concerning the functionalities and standards to which installed smart meters should comply to for interoperability needs and the deadlines for the roll-out completion (and consequently the reimbursement scheme).

- **Deadlines to fulfil 155/08 regulatory order and reimbursement scheme.** The present consultation paper delays the deadline to achieve the installation of 80% of total domestic meters (G4 and G6) to December 31 2017 (the 155/08 requested the completion to be achieved by 2016). Furthermore, it eliminates fines for intermediate deadlines requirements therefore letting to single enterprises higher degrees of freedom on the decisions on their roll-out time plan. Conversely it envisioned the introduction of decreasing standard costs for metering units to be reimbursed to DSOs on the basis of smart meters effectively installed in each year. This measure is aimed at incentivizing companies to start the deployment at early stages.

- **Interoperability requirements.** This consultation document also transposes the directives of the Mandate M/441 (which has been deployed in 2009 after the introduction of the Italian obligation) introducing a new approach aimed at exploiting synergies between the smart electric meters and smart gas meters infrastructure (and potentially for water meters if and when they'll be installed). This synergies might be achieved only by the presence of a standard interface on smart gas meters which allow them to be connected with heterogeneous external devices. In particular DCO 40/11 proposes two alternative configurations:
    1. **External modem:** which collects energy data from electric and gas meters via radio frequency and transmits them to the concentrator, which, in turn, communicates with telemetry centres (SAC) of service providers (the data could as well be transmitted to other client's accessory equipment). Figure 18 portrays the envisioned architecture:

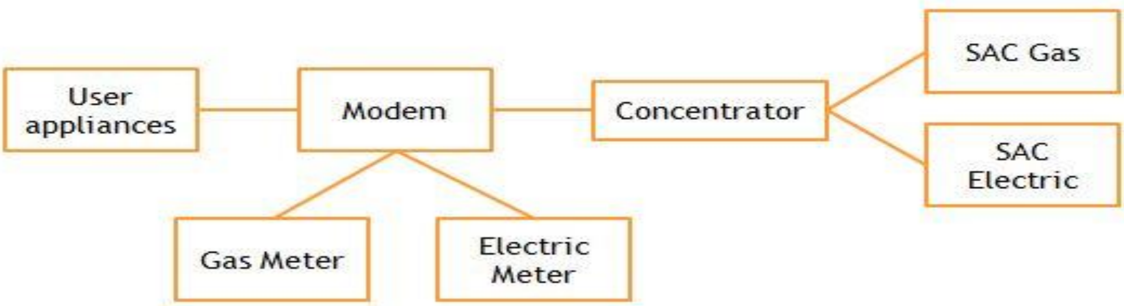

Figure 18 Communication architecture with external modem (*AEEG, 2011b*)

2. **Modem inside the electric meter:** which receives data from the gas meter and transmit them, together with those of electricity consumption (but in a separate manner), to concentrators and to user's equipment. The communication via PLC between the electric metering unit and the concentrator is allowed, but the Authority indicates that it may be less reliable in the medium term compared to radiofrequency technologies. However, it must be said that this option cannot be implemented with the electric meters currently deployed in Italy (as the embedded technology doesn't allow it) and therefore would need to wait for the deployment of the second generation electric meters (which is expected by 2016). The following scheme (Figure 19) shows the second proposed architecture:

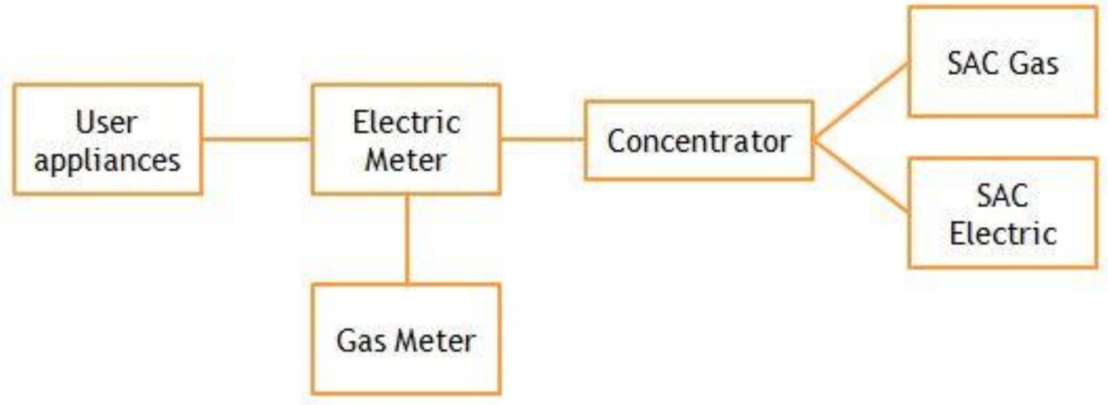

Figure 19 Communication architecture with modem inside the electric meter (*AEEG, 2011b*)

3. **Modem inside the gas meter:** which receives data from the electric meter and transmit them, together with those of gas consumption (but in a separate manner), to concentrators and to user's equipment. However this architecture results unrealistic given the impossibility of feeding the gas meter through the power grid (cf. Figure 20). AEEG proposes this third architecture, but also expresses its doubtfulness regarding its real implementation.

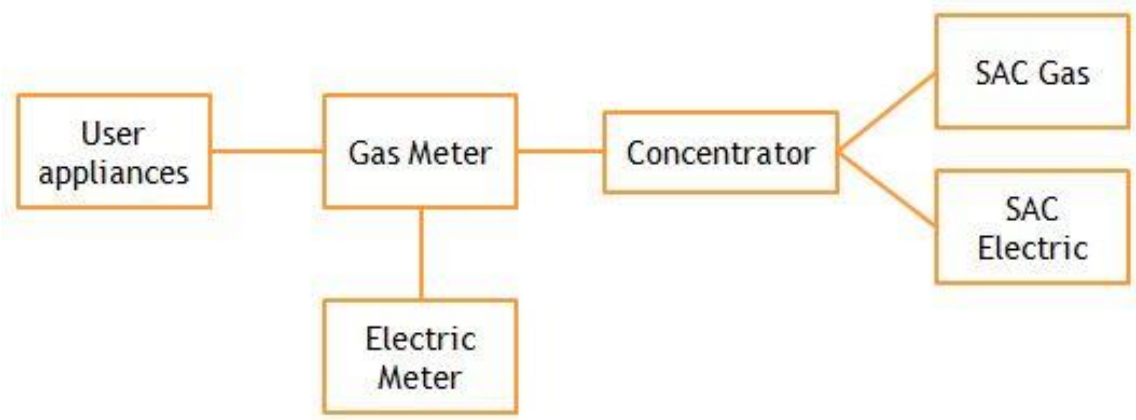

Figure 20: Communication architecture with modem inside the gas meter *(AEEG, 2011b)*

3.3.1.6 *Resolution 28/12*

This is the last resolution emitted by the Authority and further introduces novelties to the never-ending metering regulatory framework. After the countless disputes concerning the utilization of the electrovalve, this document specifies that the requirement is referred exclusively to commercial purposes and not for security reasons (therefore the electrovalve mustn't always be working without any repercussion on consumers' security). The present document also sets up modifications to the 155/08 scheme in what concerns roll-out obligations, tariffs regulation. Finally it introduces the necessity of conducting experimentations and pilot projects on new metering architectures exploiting synergies with the electricity meters and other services.

- **Roll-out obligations.** A further adjustment in the roll-out deadlines was introduce through the 28/12 resolution requiring 60% of the domestic meters to be introduced by 2018 (instead of 80% within 2017 as required by the previous DCO). This document further requires that all meters to be installed from March 2012 should fulfil the minimum requirement stated by 155/08 a part from telemetering functionality. This exception was introduced to enable DSOs to acquire the central acquisition system (SAC) once they reached a number of metering units that justifies the investment need for the SAC. The telemetering functionalities must be enabled starting from 2018 for all smart meters installed.

- **Tariff regulation.** The current resolution proposes an alteration to the reimbursement scheme proposed through DCO 17/11. In particular it merges the component covering capital expenditures for metering units and for installation and start up costs; it introduces a new component covering the operating expenditures for maintenance and metrological tests; a component to cover manual reading activities before the introduction of telemetering systems (covering costs for personnel, vehicles, etc.): this component tends to zero with the emergence of telemetering; a component covering the cost of the SAC system and for the transmission of data (or for the outsourcing of these activities); and finally a component covering the capital expenditures costs for acquiring concentrators, their installation, the rent of the space for concentrators, and their maintenance (or the equivalent component for outsourcing contracts).

- **Experimentation and pilot projects.** The Authority will issue a resolution by summer 2012 which identifies process and criterions for the selection of the investments to be financed on the trials. The trial will focus on domestic telemetering and telemanagement solutions presenting multi-service features (therefore exploiting synergies with the supply of other services). Through the experimenting the Authority intends to assess the appropriateness and feasibility of those architectures, the characteristics which new metering systems for electricity and water should have and the opportunity of differentiating the tariff component covering the costs of concentrators on the basis of a parameter of density on the location served. The last objectives is set as the number of metering units per concentrator may vary significantly as we consider for example rural environments – where few meters will be installed in a given area given the low concentration of households – or urban areas – where the radius covered by a concentrator could encompass a huge number of metering units.

3.4 Comparison between European's directives and Italy's regulatory framework

Table 4 summarizes the main differences between European directives and the Italian regulatory framework in what concerns the objectives, the focus, the cogency and the set deadlines. We notice how the Italian regulation appears to be much more stringent and detailed regarding the introduction of smart gas meters.

	Italy	Europe
Object	The initial object is the smart gas meter, with recent development to the theme of smart electricity meters	The object is energy consumption, therefore it has an integrated approach considering smart metering for gas and electricity (and potentially other services such as water, heat…)
Focus	The emphasis is mainly focused on the optimization of supply chain management and the correctness in billing users	The emphasis is primarily on information provided to users (interface with the house), to achieve the goals 20/20/20
Cogency	The installation of smart gas meter is compulsory	The installation of smart electric meter is compulsory, but it only recommends the introduction of smart gas meters after careful evaluations
Deadlines	Deadlines (initially the end of 2016, then 2017 and lately 2018) defined before the availability of established standards and products on the market	Since simply recommendations are provided, the only deadlines refer to the completion of feasibility studies (September 2012)

Table 4 Differences between European directives for smart gas metering and the Italian regulation

3.5 International comparison

Undoubtedly there is still little experience and availability of information regarding the use of smart meters both in Italy and abroad, especially in the gas sector.
It therefore reveals crucial investigating whether – and how – other countries are preparing the introduction of a national smart gas metering roll-out, for example through consultations, pilot projects or cost-benefit analysis.

At present, only Italy and the United Kingdom have set a clear plan for the roll-out of smart gas meters, while 4 other countries (France, Ireland, Netherlands and Slovenia) are still discussing on the opportunity to do so. Others – the vast majority of European members as shown through the following Table 5 – yet didn't accomplish the cost benefit analysis to determine whether this option results economically sustainable or not.

A first quick analysis suggests that, compared to Italy, other countries are moving with greater caution regarding the timings and the methods set in place to achieve the smart gas metering roll-out. In fact Italy seems to be the only country which set a roll-out time schedule so detailed and ambitious.

Roll-out plan approved	Roll-out plan in discussion	No roll-out plan
Italy	Austria	Belgium
United Kingdom	France	Czech Republic
	Ireland	Estonia
	Netherlands	Finland
	Poland	Germany
	Slovenia	Latvia
		Luxembourg
		Portugal
		Denmark
		Slovak Republic
		Romania
		Spain
		Sweden

Table 5 Smart gas meters roll-out initiatives in EU

3.5.1 United Kingdom

The United Kingdom is the only country apart from Italy which has already scheduled a roll-out program. Indeed the decision-making process started in early 2006 by the two regulatory bodies OFGEM (Office of the Gas and Electricity Markets) and DECC (Department of Energy and Climate Change) and involved the creation of various worktables which brought together exponents of the industry and consumer associations to analyze in details both technical and economical issues and bring proposals. The entitled worktable groups were the Smart Metering Design Group / the Data and Communications Group / the Security Technical Expert Group / the Implementation Coordination Group / the Consumer Advisory Group/ Privacy Advisory Group.

The required functionalities of installed gas meters are less stringent than the Italian ones as the temperature correction is not foreseen to be integrated to the meter – the correction will be performed through sensors in the household and the information will be elaborated through the In-house-display. However UK is the only other member state which foreseen the obligation of installing an electrovalve on future gas meters.

As for the communication system, DECC intends to create a new regulated company for the acquisition of data in the field and transmission to all parties with relative credentials (DataCommsCo or DCC). The DCC will be responsible for the provision and management of both smart electric and gas meters' data and services communication.

To support the decision making process OFGEM mandated the realization of a pilot project with the objective of assessing the appropriateness of providing to each household an In-House-Display (IHD). This device is a user friendly display to be located inside each household which is directly connected to both the electrical and gas meter. The device provides real time information on power consumptions, and near real-time information (with a maximum 30 minutes delay) on gas withdrawals. Actual energy consumption are provided to consumers both in terms of their energy units (Watts for electricity – and m^3 for gas) and of their cost. The device also illustrates graphical elaborations of consumer's energy consumption patterns and provides advices to increase the energy efficiency.

The pilot project involved installing both gas and electric smart meters in 18.000 households between 2007 and 2010, and proved that household's owners where an IHD was installed allowed an average 2% reduction in overall gas consumption; it also underlined that these results were achieved only in households where the energy consumption was provided in terms of its cost. The pilot also revealed that whether the information was provided through an internet portal, no significant results were revealed.

The roll-out program foresees a joint roll-out for both electricity and gas (Dual Fuel) to leverage on synergies for the installation process (installing only smart gas meter would cost 49£/meter and exclusively a smart electric meter 29£/meter; while the joint installation is estimated to cost 68£/meter resulting in a reduction of 10£/meter) and the communication system.

3.5.2 France

The French position in what concerns smart metering in the gas sector was expressed through the resolution of 3 September 2009 of the Commission de Régulation de l'Énergie (CRE, 2009) and in the recent consultation (Pöyry and Sopra Consulting, 2011), emitted after the availability of the first results of the trial launched in 2010 involving 18.500 domestic consumers, which involved the use of four different communication technologies and meters pertaining to four different vendors. The legislation specifications on the topic are not yet defined, but a time schedule for their evaluation has been set. Furthermore an initial set of recommendations outlining the directions to take regarding services that could or should be offered through the smart gas meters introduction have been published. We are now in the so called "Construction de la Solution" phase where a detailed analysis for defining the optimal requirements (both technical and organisational) is being performed and specific norms and regulations are being developed in addition to a further large scale pilot project (involving 100.000 domestic consumers) undertaken by the biggest French distributor – covering 96% of the market – which will end in 2014. Depending on the results of this project, the decision whether to enact the mandatory roll-out plan which would involve completing it by 2020, will be taken or not.

So far, the French configuration presents significant lower functionalities than the Italian one as no electrovalve will be requested, and neither the temperature correction; while the sustainability of the IHD for the business case is currently being assessed. It should be noted that, whether the IHD will not be required, the French regulator envisions the provision of information at most on a daily basis through an appropriate web page.

The following table illustrates the differences between the three most advanced countries in what concerns smart gas metering activity.

	Italy	France	UK
Compulsory	Yes	To be defined following results of pilot projects	Yes
Timing	Roll-out mandated in 2008 To be completed by 2018	Whether the assessment results positive; roll-out between 2014 and 2020	Roll-out mandated in 2011 To be completed by 2019
Investment	Borne by Distributors (presence of many small distributors: 245)	Borne by distributors (market very concentrated)	Borne by the supplier
Meter characteristics	• Electrovalve • Temperature correction • No constraint for the IHD	• No electrovalve • No temperature correction • IHD presence under assessment	• Electrovalve • Temperature correction undertaken through LAN • Mandatory IHD provision
Integration with the electric smart meter	Under assessment after the emission of consultation paper 40/11	No integration	Joint roll-out
Data communication	Depends from distributors decision whether to outsource	Will be defined through the currently pending “construction of the solution”	Regulated created company to manage all meter’s data communication

Table 6 Comparison of smart metering initiatives in Italy, France and UK

3.5.3 Other countries initiatives

- **Germany:**
  They have started experiments and pilot projects, but due to a lack of time, they yet didn’t initiate the comprehensive costs-benefits analysis of their smart metering program.

A simultaneous roll-out of gas and electric meters is though envisioned, and the electric meter should act as a gateway for the communication of data outside households.

- **Austria and Ireland:**
The cost-benefit analysis on the introduction of smart gas meters for electricity and gas has been performed outlining all pros and cons for all parties involved. The electrical infrastructure is planned to be used as the communication infrastructure for the transmission of both meters' data in an integrated manner.

- **Holland**
The cost-benefit analysis has already been carried out considering jointly electrical and gas systems. After an initial enthusiasm, Government has had to back the smart meters' roll-out plan due to oppositions from consumer groups for privacy reasons (KEMA, 2010). Currently they are in the development of the solution phase (defining the regulatory framework and defining directions for the roll-out program).

Chapter 4 - Smart Metering: Technology overview

This section will initially discuss the components, characteristics, requirements and criticalities of the hardware infrastructure demanded by smart metering. Subsequently the software and communication issues will be tackled drawing our attention on the technologies available, their strengths and drawbacks, on standardization issues, and on security and privacy issues. Then, different communication architecture configurations will be examined, identifying their strengths and criticalities. And finally the attention will be drawn on the technical issues related to the program implementation and the requirements for optimizing the roll-out plan.

4.1 Premise

As stated since the early 1999 by Guy & Marvin, "In smart metering projects, the biggest risk is the future. Market requirements, regulatory mandates, and technology will all change over the lifecycle of the smart metering investment." (Guy and Marvin, 1999) This was true in 1999 and remains proper nowadays. The Italian regulator seemed to be convinced this issue is characteristic of any type of innovation and though decided that the risk had to be faced (sooner or later); the investment had to be planned. The 155/08 regulatory order is not limited to planning the smart gas meters roll-out but introduced noteworthy novelties and innovations regarding functionalities and uses of gas meters (newly conceived temperature correction mechanisms, telemetering, telemanagement, electrovalve, etc.). These innovations, despite having fostered remarkable progress in the sector, caused relevant practical and technical problems. First, the production of smart gas meters fulfilling 155/08 technical specification couldn't meet the original time schedule. In fact, meter suppliers couldn't meet the deadlines, given the high demand from DSOs and the complexity of the required meter itself. After a careful analysis of the supply market it emerged that production process of most advanced meter suppliers is still in its pre-industrialization phase. Furthermore the regulatory framework sustaining the 155/08 obligation is not yet comprehensively completed as most technical specifications emitted by the CIG have been approved through public inquiries and published by UNI, however some norms still need to be approved (UNI/TS 11291-3; UNI/TS 11291-6; UNI/TS 11291-8) and the most crucial one regarding our analysis, the UNI/TS 11291-7 which deals with telemanagement systems, concentrators, repeaters and translators is still under elaboration.

The innumerable news and adjustments to the original 155/08 order, together with the need of being aligned with other bodies – such as legal metrology, or European standardization organizations – made it impossible to respect the initial time schedule.

The many criticalities to be faced from the technological view point concern both the hardware of the physical meters and the software and communication (with a particular concern for data security and privacy).

This section will therefore initially discuss the components, characteristics, requirements and criticalities of the hardware infrastructure demanded by smart metering. Subsequently the software and communication issues will be tackled drawing our attention on the technologies available, their strengths and drawbacks, on standardization issues, and on security and privacy issues. Then, different communication architecture configurations will be examined, identifying their strengths and criticalities. And finally the attention will be drawn on the technical issues related to the program implementation and the requirements for optimizing the roll-out plan.

4.2 The Hardware Infrastructure

Smart metering devices for the mass market, in particular metering units of class G4 and G6 are composed by several modules that have to be integrated in a single device**.** In fact, in order to fulfil several smart metering functionalities (i.e. timely read-outs, switching purposes, billing customers on actual consumption, etc.) two alternative solution may be considered: a simple but practical solution such as a remote index-reading only solution, and the integrated new smart meter solution.

- **Remote index-reading only solution.** This technical scenario doesn't require the replacement of the traditional meter, but entails the introduction of a retrofit module to the conventional meter (cf. Figure 21). The retrofit kit provides the remote index reading functionality with possible bidirectional communication. This approach represents a low cost solution as the investment needed for its roll-out could be a quarter of that of providing remote reading functionality by replacing the meters as reported by a Eurogas report on gas meters (Eurogas, 2008). The meter must be equipped with a pulse output, to which the retrofit kit will be connected. Pulses are generated by a small magnet which is incorporated in the last number of the meter integrator and the pulses are captured by a Reed Relay. There is no wired connection between the emission and capture of the signal; transmission is performed by magnetism. The meters will have to be equipped with a module which is able to "count" the pulses and include a radio frequency transmitter/receiver that allows the meter to send and receive data to and from a concentrator through Radio Frequency (RF). This module is powered by batteries.
  Among the functionalities enabled by this simple solution we may list remote readings; 2-way communication; communication with other devices (not with a seamless integration and depending on the battery lifetime); provision of information to a Home Area Network enabling customers to access and analyse metering data, consumption data and billing data (again this functionality has to be balanced with batteries lifetime).

Figure 21 Retrofit kit

- **Integrated new smart meter solution (fulfilling 155/08 regulatory order).** These smart meters are composed by a metering module (the device performing the counts) and from four other modules: the electrovalve; a unit for converting withdrawn

volumes in Standard cubic meters; a unit to register the data (data logger); and a communication module for the transmission of the data to the centre. These components must be integrated possibly into a single compact device (cf. Figure 22). This solution requires the substitution of traditional meters, and therefore its installation requires additional operations to be carried out after the replacement which are mandated by the legal metrology acts, such as a purge (depressurizing the entire installation) and tightness tests. (Benzi, 2011)
There are different traditional and innovative metering technologies which can be adapted to the order requirement:

- *Volumetric diaphragm/bellows meters*, these are the most diffused types of gas meters. Within the meter there are two chambers formed by movable diaphragms. With the gas flow directed by internal valves, the chambers alternately fill and expel gas, producing a near continuous flow through the meter.
- *Volumetric rotary meters,* within this type of meter, two figure "8" shaped bodies, the rotors (or pistons), rotate in precise alignment. With each turn, they move a specific quantity of gas through the meter.
- *Ultrasonic flow meters*, which measure the speed of gas movement by measuring the speed at which sound travels in the gaseous medium within the pipe.
- *Coriolis meters*, which are composed by one or more pipes with longitudinally displaced sections that are excited to vibrate at resonant frequencies. The frequency of this vibration is determined by the overall density of the pipe. This allows the meter to measure the flowing density of the gas in real time.

The first two categories correspond to the traditional mechanical meters and are characterized by a lower cost of the apparatus, which need to be integrated with all electronic components requested by the legislation (microprocessor, clock, temperature sensor, memory, modem, local communication interface, graphic display, electrovalve and battery). As for the second two categories which are static meters, embodying more innovative technologies, and already containing a primary electronic element (which registers the metered data in an electric or digital signal) the mere integration with the required software technology (ensuring the minimum functionalities) is needed. On the other hand, the static meters are characterized by higher energy consumption as power is required not only for ancillary functions, but also for the primary electronic element. (Lanzarone and Zanzi, 2010)

Figure 22 Examples of smart gas meters

The 155/08 regulatory order doesn't allow the simplest solution to be implemented given the detailed set of requirements imposed for metering units; the retrofit solution can't be chosen essentially because of the need of correcting withdrawn volumes on the basis of actual temperatures at meter level, and because the presence of an electrovalve is requested.

4.3 Software and Communication

The communication infrastructure is without any doubts the most crucial element for the development of smart metering. In the Italian electricity sector, where telemanagement was achieved a decade ago, the communication vectors used for the remote control of substation and secondary cabins are based on private infrastructure owned by the utilities themselves. These vectors make use of a mix of different technologies among which optical fibres, power line carriers and various wireless technologies which resulted onerous for their owners; but the benefits they allowed justified the investment. (Corral et al., 2012)

This section is first aimed at identifying and characterizing the different components required by the communication network; subsequently an accurate review of possible communication vectors and protocols will be performed assessing their strengths and weaknesses; for finally analysing the different communication architecture.

By analysing the required metering infrastructure we can distinguish four main components for data transmission from customers to DSOs and sales companies:

- **Gas Meter,** which requires an interface to be part of the Radio Frequency (RF) communication network with the capacity to be read
- **Concentrator,** which receives and sends the information to and from all meters which are connected to the network. It's the interface that aggregates data from various meters and transmit it to the central acquisition system. Its range can cover diverse kilometres depending on the communication technology used and the presence of infrastructural barriers.
- **Communication System,** several communication protocols and standards are available such as GPRS, GSM, PSTN, ADSL (xDSL), WMbus, ZigBee or PLC (only to a substation where the power grid can be used for communications), etc.

- **Central Acquisition System,** for the information to be sent and received. This system can be either integrated or separated from the AMM system (Advanced Meter Management) which is the intelligent software platform which has to be integrated with other processes in the company (billing systems, business intelligent systems, work force management systems, etc.)

Additional auxiliary equipment such as the repeaters, or translators might also be necessary for the proper functioning of the communication network. The repeaters are responsible for providing amplification to the RF signal, adding greater range of coverage.

Repeaters and concentrators deployment need agreements for space renting and hosting. This might involve long-term negotiations, with associated financial impact and consequences.

Also, it is important to mention that all this equipment which makes part of the communication network requires power supply for communicating, either through electricity or through batteries.

The choice of the communication standard is not independent from the type of platform that will be used in the medium-long term for the transmission of all telemetering and telemanagement data. At present, distributors make intensive use of the GSM/GPRS network given its almost total coverage of the Italian territory and relatively contained cost. Nevertheless, in the medium-long term other innovative communication technologies – not yet developed and diffused – seem predestined to substitute the GSM network for smart metering communication purposes.

Following are reported the main communication technologies which may be used in the metering architecture; for each of these technologies, features, requirements, strengths and weaknesses will be briefly discussed.

- **PSTN**

  The Public Switched Telephone Network is a technology which uses as communication route the existing telephone line and therefore has a remarkable capillarity. One of its main drawbacks is related to its cost: in fact this carrier requires the presence of a modem at both end point of the line. Furthermore, the carrier might be shared between different users or clients and this causes reliability issues as the data exchange could have the effect of activating a wrong terminal. (Choi et al., 2008)

- **ADSL**

  Asymmetric Digital Subscriber Line is a data communications technology that enables faster data transmission over copper telephone lines than a conventional voice band modem can provide – and that a smart meter would necessitate. It does this by utilizing frequencies that are not used by a voice telephone call. It is a consolidated technology and has a significant diffusion, although its development in the gas sector seems into doubt for three main reasons: 1- they are not controlled neither by DSOs, neither by sales companies and there are no dispatching priorities; 2-requires the presence of a modem; 3- the carrier is not always available. (Selga et al., 2007)

- **Power Line Carrier (PLC)**

This technology carries data on a conductor also used for electric power transmission. The main drawback related to its uses in the gas sector is that the gas meter can't be connected to an electric power supply due to security issues. Furthermore this carrier is characterized by a limited bandwidth, and therefore could offer a limited number of services.

- **GSM**

Global System for Mobile is the carrier used for the voice service of cell phones. The technology is very similar to the PTSN as it requires a modem to enable the communication. The costs of this technology depend on the rates applied by Telcos – which in turn depend on the number of connections and time elapsed in each connection for data transmission – and comprises the cost of the SIM, SIM-keeping maintenance tariff, maintenance of the telephone number. The communication is ensured by the use of SMS whose main drawback is the quantity of data supported by one SMS and its battery consumption; in the other hand SMS require marginal power consumption. Another weakness of this carrier is the inability to guarantee network coverage in the all territory. Through the interviews with supply chain actors this issue emerged and negotiation have to be undertaken with Telcos in order to reach commercial offers where the roaming is guaranteed through contracts with different GSM companies. Although this vector was chosen for end-to-end communications for gas meters of big consumers (over G40), integrating a SIM in all 17.5 million domestic smart meters seems inopportune and would result in being to onerous. (Tan et al., 2007)

- **GPRS**

General Packet Radio Service is a service for data transmission offered to users of GSM cell phones. It is characterized by a moderate data transfer rate which decreases logarithmically with the distance (which may cause problems in rural areas). The costs of the service are still dependent on Telcos' tariffs, even though they are generally lower compared to SMS (and depend on the amount of data sent). The other costs to be taken into account are identical to the ones listed for the GSM. (Tan et al., 2007)

- **WiFi**

It's a communication protocol very diffused for connecting electronic devices on a short range. It could be used for connecting the smart meter to the home network through TCP/IP as the security of this vector still presents considerable risks – cannot be chosen as the main vector for exporting data from meters to concentrator given its low information security. (Selga et al., 2007)

- **WiMax**

Worldwide Interoperability for Microwave Access is a technology which is still in its early development stage and which was conceived for creating an more sustainable alternative to the PSTN, or other long range wireless connection. It actually uses licensed frequencies and therefore is still characterized by a high costs. (Selga et al., 2007)

- **ZigBee**

This is an emerging technology which is rapidly developing given to its disparate fields of application and its capability for managing communication between a large set of nodes through meshed networks (over 64 000 nodes). The technology is being developed by an association to which adhered a considerable number of leader ICT enablers and providers: the ZigBee Alliance. Its diffusion is growing surprisingly in Smart Home and Smart Building fields. It is characterized by a lower speed of transmission and lower range compared to WiFi but results in being much more convenient given the lower battery consumption. This is due to its need of low computation capabilities (in the end node) and though the necessity of less powerful processors. This makes this standard an optimal candidate for the smart metering solution. (Corral et al., 2012)

Table 7 summarizes the strengths and weaknesses of the discussed communication technologies in relation to their utilization for the metering infrastructure:

Technology	Connection	Strengths	Weaknesses
PSTN	Wired	Reliability; bandwidth; multi-user shared connection	Requires the presence of a modem; quality of service
ADSL	Wired	Broadband connection on telephone line; speed transfer rate;	Not controllable by DSOs; not always present
PLC	Wired	Low cost; reliability	Needs to be connected to the power line; low bandwidth
GSM	Wireless	Reliability; doesn't require too broad bands; high network coverage	Cost of SIM (and related costs); cost of SMS; battery usage; insufficient data contained in one SMS
GPRS	Wireless	Speed transfer rate; reliability; network coverage	Cost of SIM (and related costs); transfer rate decreases logarithmically with the distance

WiFi	Wireless	Bandwidth; consolidation and diffusion of the technology	Information security
WiMax	Wireless	Broadband; speed transfer rate;	Needs power supply; limited network coverage
ZigBee	Wireless	Contained costs; low computational capabilities required; low battery consumption	Bandwidth; short range

Table 7 Metering communication technologies: strengths and weaknesses

Through interviews performed with the different actors of the supply chain and the analysis of diverse metering projects in Italy and Europe (cf. methodology) it emerges that DSOs are heading towards wireless technologies; the most appreciated communication vectors for last mile (from meters to concentrators) mass market gas metering purposes are RF technologies: ZigBee2.4GHz, WMbus868MHz and WMbus169MHz (these technologies allow the communication system cost optimization through the balance of the number of meters per concentrator in different environments as will be discussed further); while from concentrators to central acquisition systems, which represents a less critical issue various technologies can be exploited among which WiFi, GSM, GPRS, etc.

4.4 The network architecture

As mentioned on the communication system part, there are several communication technologies which can be leveraged for erecting the transmission infrastructure which differ in terms of features, costs and enabled benefits. The effort and mandate of the UNI/CIG is precisely aimed at ordering and harmonizing the diverse communication protocols and standards. The scheme in Figure 23 General architecture for smart metering (UNI/TS 11291-1) was published in the UNI/TS 11291-1, and represents the general architecture for smart metering – considering all classes of meters from domestic consumer: G4-G6 to big industrial customers: over G40 – proposed by the established standardization working table, and as we can see different configuration can coexist with different profiles and standards (PM1-PM2-PP3-PP4-PP5[8]).

[8] These abbreviation identify specific profiles which encompass different technologies:
-PM1 allows communication through Wireless M-Bus and ZigBee
-PM2 allows communication also through proprietary vectors (Sitred is the communication vector used by electric meters which was first introduced by ENEL) and PLC
-Profile PP4 uses PSTN, GSM and GPRS (with standards emitted by UNI/CIG)
-Profile PP3 and PP5 make use of a set of different technologies both wired (mainly PSTN and WiFi) and wireless (WM-Bus and ZigBee) – among which some proprietary vectors are not allowed

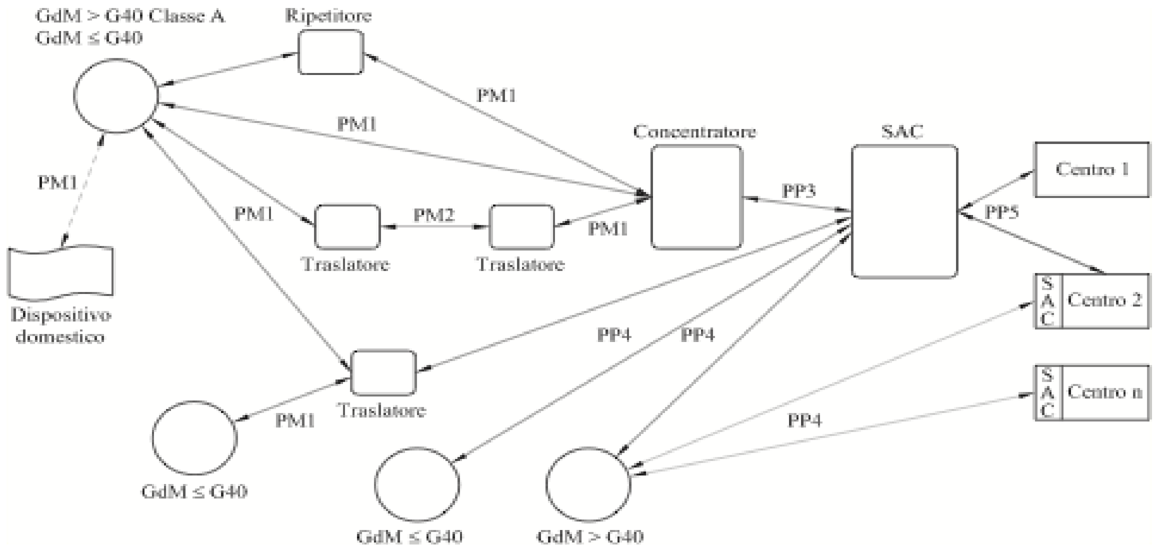

Figure 23 General architecture for smart metering (UNI/TS 11291-1)

Considering the above scheme and the requirement of the regulatory order 155/08; and bearing in mind the initiatives of most recently emitted consultation papers DCO 40/11 and DCO 28/12, fostering widening the spectrum of analysis for finding the optimal gas metering solution (taking into account synergies that can be exploited by sharing the communication infrastructure with other services) five main different architecture configuration which may fulfill the regulatory order have been identified.

- **Direct end-to-end communication (cf. Figure 24):**

The communication is undertaken directly from the meter to the management system via a modem. This communication may be carried out by different media, GPRS - GSM, PSTN, ADSL, FO (Fiber Optic), etc., but the most common and diffused option is through GPRS / GSM.

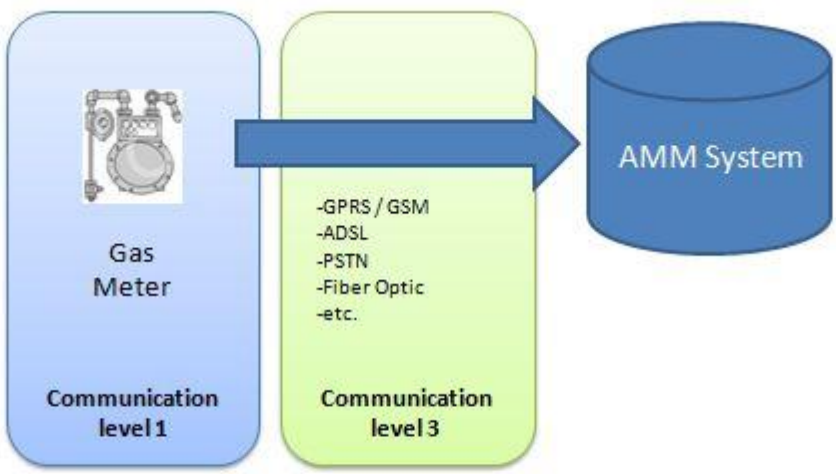

Figure 24 Direct end-to-end communication architecture

This configuration architecture is the one which has been used for big industrial consumers (meter class G40). For this category of customers the current configuration seems appropriate given the low number of customer to be managed and the higher cost for meter acquisition and installation which makes the cost of the SIM (and related costs) marginal compared to the overall metering cost. Conversely, for the mass market this communication infrastructure would result in being too onerous for DSOs which should foresee the acquisition of as many SIM as the smart meters to be installed, not leveraging on the possibility to share a communication infrastructure – for example in a building where 15 meters are all placed one next to another and a single communication vector could aggregate their information transmitting it to the central acquisition system through a single long range transmission. Furthermore the use of this architecture would create significant inequalities in DSOs market as this solution involves the need of negotiating with Telcos for reaching appropriate commercial offers, therefore benefitting large DSOs given their higher bargaining power – to highlight the magnitude of this issue, it is important to mention that the cost of the communication architecture, as we will see in the cost analysis, accounts for the major part of the roll-out program. The Figure 24 illustrates the discussed communication architecture. (Selmi et al., 2011)

- **Communication from the meter to a concentrator which is in turn connected to the AMM system (cf. Figure 25):**

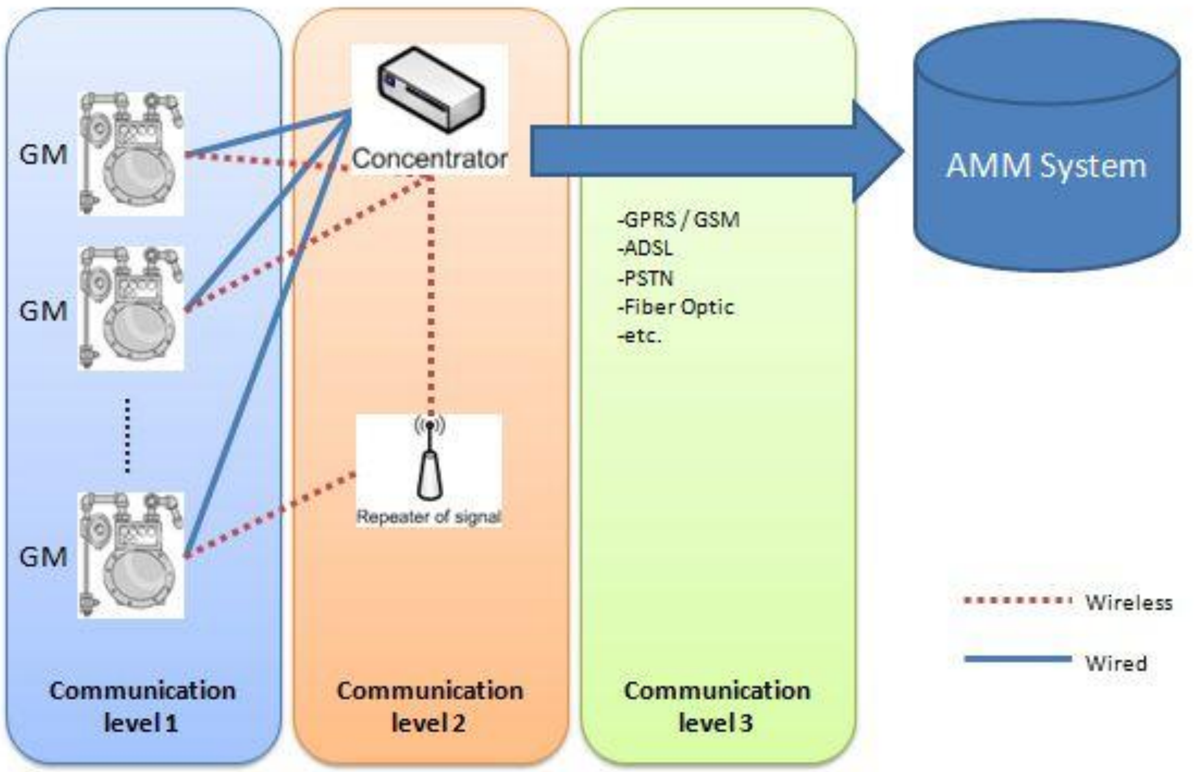

Figure 25 Meter-concentrator-AMM communication architecture

The first communication is from the meters to the concentrators. This communication could be either wireless or wired. In case of wireless communication, the concentrator can be placed in strategic locations for covering the maximum number of buildings but the signal may not be sufficient for reaching all meters, therefore an intermediate connection through a repeater is needed. As mentioned in the last section, repeaters are also powered by batteries, and consequently burden on the cost for batteries and maintenance of the communication system. If wired communication from the meter to the concentrator is used (this can be done depending on the distance meter –concentrator), it could also be possible to power the meters from the concentrator, through the communication cable itself (depending on the measures which will be taken by the legal metrology body). In this case, the use of batteries would solely be a backup system in case of failure of communication from the concentrator. (Eurogas, 2010)

The second communication is between the concentrator to the AMM, and this is generally performed through Telco operators. The choice of the vector to be exploited for this communication depends once again on Telco's offers and DSOs abilities in negotiating and might comprise GSM, GPRS, PSTN, FO, ADSL, etc.

- **Communication from the meter to a concentrator used for different utilities services which is in turn connected to the AMM system (cf. Figure 26):**

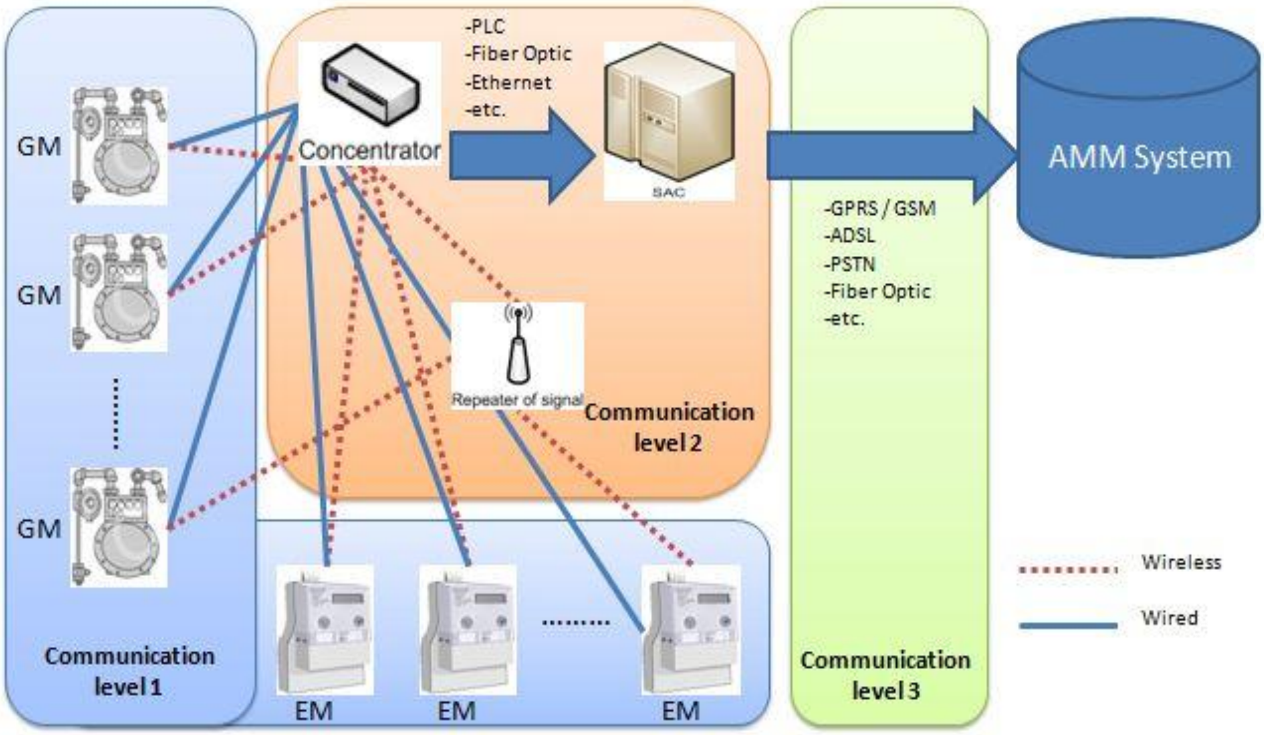

Figure 26 Communication through a multi-utility concentrator

In this situation different utilities share the same communication infrastructure following the directives of the European Mandate M/441. The meters of different utilities (electricity, gas and potentially also water, heat, etc.) are connected to a shared concentrator which aggregates all the data and sends it to a secondary station concentrator (which in fact is a shared SAC). The introduction of this new communication layer allows to reduce the costs of the communication system by exploiting synergies and economies of scale for centrally acquiring the data (send and receive transmissions) and reducing the installation (in case a simultaneous roll-out is possible) and maintenance costs of the system. The communication between the concentrator and secondary station concentrator – as illustrated in Figure 14 – can exploit the electricity distribution network for the transmission of data (PLC or FO). The secondary station concentrator then filters and transmits the data to each utility's AMM. This communication can be performed through the usual Medias (GPRS-GSM-PSTN-ADSL-etc.). (Eurogas, 2010)

This network architecture is one of the option which were asked to deeply analyze and develop through the DCO 40/11 (cf. Figure 18. – where the device called modem on the act is what we described as the first concentrator).

- **Communication from the gas meter to the electricity meter, which then transmits the data to the secondary station concentrator (cf. Figure 27):**

This represents the second option proposed by the DCO 40/11 consultation paper. In this case the communication is done through the electricity meter that performs the relay function. It is substantially similar to the previous architecture, but the concentrator here is embodied by the electricity meter which collects the data from the smart meter, and sends it directly to the secondary station concentrator (or SAC).

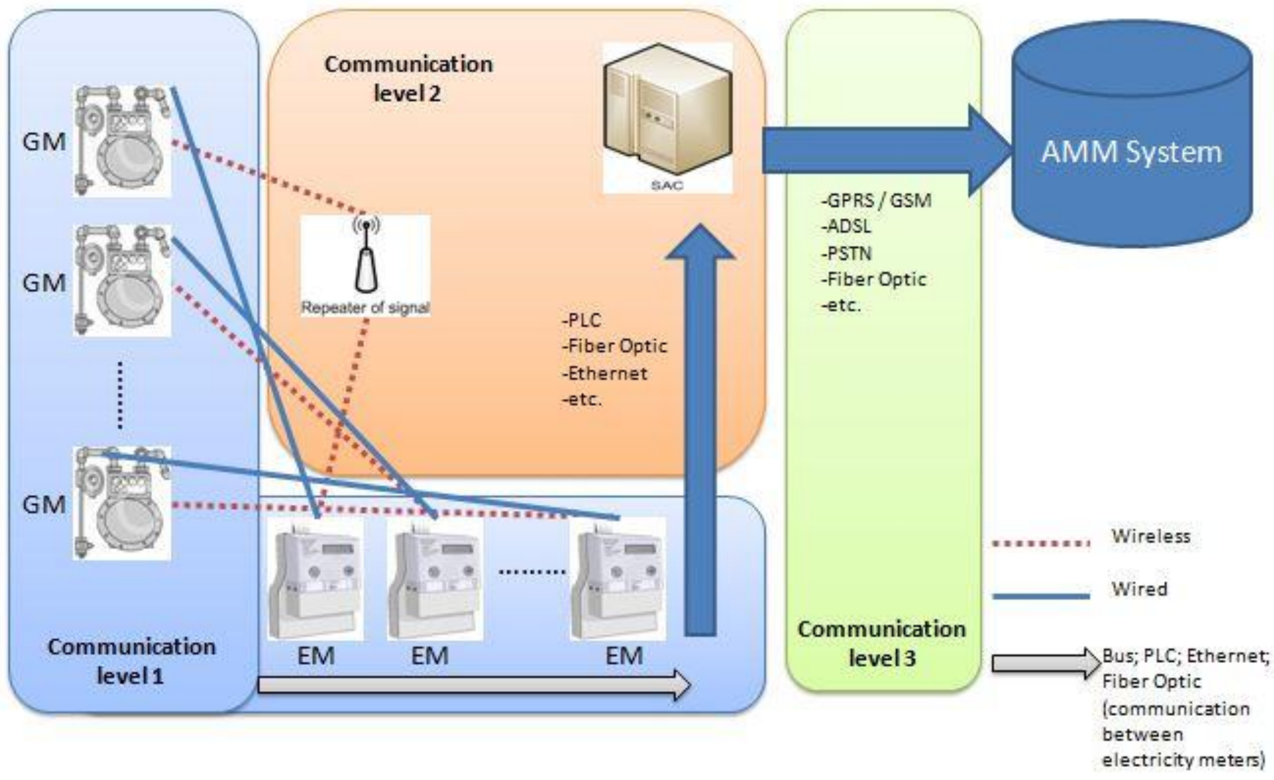

Figure 27 Communication architecture with the electric meter as a gateway

This configuration is particularly attractive when a simultaneous roll-out of electric and gas metering system is planned as it allows to reduce the installation, setup, and maintenance cost of the system also enabling lower operative costs (given the lower transmission costs resulting by the proximity between the electric and gas meters). This said, the current architecture configuration doesn't seem fitted for the Italian roll-out program as the smart electric meter are already installed in Italian households (since early 2001) and their features and functionalities would require too many adjustment in order to be used as gateways. The electric smart meters have a lifetime of 15 years, and therefore will be replaced starting from 2016, the synergies to be exploited for a joint roll-out would therefore involve waiting that time for the implementation (but AEEG doesn't seem to envisage that option). Another barrier towards the development of this alternative is the reluctance of DSOs to rely on electricity distributors (which are considered direct competitors) for such a core business activity – it is important to mention that DSOs main retribution tariffs are based on the activities carried out for the provision of three services: physical distribution service; meter reading service; development of commercial services. The following scheme illustrates the given architecture.

4.5 Technical optimization issues

This section focuses on the field data collection process (from the meter to the concentrator) and is meant at analyzing the different infrastructural scenarios that may characterize the last mile metering environment in order to rationalize the major technical constraints and solutions and to better understand the organizational issues related to the program roll-out.

The concentrator – and with a relatively lower weight the repeater – is a crucial element of the last mile connection. It is a device which needs punctual and recurrent maintenance and its cost is relevant both for its acquisition and operation. Thus, its positioning – and though the number of concentrator to be acquired – is a critical issue for the entire system roll-out.

Its position must be valued considering both technical and organizational parameters. Different field constraints emerged through the pilot projects analysis, case study analysis and distributors interviews. Following these are grouped into six major categories:

- ✓ **Installation constraint in private properties:** Clients availability of accepting the relative equipment (concentrator and repeaters) to be installed in their building's façade or in other places of the condominium is not always guaranteed, and perhaps these could ask an economic counterbalance for the service.

- ✓ **Installation constraints in public properties:** First, legitimacy issues when installing equipment in public spaces without the responsible public entity authorization has to be assessed. Moreover thefts and vandalistic behaviors needs to be considered. Indeed the concentrator is a device attractive to thieves as it is expensive, it contains a modem and a SIM which can be used for illegal behaviors, and it contains precious and costly materials like lithium batteries. The use of protection boxes reduces this issue (while increasing the costs) but often increases vandalistic behaviors (when breaking the box to check its contents).

- ✓ **Maintenance constraints:** Installing concentrators in protected areas, perhaps on a pole, requires higher investment costs and also higher operating costs as it implies the use of a ladder or of air platforms which increase the time required for maintenance. Whether the concentrator is positioned inside customer's property, maintenance activities can be subject to obligation set with the customer (like time of interventions) or could simply be inaccessible when needed.

- ✓ **Energetic constraints:** The concentrator can be powered by the electric distribution grid or through batteries. The cost of realizing an electric connection (whether possible) and of power consumption to be negotiated with the electric distributor needs to be balanced with the cost of batteries. Moreover, the option of feeding the batteries of the concentrator through a photovoltaic panel needs to be considered.

- ✓ **Transmission constraints:** The position of the concentrator needs to guarantee the effective communication both towards smart meters and towards the central acquisition system (SAC). This issue impacts both the quality of the service and installation and operating costs.

The installation of smart meters also represents significant criticalities for the distributor which are all related to its position. Indeed different field configuration can be found and derive different technical solutions: meters inside the household's property; or outside the household property; meters positioned in sets (10 or more meters positioned one next to the other); single meters; and meters positioned inside apartments.

Recalling the last adjustment to the 155/08 regulatory order (DCO 28/12), smart meters need to be installed in 60% of all Italian household. This suggests the identification of which scenario or field configuration to keep out of the roll-out program.

Distributors tip towards the option of leaving out of the roll-out program the following meter configurations:

- ✓ Meters positioned in isolated location: the cost of telemetering in this case would be too high given the low ratio meter–concentrator
- ✓ Inaccessible meters: represented by those meters where, even though repeating the attempts to install the meter, the impossibility to perform the substitution persists
- ✓ Unreachable meters: when installing the concentrators, they represents those meters that can't be reached by the signal given the infrastructural barriers or because screened.
- ✓ Meters located in confined spaces: these meters are left out of the roll-out program as they would require excessive maintenance costs, given the uncomfortable location

Chapter 5 - Literature review on smart metering

The aim of this Chapter is to value the state of research on the smart metering topic by examining the published literature in order to provide insights of practitioners and researchers on the benefits it enables, the implications on affected stakeholders, the opportunities and the technological trends.

5.1 Scope and methodology

Development of the smart grid has been given an urgent global priority as it promises huge economic, environmental, and societal benefits. This is reflected in the literature by a recent great interest in the sector of communication technologies as they will play a vital role in providing today's power grid with the capability of supporting two-way energy and information flows, isolating and restoring power outages automatically, facilitating the integration of renewable energy sources into the grid, and allowing the consumers to optimize their energy consumption. Smart metering is known for laying the foundations of the smart grid paradigm and unlike the latter one is a reality characterized by a history of implementations.

The aim of this study is to understand the state of research on the smart metering topic by examining the published literature to provide insights of practitioners and researchers on the benefits it enables, the implications on affected stakeholders, the opportunities and the technological trends.

Although smart metering is closely related, and represents a major enabling factor for the emergence of smart grids, studies on advanced smart grid services and applications lay out from this analysis to be coherent with the purpose of this research thesis. Indeed, this work tackles the smart metering systems from the gas point of view, thus reviewing the manifold studies on capabilities and issues of smart grid would have deviated the analysis from its primary scope as a smart grid equivalent is not present in the gas sector. This said, to reach a comprehensive state of art picture on the smart metering topic in order to evaluate its implementation and potentials in the gas sector, a review of the literature including contributions from each sector where smart metering technologies are implemented is of fundamental importance. In particular, a focus on the electricity sector where this technology has proved greater maturity results unavoidable for the correct comprehension of this work.

5.2 Selection process

This research is based on the examination of various journals and conference papers. Due to the diversity of this area of research, journal articles are scattered across a range of journals, and thus a literature search was conducted using the following search engines and electronic databases.

- http://www.isiwebofknowledge.com/
- http://www.jstor.org/
- http://scholar.google.it/
- http://www.scopus.com/home.url

The research has been conducted using key words: “smart metering”, “smart metering benefits”, “smart metering assessment”, “smart metering technology”, “Automated Meter Reading (AMR)”, “Automated Meter Management”, “Automated Meter Infrastructure”, “Multiservice metering”, “Natural gas Metering” “Prepaid metering”.

More specifically, the analysis considers multiple sources of information:

- scientific international journals;
- proceedings of international conferences;
- research reports and white papers (e.g. the white papers of the Auto-Id Labs, the reports of the Italian Observatory on IoT of the School of management of the Politecnico di Milano);
- news and case studies about RFId projects.

The full text of each article was reviewed to eliminate articles that were not really related to smart metering performances or those that had too specific perspective, perhaps focused on specific issues affecting the realization of smart grids. A classification of the analyzed papers has then been performed in order to better focus the examination on the relevant topics for this research thesis. As a result, five main areas of research tackled when dealing with smart metering systems were identified:

- Technology
- Industrial processes optimization
- Customer awareness and behavioral changes
- Demand side management and dynamic prices

Filtering the Literature according to these five areas of research, a smaller subset has been been identified and as a result, in total, 60 papers were selected.

5.3 Classification

The identified papers have been classified using different metrics and parameters in order to provide the lecturer with a quick view of the area of research analyzed. In particular, papers have been classified depending on:

- The focus of the analysis: recovering the classification above mentioned; i.e. Technology; Industrial processes optimization; Customer awareness and behavioral changes and Demand side management and dynamic prices
- The sector: distinguishing between electricity, water, gas, and multipurpose metering studies. The following Table 8 highlights the focus of the international scientific community on smart metering for the electricity sector.
- The type of analysis: distinguishing between qualitative, empirical and quantitative models
- The research methodology: distinguishing between analyses based on experts valuation, surveys, case studies (often through the pilot project analysis) and simulations.
- The type of analysis: distinguishing between qualitative, empirical and quantitative models
- The research methodology: distinguishing between analyses based on experts valuation, surveys, case studies (often through the pilot project analysis) and simulations.

Electricity	Gas	Water	Multiservice
Abrahamse et al., 2007 Allcott, 2011 Anderson and White, 2009 Asif et al., 2008 Baranski and Voss, 2003 Bharath et al., 2008 Billewicz, 2008 Billewicz, K., 2012 Boardman, 2004 Burgess and Nye, 2008 Casarin and Nicollier, 2008 Chiaroni et al., 2012 Choi et al., 2008 Custodio et al., 2009 Darby, 2006 Doug, 2005 Friedman, 2011 Giordano, 2011 Gottwalt et al., 2011 Hargreaves, 2010 Huibin et al., 2009 Jagstaidt, 2011 Kidd and Williams, 2008 Kim et al., 2009 Kim, 2011 Lasciandare et al., 2007 Mak Sioe, 2006 Moreno-Munoz et al., 2007 Oksa et al., 2006 Olmos et al., 2010 Parker et al., 2008 Sarah, 2011 Selga et al., 2007 Tram, 2008 Ueno et al., 2005 Walawalkar et al., 2010 Wang and Schulz, 2006 Wood and Newborough, 2007 Yu, 2011	Khan et al., 2009 Khan et al., 2007 Cervigni et al., 2011 Lanzarone and Zanzi, 2010 Tewolde and Longtin, 2010 Selmi et al., 2011	Cara, 2012 Wasnarat and Tipsuwan, 2006 Willis et al., 2011 Lanzarone and Zanzi, 2010	Abdollahi et al., 2007 Benzi, 2011 Brasek, 2005 Choi et al., 2008 Khalifa, 2011 Ileana et al., 2009 Corral et al., 2012 Das Vinu, 2009 Tan et al., 2007 Tram et al., 2005 Netl and Oeder, 2008 Van Gerwen et al., 2006 Zerfos et al., 2006

Table 8 Classification of analyzed papers based on the sector of analysis

5.4 Discussion

5.4.1 Technology

Paper	Type of analysis	Methodology	Sector			
			Electri-city	Gas	Water	Multi-service
Abdollahi et al., 2007	Qualitative	Experts	X	X	X	X
Billewicz, 2008	Qualitative	Experts	X			
Choi et al., 2008	Qualitative	Experts	X			
Corral et al., 2012	Qualitative	Experts	X	X	X	X
Huibin et al., 2009	Empirical	Case study	X			
Jagstaidt, 2011	Qualitative	Experts	X			
Khalifa, 2011	Qualitative	survey	X	X	X	X
Kim et al., 2009	Qualitative	Experts	X			
Kim, 2011	Quantitative model	Simulations	X			
Lasciandare et al., 2007	Quantitative model	Case study	X			
Oksa et al., 2006	Qualitative	Experts	X			
Selga et al., 2007	Empirical	Case study	X			
Tan et al., 2007	Empirical	Case Study	X			
Walawalkar et al., 2010	Qualitative	Experts	X			
Wang and Schulz, 2006	Qualitative	Experts	X			
Wasnarat and Tipsuwan, 2006	Quantitative model	Simulations			X	
Yu, 2011	Qualitative	Experts	X			
Zerfos et al., 2006	Empirical	Case study	X	X	X	X

Table 9 Classification of analyzed papers with focus on technology

The terms Automatic Meter Reading (AMR) or Smart Metering System refers to the technology whose goal is to help collect the meter measurement automatically and possibly send commands to the meters. Automation ranges from connecting to a meter through wired interfaces, via Infrared, or short range radio frequency for the transmission of the meter measurements all the way from the meter to the utility company. (Billewicz, 2008)

In emerging smart grid networks, massive amounts of data will be continuously generated from measurement devices embedded in the power grid such as phasor management units (PMUs), intelligent electronic devices, advanced meters, or electric vehicle charging stations. Data generated from advanced metering systems must be delivered immediately, reliably, and safely to specific locations for wide-area monitoring and grid control. (Kim, 2011). The amounts of data to be managed by utilities will therefore increase of at least three orders of magnitude, representing a great challenge for these actors, which will have to leverage on advanced software technologies for the adequate processing, storing and redirection of large sets of data. (Jagstaidt, 2011)(Selga et al., 2007)(Corral et al., 2012) However, although this issue might cause significant burden to utilities, mature and consolidated technologies are widely available for managing large sets of data; success of applications relative to this task will vary according to utilities ability in optimizing the system's drivers and design specifics. (Khalifa, 2011)

Greater relevance in the Literature on smart metering systems is laid on the communication technologies and architectures used for data gathering, and transmission until the control centers. (Lasciandare et al., 2007) (Choi et al., 2008) (Selga et al., 2007) (Oksa et al., 2006) There are three major types of AMR communication networks: power line carrier (PLC), cellular network and short range radio frequency.

- **Cellular Networks (GSM & GPRS):** The popularity and wide area coverage of cellular networks have attracted researchers towards considering this communication vector for smart metering systems. This solution involves equipping smart meters with a SIM card for only messaging which allows the unique identification of the customer. (Tan et al., 2007) and (Abdollahi et al., 2007) for instance, both suggest the use of GSM networks for low frequent meter data transmission (i.e. monthly communications) and prove through their papers the effectiveness of the solution for optimizing the consumption-to-bill process. In both systems both one-way or two-way communication are enabled, however bi-directional communications – although providing greater control over the meters – significantly burdens on the meter energy usage (which represents an issue outside the electricity sector) as the meter needs to be active all time to receive commands. However, metrics to evaluate reliability, performances, and strengths of these systems are not identified in those papers. (Wood and Newborough, 2007) and (Zerfos et al., 2006) conversely, argue that scalability and reliability of such networks is questionable, especially under high loads. (Zerfos et al., 2006) in particular, carried out an empirical analysis on the GSM network in India, and found that the SMS delivery success rate was of 94.9%, with about 5% of successfully delivered messages employing over an hour and half for reaching destination. Finally, it has to be said that researchers discarded GSM networks for sustaining the huge amount of data transmission required by the emergence of smart grids in the electricity sector given its latency and failure ratios. (Yu, 2011) (Anderson and White, 2009) (Khalifa, 2011)

- **Power Line Carrier:** This technology allows the transmission of data over voltage transmission lines along with the electricity power. A great interest has been placed on PLC for the AMR backhaul network as no extra cabling is required. (Choi et al., 2008) proposes the use of PLC as means for delivering the electricity, gas and water consumption data to the utility providers. Indeed, after communicating the meter's data to a concentrator through wireless technologies, the PLC vector is used to transfer aggregated data to utilities; however no metrics of evaluation and comparisons with different network design are provided. (Oksa et al., 2006) conversely provides testing results for the communication between two subsequent routers over the PLC vector and prove that the length of the cable and the structure of the power grid affect the throughput causing a 65% reduction when the cable length reaches 10 meters. The limits of such vectors are widely discussed and consolidated in the Literature as many researchers deem the PLC technology characterized by a too high data loss rate as this vector is affected by high signal attenuation, noisy medium and susceptibility to interface from nearby devices. Furthermore it provides low margins for scalability as they take advantage of already deployed infrastructures. (Wang and Schulz, 2006) (Lasciandare et al., 2007) (Selga et al., 2007) (Walawalkar et al., 2010) And finally it is unlikely that the gas and water meters will share the same power line communications infrastructure because utility companies may not share their network infrastructure (Brasek, 2005).

- **Short range Radio Frequencies:** This term comprises a set of different communication technologies such as Bluetooth, WiFi, Z-Wave and ZigBee, differing on signal power and frequency band. Although after an initial enthusiasm, some of these vectors (e.g. Bluetooth and WiFi) have been discarded in the Literature as a solution for smart metering, recent publications portray a growing attention to these wireless technologies as many researchers deem RF to be the future of smart metering. (Anderson and White, 2009) (Billewicz, 2008) (Yu, 2011) Although different standards exist, the research community interest is related to the exploration of solutions for lower power consumption in data transmission. To this respect, Zigbee has attracted much attention as a solution for smart metering (Anderson and White, 2009) (Billewicz, 2008); indeed the technology is already designed for low rate applications and consumes minimal energy, enabling a device to last for a higher number of years as proved by simulations undertaken by (Asif et al., 2008). Furthermore, ZigBee supports a variety of strong routing protocols which allows greater interoperability. Some researcher although claim that this standard provides a too low bandwidth for AMR system, and that by increasing the number of nodes, interference increases significantly, thus making the technology hardly reliable and scalable. (Khalifa, 2011)

  Other studies picture the smart metering infrastructure as a WSN; indeed, a meter device functionally is a sensor node that provides energy (electricity, gas, or water) consumption measurement. The number of meters can grow to thousands, and data are typically aggregated and delivered to a centralized location for processing and decision making. Therefore smart metering system can benefit from the extensive investigation characterizing the literature on the WSN topic. In particular, (Wasnarat and Tipsuwan, 2006) proposes a WSN structure for networking different meters tackling the problem of the network architecture for reducing meter’s energy consumption (as they are powered through batteries). They propose an energy saving system based on the avoidance of long packet transmission; each meter forms sub-trees with a base station and reports its measurement through other meters. The base station then sends aggregated data through the cellular networks to control rooms. This architecture can be used in different sectors and allows the integration of different utility meters (including gas, heat and water meters).

Although different technology can be levied for implementing an advanced metering infrastructure, some researcher deem that new protocols should be designed as the transport requirements for periodic measurement data are characterized as continual, reliable, and secure delivery of small-sized packets (less than 1.5 KB) over a utility-owned wide area network (WAN) and that no well-known transport protocol adequately meets these requirements. (Kim, 2011)

Similarly, (Yu, 2011) deems that the current uncertainty regarding the definition of compliance requirements (in terms of electromagnetic interference, safety and environmental issues) derive the potential for technologies to be developed or implemented using sizable public and private funding (considering that the meter life is of 15 years approximately), without proper measures necessary to ensure performance, security, and safety. Therefore implementations should wait for further research to increase the consolidation of technologies.

The review of this portion of Literature has therefore highlighted the inadequateness of consolidated technologies used for traditional smart metering system, widely deployed in the electricity sector (PLC – GSM – Bluetooth – etc.), for meeting the requirements of the emerging smart grid paradigm. This is translated into the recent publication of various qualitative studies and field experimentations investigating on new communication protocols and architectures especially in the WSN research area. Although all reviewed papers focus either on the electricity sector or on multiservice architectures, the gas sector might be leveraging from this new research direction. Indeed the peculiarities of the gas sector which discard the possibility of using consolidated technologies (e.g. no access to the power grid) present great similarities with the requirements of next generation electricity meters (e.g. interoperability, bi-directional communication, communication reliability, etc.)

5.4.2 Industrial process optimization

Paper	Type of analysis	Methodology	Sector			
			Electri-city	Gas	Water	Multi-service
Asif et al., 2008	Quantitative model	Experts	X			
Baranski and Voss, 2003	Quantitative model	Simulation	X			
Bharath et al., 2008	Qualitative	Experts	X			
Billewicz, 2008	Quantitative model	Simulation	X			
Billewicz, K., 2012	Quantitative model	case study	X			
Brasek, 2005	Empirical	Case study	X	X	X	X
Casarin and Nicollier, 2008	Quantitative model	Case study	X			
Cervigni et al., 2011	Qualitative	Experts		X		

Paper	Type of analysis	Methodology	Sector			
			Electricity	**Gas**	**Water**	**Multi-service**
Das Vinu, 2009	Qualitative	Experts	X	X	X	X
Ileana et al., 2009	Qualitative	Case study	X	X	X	X
Khan et al., 2007	Qualitative	Experts	X	X	X	X
Khan et al., 2009	Empirical	Case study		X		
Mak Sioe, 2006	Quantitative model	Simulation	X			
Moreno-Munoz et al., 2007	Quantitative model	Experts	X			
Netl and Oeder, 2008	Qualitative	Experts	X	X	X	X
Selmi et al., 2011	Qualitative	Experts	X			
Tewolde and Longtin, 2010	Qualitative	Experts	X			
Tram et al., 2005	Qualitative	Experts	X	X	X	X
Tram, 2008	Qualitative	Case study	X			
Van Gerwen et al., 2006	Qualitative	Experts	X	X	X	X
Wang and Schulz, 2006	Quantitative model	Experts	X			

Table 10 Classification of analyzed papers with focus on Industrial Process Optimization

In the electricity sector, benefits for industrial processes have largely been studied mainly through the case study tools based on empirical quantitative models as many implementation projects are available, and the benefits for utilities' activities seem consolidated. (Custodio et al., 2009) (Bharath et al., 2008) These result quite evident and realizable on a medium short term: smart electric metering systems provide a more timely and precise billing and reduce the costs of interacting with customers by activating, closing, or suspending contracts with no personnel displacement, it also gives significant help in avoiding electricity-related frauds. Indeed, manifold data can be gathered through electricity meters, and the work of (Billewicz, 2008) shows that through these data potential spots of thefts of energy can be pointed out. The work presents a method based on the balance and control of speed increasing of counter indication, which allow the detection of these places. Simulations prove that the method does not detect all cases of illegal consumption but helps to find the most often ones. Smart meters provide a more timely and precise consumption information, that even in systems where a real time data communication is not feasible (for sustainability reasons), studies and algorithmic models on efficient load estimation tools allow the enhancement of these data into relevant information which can then be used for value added service (Wang and Schulz, 2006) (Moreno-Munos et al., 2007). Outage management is another topic widely discussed in the scientific community; (Tram, 2008) shows through a survey of the Automated Meter Reading Association (AMRA), that utilities proved to consider the use of advanced metering infrastructures to improve outage management and service reliability the highest priority behind the meter to bill process. Other articles provide algorithmic models for promptly localizing the outage; indeed an efficient outage location method dramatically reduces the outage duration and costs. (Asif et al., 2008) (Moreno-Munoz et al., 2007) (Mak Sioe, 2006)

Recent publications demonstrate that the focus of the scientific community seems to have shifted from the direct benefits above mentioned affecting electric utilities to the indirect ones enabled by advanced metering infrastructures relative to the balance of the distribution grid such as the potential for better power peak control and distribution (Billewicz, K., 2012), the impacts on infrastructural planning and management of dynamic prices and demand side management strategies. Indeed, (Tram, 2008) shows through a survey of the Automated Meter Reading Association (AMRA), that utilities proved to consider the use of advanced metering infrastructures to improve outage management and service reliability the highest priority behind the meter to bill process. Other articles also tackle this issue (Asif et al., 2008) (Moreno-Munoz et al., 2007) and provide algorithmic models for promptly localizing the outage; indeed an efficient outage location method could dramatically reduce the outage duration and costs.

In parallel, other sectors of application are characterized by a lower number of publications (only two for the gas sector and 7 papers on multiservice architectures), and seem concentrated on a lower number of macro benefit areas. Indeed, in the gas and water sectors, a greater relevance is given to the possibility of reducing the laborious task and financial wastage by automating the manual meter reading process and the bill data entry process. (Khan et al., 2007) (Ileana et al., 2009) (Das Vinu, 2009)

It has to be mentioned that all the papers analyzed a part from (Khan et al., 2009) tackling the smart metering topic in the gas sector – or for multiservice architectures – are based on qualitative analysis made by experts and never focus exclusively on the gas sector. This aspect highlights the greater uncertainty characterizing smart metering applications outside the electricity sector.

Alternative solutions

When reviewing the literature focusing on the benefits smart metering technologies enable for industrial processes of utilities apart from electricity, it has to be stated that a large set of these can be obtained through substitutive solutions. Indeed, gas, water and heating sectors are characterized by a higher uncertainty regarding reachable consumption behavioral change in the domestic market and by different infrastructural assets and requirements which often involves the necessity of a much less frequent data transmission (monthly or even yearly). These solutions present a significant lower investment especially in countries with high infrastructural barriers or where utility meters are mainly of mechanical type. In particular, for the automatic reading and recognition of registered data on utility meters, (Ileana et al., 2009) proposes for the Romanian case an intelligent optical acquisition system which stores the read values in desktop and mobile devices. This paper proves through the case study analysis that the larger part of benefits enabled through smart metering in this field can be obtained by a mobile solution, while avoiding the massive smart metering investment needed to replace every domestic meter.

A further substitutive solution would be the creation of a new network communication system for energy meter reading by integrating communication technology and software system along with the existing meters, i.e., integrating deployed meter with a retrofit module (Cervigni et al., 2011) this solution is particularly interesting as it results secure, may enable frequent communications with the meter at lower costs, avoids any tampering or break down of energy meters and reduces significantly the roll-out cost (reduced installation, personnel, and maintenance costs). (Das Vinu, 2009) However its main drawback is related to the reduced interoperability. Indeed this solution doesn’t allow a direct access to the meter itself (i.e. doesn’t allow activation, deactivation of supply or other remote transactions with the meter). (Selmi et al., 2011) Therefore this solution is mainly contemplated outside the electricity sector as it doesn’t allow the creation of many of the ancillary services targeted by the smart grid paradigm. In the gas and water sectors, however, the uncertainty on value added service creation above the smart metering infrastructure make the use of retrofit kits interesting solution for enabling smart metering benefits for industrial processes of utilities.

Prepaid utility meters are another alternative solution as they are deemed to make the consumers more conscious on their consumption behavior and also promise easy, fast and accurate billing schemes (although not enabling the remote access to the meter) (Owen and Ward, 2010). In the paper (Khan et al., 2007) a prepaid meter solution is proposed for the Pakistani market to automate the billing process and two years later, after its implementation, the paper (Khan et al., 2009) discusses its results and enlarges the solution to a state-of-the-art digital and information technology prototype of a prepaid system to be implemented in different distribution grid infrastructures (notably in developing countries), and tests it. Prepaid utility meters, including gas, water and electricity meters are currently widely deployed in many countries, among which UK (2.5 million gas prepayment meters and 3.7 million electricity prepayment meters) (Owen and ward, 2010), Argentina, South Africa, Northern Ireland, Arizona, etc. The advantages of this system are related to the reduction of arrears in accounts receivables and of operational and financial costs and risks for utilities and to a better, and more informed allocation of resources for the user. (Casarin and Nicollier, 2008) Owen and Ward argue that the introduction of smart meters will provide the opportunity to improve prepayment systems, reducing costs for suppliers and bringing major benefits to consumers -including new payment methods, more customer friendly forms of emergency and friendly credit and lower prices. (Lliev, 2005)

5.4.3 Customer awareness and behavioral changes

Paper	Type of analysis	Methodology	Sector			
			Electri-city	Gas	Water	Multi-service
Abrahamse et al., 2007	Empirical	Case study	X			
Anderson and White, 2009	Empirical	Case study	X			
Benzi, 2011	Qualitative	Experts	X		X	X
Boardman, 2004	Qualitative	Experts	X			
Burgess and Nye, 2008	Qualitative	Experts	X			
Cara, 2012	Empirical	Survey			X	
Darby, 2006	Qualitative	Experts	X			
Hargreaves, 2009	Qualitative	Experts	X			
Kidd and Williams, 2008	Empirical	Case study / Pilot	X			
Lanzarone and Zanzi, 2010	Qualitative	Experts		X	X	
Parker et al., 2008	Empirical	Survey/ Pilot	X			
Ueno et al., 2005	Empirical	Case study - survey	X			
Willis et al., 2011	Quantitative model	Survey			X	
Wood and Newborough, 2007	Empirical	Survey	X			

Table 11 Classification of analyzed papers with focus on Customers Awareness and Behavioural Changes

The recent worldwide measures for energy savings call for a larger awareness of the household energy consumption, given the relevant contribution of domestic load to the national energy balance. On the other hand, electricity smart meters together with gas, heat, and water meters can be interconnected in a large network offering a potential value to implement energy savings and other energy-related services, as long as an efficient interface with the final user is deployed. Unfortunately, so far, the interface of such devices is mainly designed and addressed at the utilities supervising the system, giving them relevant advantages which have been discussed above, while the communication with the household is often let aside.

Following these observations, a big set of Literature research and practical trialling has attempted to make energy visible to householders through the provision of various kinds of feedback. This is particularly true in the electricity sector, and has included providing more informative bills putting energy labels on domestic appliances (Boardman, 2004); providing in-depth energy advice via leaflets, websites and face-to-face (Abrahamse et al., 2007), and (Darby, 2006) and, most recently, through a range of in-home real time displays and monitors (Anderson and White, 2009), (Parker et al., 2008) and (Wood and Newborough, 2007).

(Kidd and Williams, 2008) and (Anderson and White, 2009) through their studies on the modalities of providing feedbacks to consumers, emphasize the need of a user friendly interface which shouldn't be limited at providing an energy consumption data, but should primarily convert it into the cost of the consumed quantities. Furthermore, Kidd and Williams show through a survey that consumer response increases as the feedback provided results more frequent (possibly immediate), clearer, user-specific and as the information provided results more elaborated – i.e. providing graphical interface which allow the comparison with past time periods, with similar household, and provides personalized energy saving advices. In general, these studies highlight the success of providing enhanced power consumption feedbacks resulting in savings between 5 to 15% (Darby, 2006).

In parallel, some evaluations have been carried out in the water sector, but with a different objective. Indeed water meters are not expected to be widely deployed as electricity meters, and therefore studies on water consumption behavior are targeted at providing policy makers tools for triggering behavioral changes (perhaps demand management policies such as targeted community education programs or community-based social marketing), instead as a mean for assessing customer response to prompt consumption feedback. (Willis et al.,, 2011) All papers dealing with water consumption behavior are carried out by Australian studies. Indeed, elsewhere, the current low cost of water doesn't justify smart metering implementations. Studies have shown that householders' perceptions of their water use are often not well matched with their actual water use. (Cara, 2012) investigates on the reasons of this bias identifies, through a series of univariate tests, clusters of end users based on specific types of socio-demographic and socio-psychological household

(Lanzarone and Zanzi, 2010) is the only reviewed article which studies a communication system for providing feedback to consumers on their gas consumption. Indeed, the study proposes a system to monitor and interactively control water and gas utilization, allowing consumers to be better informed about their consumption behavior and challenging them to improve efficiency in utilization along with saving costs. However, the proposed system remains a model; indeed, not being implemented doesn't allow to evaluate the real impact on households' gas and water consumption.

The review of this portion of the Literature, although revealing the importance of providing frequent and user friendly energy consumption feedbacks to households to foster their consumption behavioral change, highlights the absence of any scientific study on the real impact of such feedbacks on the gas sector. Moreover, unlike the water sector, studies on the patterns of domestic gas consumption have not been published in the Literature.

5.4.4 Demand Side Management and Dynamic Pricing

Paper	Type of analysis	Methodology	Sector			
			Electri-city	Gas	Water	Multi-service
Allcott, 2011	Empirical	Survey	X			
Custodio et al., 2009	Qualitative	Experts	X			
Chiaroni et al., 2012	Quantitative model	Simulations	X			
Friedman, 2011	Quantitative model	Simulations	X			
Gottwalt et al., 2011	Quantitative model	Simulations	X			
Houseman, 2005	Qualitative	case study	X			
Olmos et al., 2010	Quantitative model	Case study	X			
Sarah, 2011	Qualitative	Experts	X			
Walawalkar et al., 2010	Qualitative	Case study	X			

Table 12 Classification of analyzed papers with focus on Demand Side Management and Dynamic Pricing

This research area, as depicted by the above Table 12, is relative to the electricity sector exclusively. However, since studies on the benefits of smart gas metering mention the possibility of changing domestic consumption behaviors through the implementation of adequate time of use pricing strategies, these articles have been reviewed to provide insights of practitioners and researchers on these applications.

Demand side management (DSM) indeed represents an emerging wide area of research related to the implementation of smart grids. It may be considered an evolution of the above studied customer behavioral changes as its goal is the modification of consumer demand for energy through various methods such as financial incentives and Demand Response strategies (DR) (Walawalkar et al., 2010). The Demand Response and Smart Grid Coalition (DRSG) define Demand response as the reduction of customer energy usage at times of peak usage in order to help address system reliability, reflect market conditions and pricing, and support infrastructure optimization or deferral. In brief, Demand Response Management Systems are information systems able to manage in real time a diverse set of data coming from the different components of the future smart grids; indeed they should be able to forecast the power production by renewable sources, forecast the demand, load forecasts on the transmission grid and forecasts on the status of the distribution grid. (Chiaroni et al., 2012)

In the research Literature and practical field tests different aspects of DSM have been explored. A great number of research papers focus on the benefits of DSM. These range from the direct ones, relative to consumers consumption patterns modifications, to the indirect ones, encompassed by the wider smart grid paradigm, such as the increased balance of demand and supply in systems with high shares of intermittent renewable sources, paving the way for a large scale distributed energy generation (Allcott, 2011), enablement of the electric mobility, (Giordano 2011), improvement of the investment in transmission and distribution grid through increased utilization, etc.

It is undoubted that for the success of these applications, a real time (or nearly real time) communication of consumption data is of utmost importance. (Allcott, 2011) perhaps evaluates the first program to expose residential consumers to hourly real-time pricing (RIP). He illustrates through a survey that enrolled households are statistically significantly price elastic and that consumers respond by conserving energy during peak hours. However, they didn't increase average consumption during off-peak times. Simulations showed that consumer surplus would increase by $10 per household per year, representing a one to two percent of the electricity cost.

Demand response programs are a major tool of DSM which is widely represented in the Literature. It includes dynamic pricing, price responsive demand bidding, contractually obligated and voluntary limitation, and direct load control/cycling. Based on the type of signal used to activate the DR program, these programs can be categorized as either Emergency DR programs (or Reliability based) – aimed at avoiding system outage in case of grid failures or inefficiencies – and Economic DR programs (Price based) – aimed at reducing the cost of electricity by enabling the demand side participation in electricity markets. (Olmos et al., 2010) argues that in the current situation Emergency DR are the most successful as they require relatively modest commitments from end users. However for the real implementation of the smart grid paradigm, Economic DR are estimated to gain greater emphasis as smart appliances will gain greater diffusion in customer's households (Custodio et al., 2009).

Conflicting results are although presented by the work of (Gottwalt et al., 2011) which presents a simulation model that generates household load profiles under flat tariffs and simulates changes in these profiles when households are equipped with smart appliances and face time-based electricity prices. The work shows that for households the savings from equipping those with smart appliances are moderate compared to the required investment and that the implementation of day-ahead hourly prices will result in creating new load-peaks which will have to be faced by utilities.

5.5 Conclusions

This Literature review revealed that although smart metering is not a novel technology, its evolution in relation to nowadays emerging trends (i.e. smart grid requirements) attracts great attention from the scientific community, and calls for further research on the topic. While the main relevant areas of research are addressed in the electricity sector, the review proved a poor contribution in other smart metering fields of application, notably in the gas sector. In particular the impacts of consumers' feedbacks on consumption behavior remain obscure, and therefore the impacts of dynamic pricing can't either be assessed. The benefits for industrial processes are tackled in the Literature either just for electricity, or for a multi-service architecture, however a focused assessment of an ad-hoc metering system for the gas exclusively is not dealt. And finally, the technology is still a topic of research both for the electricity and multiservice architectures, as the emerging trends characterizing this period in time might render consolidated technologies for smart metering obsolete (i.e. GSM – PLC – etc.).

Chapter 6 - Research objectives and methodology

This chapter describes the research objectives of this master thesis and formulates the main research questions to be answered. The research steps and methodologies used to achieve the goals are illustrated as well.

6.1 Premise

Although smart metering isn't a novel technology, and represents the object of manifold studies in the Literature, the lack of scientific contributions tackling the smart metering topic in the gas sector has emerged. In the present state, the balance between costs and benefits deriving from the introduction of smart gas meters on a large scale is not granted. In fact there is a great level of uncertainty regarding on one hand the technology and instruments enabling telemetering, and on the other on the actual value of the benefits which may be obtained.

6.2 Research objectives

In early 2008, the regulating Authority AEEG (Autorità per l'Energia Elettrica ed il Gas) performed a cost-benefit analysis for the introduction of smart gas meters which led it to the ratification of the regulatory order Arg/Gas155/08 mandating their roll-out. Unfortunately, the outputs of this study are only partly published, and therefore an accurate evaluation of the methodology and outputs provided can't be pursued. However, by reviewing the published outcomes a certain level of ambiguity emerges regarding the real amounts of benefits enabled. Indeed, the fact that, besides stating that the costs of introducing smart meters for domestic consumers (representing 95% of the total customers) outweigh the benefits (AEEG, 2008) the roll-out decision has been taken, reflects the AEEG conviction that other benefits enabled by the smart gas metering allow the sustainability of the investment. These benefits however, are not elucidated.

Moreover, given the high level of investments needed to achieve the ambitious targets set by the Italian regulator – requiring an estimated total investment of €3,520 Millions (Tani et al., 2011) – it seems necessary to deepen the analysis into the state of art technology available on the market, to assess the technical and economic barriers to their diffusion, with a particular focus on the costs and benefit impacts for major stakeholders. Indeed the regulatory order 155/08 introduces severe obligations for some actors of the gas supply chain (in particular for distributors: the owners of the physical distribution grid) seeking a wide set of benefits for the entire sector.

Objective 1. The first macro objective of this research work is the assessment of the economic implications of merely fulfilling the smart gas metering roll-out obligation in Italy:

- What is the real amount of benefits enabled by the 155/08 regulatory order?
- What are the minimum functionalities that a smart gas metering system should provide for the realization of these benefits and their costs?
- Can the electric smart metering case be brought as an example to appreciate the enabled benefit of smart metering in the gas sector?
- Does the status of technology allow their implementation in an economically sustainable manner?

The first part of this work will guide you through these questions focusing on the Italian smart gas metering plan, but incorporating results of various projects in Europe and outside.

The smart metering technology can be classified in the wider category of Internet of Things technologies. In fact, the "Internet of Things" is a paradigm that is emerging – sustained by the progress in nanotechnologies, sensing, software and communication technologies – and which allows the transformation of various common objects into smart interconnected objects – able to sense their environment, elaborate and communicate information – in an economically sustainable manner. This process of innovation is further fostered by the current commitment of the EU, and in cascade of Member States and local authorities towards the implementation of the smart city concept (which as well strongly leverages on the opportunity enabled by that paradigm). Indeed the Internet of Things paradigm represents a necessary requisite to facilitate the development of smart cities as it allows the realization of a ubiquitous infrastructure made of objects aimed at sensing the needs of cities and citizens through their real-time context awareness.

The proliferation of these smart objects (such as meters, lamp posts, traffic lights or buildings) implies the creation of various communication network infrastructures to support different applications in diverse fields.

Objective 2. The second macro objective of this thesis is the investigation on opportunities not sought by the 155/08 regulatory order but which may increase the sustainability of the business case:

- Could synergies with other "Internet of Things" and "Smart City" fields of applications be leveraged on to reduce the burden of the smart metering investment?
- What is the state of art picture of each smart city field of application's development in Italy and its future trends?
- What would be the economic impact on the smart metering investment of exploiting synergies with the most prominent fields of application?

6.3 Research methodology

In order to reach the goals described in the previous paragraph, the research project is structured into six phases that will be described in the following paragraphs (cf. Figure 28)

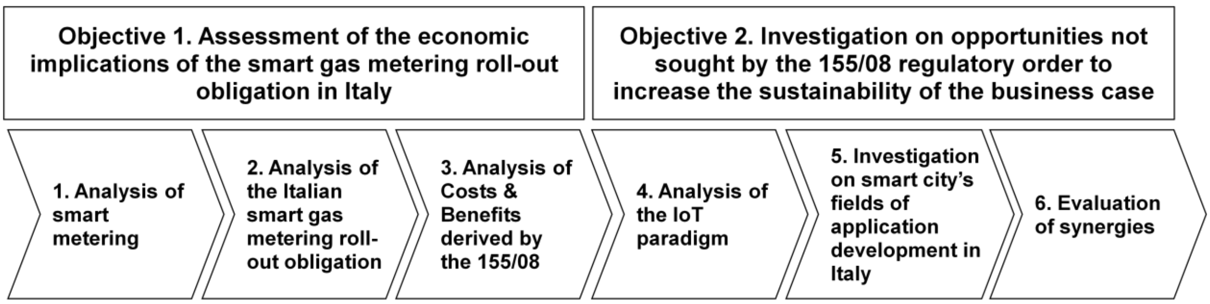

Figure 28: The research steps

6.3.1 Phase 1- Analysis of smart metering

The first research phase aims at identifying the state of research on the smart metering topic relatively to the benefits it enables, the implications on affected stakeholders, the opportunities and the technological trends. This phase mainly resorts to literature review methodology. More specifically, the analysis considers 60 papers from multiple sources of information:

- scientific international journals;
- proceedings of international conferences;
- research reports and white papers (e.g. the white papers of the Eurogas, the reports of the Observatory of the School of management of the Politecnico di Milano);
- news and case studies about smart metering projects.

The output of this research phase is detailed in chapter 5.

6.3.2 Phase 2 - Analysis of the Italian smart gas metering obligation

This research phase is aimed at understanding the general framework on which the smart metering technology will be implemented. To this aim different research activities have been carried out:

- **Supply chain analysis:** identifying all the actors of the gas supply chain, their role and interfaces as well as assessing how the supply chain would be modified by the introduction of smart meters (e.g. appearance of new actors, outsourcing of some segments of business, etc.)
- **Comprehensive review of norms and regulations:** the analysis of the regulatory framework was undertaken considering first the European directories, and then focusing on the Italian framework taking into account the six regulatory orders and consultations emitted by AEEG in the last four years (Autorità per l'Energia Elettrica e il Gas; i.e. the Italian authority for gas and electricity). Following, the comparison with other European countries' major initiatives was also accomplished. A face to face interview with the AEEG responsible of the smart gas metering division has also been carried out and resulted precious for eliminating the ambiguity and controversies present on the progressively emitted acts.

6.3.3 Phase 3 - Analysis of costs and benefits of the 155/08 regulatory order

This phase is aimed at providing the economical valuation of the Italian roll-out plan. The different sub-steps of this analysis leveraged on different methodological tools:

- **Analysis of the supply market:** in addition to the indirect sources of information, three face to face interviews have been performed with leader suppliers of the hardware, software and communication solutions for gas metering.
- **Qualitative assessment of the costs and benefits of smart gas metering:** benefits and costs of the smart metering roll-out were analysed discussing for each of them the economic mechanism through which they should be achieved, the actors of the supply chain impacted, the methodology and main parameters to take into account for assessing their economic value, a qualitative assessment of the impact in relative terms, and the alternative solutions that may derive the realization of the same benefit. To this aim, in addition to the analysis of major projects undertaken in Italy and abroad, seven meetings

with key players in the gas sector have been organized, with the objective of studying the implications and opportunities related to the fulfilment of legal requirements. These meetings emphasized the concerns and hardships different actors in the supply chain were facing.

- **Comparison with the electric smart metering roll-out:** after clarifying the major similarities and differences of the two sectors, an item-per-item comparison of each cost and benefit item has been pursued.
- **Development of the model for quantifying the operative benefits:** this work has been carried out mainly resorting to the activity-based costing methodology. The inputs and formulas of the model will be discussed in chapter 7.
- **Battery lifetime analysis:** a set of simulations aimed at appreciating the impact on the battery lifetime of increasing the frequency of communication windows were undertaken with the Electronic and Information Department of Politecnico di Milano. In particular these simulations assess the influence of using four different communication technologies on the meter's battery lifetime in two different scenarios. An ad-hoc methodological overview to underline the approach used in this analysis is provided in § 7.4.3
- **Comparison with other countries:** this activity mainly resorts to the review of the French and UK regulations in the smart metering topic. The comparison with other countries has also been pursued through the case study tool and the research from secondary sources.

6.3.4 Phase 4 - Analysis of the "Internet of Things" paradigm

This phase is aimed at analyzing the "Internet of Things" reference architecture, its main enabling technologies, their state of art picture and future trends, as well as understanding the barriers to its diffusion. The IoT main fields of application have also been explored. To this aim the Literature review methodology has been exploited as well as the participation to a set of 4 workshops and 4 worktables with experts and professionals representing the leading Italian companies in this technological innovation sector. These workshops were aimed at sharing the experience of professional with the results of the academic research.

6.3.5 Phase 5 - Investigation on smart city's fields of application development in Italy

This research phase is aimed at assessing the state of art picture of each "Internet of Things" field of application encompassed by the smart city concept development in Italy. The analysis is based on the explorative case study tool – both direct, through 17 interviews to project personnel in order to get a clearer picture of the decision making process that led to the implementation, the expected benefits, the encountered criticalities, the differences between forecasted and actual results and finally the ways forward; and indirect, through the analysis of 54 projects for a total of 75 applications using Internet of Things technologies in Italy and abroad (cf. Table 13) – with the objective of assessing the state of art picture of each field of application's development,

judging their adherence to the IoT paradigm and their maturity and diffusion to better value their future growth.
A case study is “an empirical inquiry that investigates a contemporary phenomenon within its real-life context, when the boundaries between the phenomenon and the context are not clearly evident and in which multiple sources of evidence are used” (Yin, 1984).
The output of this analysis is illustrated in chapter 8.

Project Name	Direct	Indirect
Advanced Meter & Communication Infrastructure	X	
Agrindustria	X	
AIM		X
Autobot		X
Beywatch	X	
Chicago fire department		X
City of Los Angeles		X
Comune di Nettuno	X	
Consorzio Chierese	X	
Copenhagen wheel		X
CoVel		X
Customer Led Network Revolution		X
DEHEMS		X
eCall		X
E-Cives	X	
Emet Isera		X
e-Moving	X	
Energia per la Sapienza		X
Energy Efficiency @ Home		X
Eye on Earth		X
Gaz reseau Distribution France (GrDF)		X
Grid4EU		X
Hutchinson Utilities		X
Imperia	X	
Integrated distributed Energy resources management pilot		X
Integris	X	
Intesa San Paolo		X
Intesa San Paolo	X	
Italgas gas metering project	X	
Libra 350 i Gas meter		X
Linky		X
London Girls' School		X
Low2no		X
Maison Equipée		X
ME3Gas Project		X
Mi muovo elettrico		X
Milano Wipower	X	
Muovetevi	X	
NEC & ENEL Smart grid		X
NiceGrid		X

Project Name	Direct	Indirect
NO FAR ACCESS		X
Octo Telematics	X	
Parco di Castel Fusano	X	
Parma 2.0 Citta' sensibile		X
Progetto Isernia		X
Reaction		X
REFLEXE		X
Salerno Smart city		X
SEEMPubS		X
Singapore Live		X
Smart Domogrid	X	
Smart IP Bologna	X	
Smart Spaces		X
Smart Town Persiceto		X
Smart Village		X
STAmi		X
Travolution		X
Unitil		X
Wide Bay Water Corporation (WBWC)		X
Wind Energy Platform		X
Ykohama Smart City Project		X
ZEC Zero Emission City		X

Table 13: List of analyzed case studies

6.3.6 Phase 6 - Evaluation of synergies

This phase is aimed at evaluating the exploitable synergies with each smart city field of application on which the smart metering infrastructure could leverage for reducing the burden of the investment. The methodological approach consists in steps:

- Evaluation of the infrastructural requirements and costs to adapt the smart metering solution for the integration with other services.
- Identification of the most prominent fields of application for the integration with smart gas metering based on the outcome of the previous phase.
- Development of a network architectural solution for exploiting synergies with most prominent fields of application.
- Discussion of the strength and weaknesses of the identified solution.

The output of this research phase is detailed in Chapter 9

Chapter 7 - COST-BENEFIT ANALYSIS

This chapter is aimed at valuating the economic sustainability of the smart gas metering roll-out plan. This analysis has been carried out through a comparative model allowing leveraging on the experience gained from the smart electric metering roll-out. The differences between the two sectors and their consequences for smart metering capabilities will first be elucidated for subsequently analysing the costs and benefit of the smart gas metering roll-out in Italy.

7.1 Premise

Smart metering systems were first drawn into attention considering the electricity sector in the Seventh International Conference on Metering Apparatus and Tariffs for Electricity Supply in early 1992 (Cooper et al., 1992). Since then countless scientific papers and articles tackled the topic of smart metering focusing on the electricity sector, but often generalizing the results of the study to broad-spectrum smart metering systems in a more or less explicit manner. This tendency can also be recovered when reviewing the European directives. In fact, European Commission’s approach in dealing with smart metering requirement, benefits and criticalities tends to enclose the all energy sector, although providing accurate requirements exclusively for the electric system (cf. European regulation overview). Furthermore, the emergence of the “smart grid” paradigm also has the propensity to include the all energy sector as an intelligent energy grid would require the seamless integration of the gas distribution system with the electric one by exploiting possible synergies (and with other energy grids).

These aspects led to a general misunderstanding of the capabilities of smart gas metering systems, resulting in a general confusion on similarities and differences with electric smart metering systems.

This section will therefore first provide a qualitative assessment of the benefits enabled by the smart gas metering roll-out in Italy, for subsequently quantifying them through a comparative model based on the experience gained from the roll-out in the electricity sector. To this aim, similarities and differences between the two sectors and their consequences for smart metering capabilities will be elucidated. Next, the costs analysis will be carried out using an equivalent approach.

7.2 Benefits of smart gas metering: Qualitative analysis

7.2.1 Introduction

As mentioned on the regulatory overview section, the AEEG mandated the roll-out of smart gas meters since early 2008 following a cost-benefit analysis pursued by the Authority itself.

	Distributor	Supplier	Consumer
Elimination of estimates of consumption for the billing process	X	X	X
Improved capacity in predicting consumption		X	
More personalized offers to consumers		X	X
Availability of a measure in standard conditions	X	X	X
Enabling price signals and reducing consumption peaks	X	X	
Major alignment between cost of supplies and revenues	X	X	
Automation of the switching process	X	X	X
Customer's consumption awareness			X
Security	X	X	X

Table 14 Objectives of the 155/08 regulatory order ***(AEEG, 2008a)***

The output of the Authority's cost-benefit analysis reveals that the costs outweigh the benefits for domestic consumers (representing 95% of the total customers) (AEEG, 2008). This result would suggest the Authority's decision of not envisaging the roll-out for this category of customers. Though, the fact that despite these results, the roll-out plan was mandated reflects the AEEG conviction that other benefits enabled by the smart gas metering allow the sustainability of the investment. These benefits however, are not elucidated by the AEEG.

Following, the benefits deriving from the introduction of smart gas meter will be identified, discussing for each of them the economic mechanism through which they should be achieved, the actors of the supply chain impacted, the methodology and main parameters to take into account for assessing their economic value, a qualitative assessment of the impact in relative terms, and the alternative solutions that may derive the realization of the same benefit.

The estimation of the costs and benefit are based on the assumption that distributors aim at merely fulfilling the 155/08 regulatory order, that is not envisioning the extra capabilities of the infrastructure which would result in modifying the entity of the following benefits. Table 15 illustrates a first picture of these benefits.

Benefits
Mandatory meter readings
Lower mandatory reading costs
Elimination of the auto-reading process
Interventions on the meter
Reduced switching procedures and other commercial readings
Remote deactivation of supply
Remote enablement of activation
Billing process and complaints handling
Higher transparency and competitiveness of the market
Reduced call centre costs and provisions for contentious
Reduced arrears
Network balance and efficiency
Knowledge on unaccounted gas volumes
Distribution grid maintenance and improvements
Leakage and theft detection
Customer profiling and new service provision
Overall consumption reduction and co2 emissions
Overall consumption reduction
Shift in consumption patterns
Reduction in CO2 emissions

Table 15: Overview on the benefits enabled by smart gas metering

7.2.2 Telemanagement Vs Telemetering

A distinction needs to be done when analyzing the processes which may be automated through the introduction of smart meters between the telemetering and the telemanagement scenario. In fact, telemetering involves the automation of reading capabilities of the DSOs by the possibility of remotely reading the totalizer register of the meter. While telemanagement involves the enabling of a series of remote transaction which can be done with the meter; these range from the emission of alarms whether an issue is detected at meter's level to the enabling and deactivation of gas supply to end-customers. It goes without saying that the entity of benefit which are enabled in the telemanagement scenario by far exceed those enabled by telemetering, but the cost of the two solutions also has to be taken into account in order to compare their value.

The main benefits distinguishing telemetering from telemanagement derive by the utilization of the electrovalve, as this item enables the possibility of remotely deactivating gas supply. The 155/08 regulatory order mandates that the electrovalve for intercepting the flow has to be installed inside the meter corpus (cf. Figure 29) and therefore needs to comply with legal metrological standards which at present still need to be defined. Three main consideration need to be done considering this component:

- It is not a security valve, but a flow interception valve. Initially the opportunity to use it for security issues was contemplated, in order to promptly shut the valve whether gas leakages were detected or emergency situation were signalled. The use of the electrovalve for these purposes would although burdened significantly the duration of the battery as a communication system able to address a single meter at any time had to be foreseen with dramatic repercussion on the battery lifetime. In the current envisioned scenario, in order to reduce battery consumption, the meter has a wake-up window (typically of few minutes) in which its RF module is enabled for communicating.
- The functional reliability and time sealing of the electrovalve – which normally stays opened – is not guaranteed after years of potential inactivity.
- The remote activation of the electrovalve (the closure, since the opening is not allowed) may drastically impact on the lifetime of the battery.

Figure 29 Smart meter fitted with the electrovalve

A great debate arose between DSOs and the regulator on the usage of this functionality and by analyzing the distribution market (mainly through interviews to operators) different approaches were detected. The large majority of DSOs (all minor DSOs and the majority of market leaders) are reluctant towards the use of the electrovalve mainly because of security issues. Indeed DSOs are legally responsible for all security issues related to the gas provision until end-customers' households. This causes a debate on the Authority's decision of requiring the presence of the electrovalve in new smart meters given that DSOs are definitely oriented towards not utilizing it (even if present in new smart meters). It must be noted that in other European countries, and in particular in UK the use of the electrovalve didn't involve any security issues as its functional reliability seems equivalent to the current mechanic valve – and the software and the communication technology are consolidated. The main reason sustaining Italian DSOs position when presenting them the English case is related to the Italian distribution grid configuration which presents substantial differences with the English one. Indeed the gas pressure in pipelines until customers' households is seven times higher in the Italian distribution grid and this may cause problems to the capacity of the valve to stop the flow, ensuring the absence of leakages. This said there are consolidated technologies which can easily eliminate this issue (although leveraging the price of the valve). Furthermore it has to be pointed out that the correct and secure usage of the electrovalve would require a different – and more secure – communication vector than the one used for the transmission of meters' data – foreseeing the need of taking adequate measures to hamper customer's ability to screen the device impeding the communication. Finally it can be noticed that a conflict of interest might exist on the usage of the electrovalve by DSOs as the activities which would be eliminated by its enabling represent a revenue item for DSOs as all their intervention at customer's households – apart from those related to security issues – are paid by VSOs.

In the other hand, some actors – and in particular the second major actor of the market – foresee significant benefits from the usage of the electrovalve stating that the security issues can easily be solved by introducing security norms and standard procedures which would relief DSOs from excessive responsibilities in case the standard procedures were undertaken. The different approaches towards this topic can be related to the type of DSOs; indeed, multi-utilities (and in particular electric multi-utilities) which are characterized by a greater experience in the smart metering field (as smart electric meter was introduced a decade ago) and the capabilities enabled by its implementation result in being more keen to the usage of the electrovalve than gas mono-utilities (characterized by highly conservative spirit).

Ultimately, setting aside security issues, the value of the introduction of this device can be assessed only through a comprehensive comparison of the costs it implies and its benefits; and whether positive DSOs will end-up by using it.

7.2.3 Mandatory meter reading processes

As seen in the supply chain analysis, DSOs have to fulfill the obligation of performing at least an effective reading of customer's meters per year in order to emit a yearly invoice adjustment. This activity involves sending an operator with his vehicle to customers' households in order to carry out the manual reading. The meter is not always available when the operator reaches the house as the customer (previously informed) could be absent or the meter could be inaccessible. Therefore when computing the cost of the manual readings the meter inaccessibility rate has to be taken into account. Also the cost of the activity depends on the location where the reading is carried out as in rural areas the time required for reading a meter is much higher than in urban areas where households' density is high (often configured in buildings). Finally, the building configuration has to be taken into account as the time required to perform a single meter reading could vary significantly whether all building's meters are located in a single room (typically in the basement), at the entrance of each household, or inside each households.

It must be noted that the large majority of DSOs outsource this activity to local companies that better know the territory. The reading cost in urban areas therefore has a marginal cost per meter as this activity can be planned largely in advance, and accounts only for an unskilled operator hourly rate.

Whether the meter is not available, DSO communicates it to the VSO (Supplier) which is the actor meant to interface with final customers, and the supplier activates the auto-reading process. The auto-reading process involves the supplier to request the customer to access his meter and communicate – through a phone call or a web interface – the number of the totalized register which is shown on meter's display. This activity is therefore buried by VSO and is an automated process which therefore doesn't involve an appreciable cost. It must be said that when interviewing VSOs it came out that the auto-reading process success was not always verified (less than 75% of the emitted requests were fulfilled).

In case the meter is inaccessible and the auto-reading process failed, VSOs emit the yearly invoice adjustment on the basis of consumption estimates and with obvious impacts on the reliability of final bills (especially if this situation recurs in many years).

The benefits deriving by the introduction of smart meters would therefore automate the manual reading process and eliminate the auto-reading process deriving a marginal benefit for DSOs and VSOs.

The reading process automation as it is requested by the regulatory order would involve passing from a mandatory effective reading per year to a mandatory effective reading per month which would further reduce the benefit of the automation. In the other side the higher frequency supply of prompt consumption data to customer involves a benefit for consumers which may trigger the change of their consumption behaviors, but this benefit will be discussed further on. Moreover it allows the provision of a better service quality (resulting in a benefit for customers) as customers are not required to be present in the household to enable the operator access to the meter in case it is placed inside the house.

Enabled benefit	Type of benefit	Estimated impact	Stakeholder affected	Dependence on other items
Lower mandatory reading costs	Recurrent	Low	Distributor;	No
		Ø	Supplier	
		Low	Consumer	

Enabled benefit	Type of benefit	Estimated impact	Stakeholder affected	Dependence on other items
Elimination of the auto-reading process	Recurrent	Low - Null	Distributor	No
		Ø	Supplier	
		Low	Consumer	

Table 16 Mandatory meter reading process benefits

7.2.4 Interventions on the meter

The activities which in the as-is situation require an operator intervention on the meter at user's households that may be impacted by enabling telemetering and/or telemanagement are:

- **Readings for commercial purposes and switch readings.** Whether commercial actions are deployed the need of an effective meter reading might be required. These commercial actions could be of two different natures: a request from the VSO to the DSO of meter information which may arise from a customer claim or request; and a customer's switch between two different suppliers. In both cases the cost of the manual meter reading which is performed by the DSO is paid by VSOs and it is important to notice that although it is a manual reading as the one discussed in the previous paragraph, its cost is much higher since it cannot be planned in advance according to specific efficiency parameters and involves the outgoing of an operator at a household for an exclusive meter reading – the cost cannot be split between different meter readings. The cost of these transaction in an urban area is first sustained by DSOs, then reimbursed by VSOs and in turn might be invoiced to end-customers by VSOs. The introduction of telemetering or telemanagement would consequently significantly reduce the burden of this activity almost nullifying it.
The need of an effective meter reading when a switch between different gas suppliers is undertaken by the customer is crucial for assessing the quantities of gas consumed which can be invoiced by the incoming supplier and shouldn't be based on estimates as it might derive legal litigations between different suppliers with consequent inefficiencies for the entire supply chain. In order to correctly appreciate this benefit voice it has to be mentioned that in 2011 customer's switching rate in the domestic market was of 4.5% (AEEG, 2011) – therefore reducing this voice item. Although the European and Italian regulator directives are oriented to increase this percentage in order to foster the competitiveness of the market (cf. the unbundling between DSO and VSO was introduced towards this objective).
- **Deactivation of gas supply.** This function is remotely enabled by the usage of the electrovalve (therefore enabled only through telemanagement) and might be triggered as a consequence of VSOs' request to DSOs following a customer request for termination of provision or as a VSOs decision to stop the provision given customer's arrears. Remotely deactivating the provision involves the elimination of the operator's cost required for accessing customer's households in order to perform this operation and eliminates the costs related to accessing the household when the meter is not accessible. Moreover the

utilization of such device may derive a change in customers' attitude towards delaying their payments as seen by the introduction of smart meters in the electricity sector. Indeed, the threat of deactivating gas supply becomes much more credible from customers' perspective although the current regulatory framework authorizes VSOs to request the deactivation of the supply only if the payment delay exceeds 3 months. This benefit could also be obtained by incentivizing DSOs to effectively cut the provision upon VSOs requests (by making them sustaining the cost of gas provided to arrears customers). Finally, it has to be mentioned that since the usage of the electrovalve encumbers significantly on batteries lifetime and since the reactivation of the provision would request an operator's intervention at the meter itself, a frequent use of this functionality would burden on operative costs (conversely to the electricity sector).

Remote enabling of the activation. As stated, this benefit can be misleading; the remote enabling of the activation doesn't imply that DSOs can open the valve remotely enabling the provision as for security reasons this process requires an operator to access the meter and open the valve. Instead through this function DSOs can enable the manual activation of the valve. Per se this functionality doesn't imply significant benefits as the operator's intervention still needs to be sustained. However, some DSOs foresee the possibility – whether legal metrology regulation will be modified – to equip the smart meter with a dedicated button for opening the valve, which, when the remote enabling of activation is performed by DSOs could be driven directly from the customer himself. In this case the benefit derived by the electrovalve usage could turn to be significant as it would imply reducing DSOs workforce need (less costs for personnel) as both deactivation and activation of the provision can be done remotely. That being said, actual regulations impede the realization of this benefit.

Enabled benefit	Type of benefit	Estimated impact	Stakeholder affected	Dependence on other items
Reduced switching procedures and other commercial readings	Recurring	Low	Distributor	No
		Medium	Supplier	
		Low	Consumer	
Remote deactivation of supply	Recurring	Null–Low *(sc1)* Ø *(sc2)*	Distributor	On the possibility to remotely activate the supply
		Medium *(sc1)* Ø *(sc2)*	Supplier	
		Low *(sc1)* Ø *(sc2)*	Consumer	
Remote enablement of activation	Recurring	Null–Low*(sc1)* Ø *(sc2)*	Distributor	On the possibility to remotely activate the supply
		Medium *(sc1)* Ø *(sc2)*	Supplier	
		Low *(sc1)* Ø *(sc2)*	Consumer	
sc1: Telemanagement scenario *sc2: Telemetering scenario*				

Table 17 Intervention on the meter benefits

7.2.5 The billing process and complaints handling

As conferred in the regulation review part, the benefits related to the billing process were one of the main objectives of the AEEG when introducing the 155/08 regulatory order. Indeed the gas supply chain is composed by various actors and the inability to instantly measure gas consumptions requires bills to be based on estimates of consumption. This item involves in particular the bills paid by VSOs for the transportation and distribution services, and the bills paid by customers to VSOs for their consumption.

In general it is difficult to identify reliably and in details the amount of gas flowing on the transport and distribution grids pertaining to each VSO given the gas peculiarity discussed above, although the monitoring and metering mechanisms at input and output ends of the transport system result in higher identification accuracy. Furthermore, the identification of the gas flowing on the transport system would marginally be affected by the introduction of smart meters in the domestic market as these are installed at end points of the distribution grid.

For what concerns the billing process between DSOs and VSOs, the amounts of gas invoiced from DSOs are computed on the basis of estimates of final consumption; in fact the amount of gas entering the distribution grid can be reliably known through accurate metering mechanism at the entrance of the distribution grid (i.e. interconnection points with the transport grid). Typically, the input gas is then allocated to different VSOs on the basis of estimate algorithms that forecast each end-customer's consumption. The parameters used for the estimates are standardized and provided by the regulator; among these, may identify the location of the household, the type gas usages (for heating, for sanitary hot water generation, for cooking, etc.), the temperature, the number of residents per household, past consumption data, etc. VSOs might as well use their own forecasting method (which often results in being more accurate) and provide them to DSOs. The invoiced gas to VSOs is therefore computed using allocation coefficients to be applied to the gas entering the distribution grid. Therefore potential inefficiencies of the distribution grid – e.g. gas leakages or thefts – are not allocated to the owner of the infrastructure (i.e. DSOs) but paid by VSOs unless they are identified.

The billing process from VSOs to final customers also presents noteworthy criticalities. Indeed the majority of gas invoiced to final customers (all excepting the required yearly adjustment invoice) is emitted on the basis of estimates. These estimates can either be internally produced or granted by DSOs. Through the interviews performed with VSOs it came out that their billing system is similar to the one of DSOs as it overturns the amount of gas invoiced by DSOs to end-customers allocating it to each of those on the basis of similar coefficients. Therefore building a perverse mechanism through which costs of inefficiencies in the grid are first transferred to VSOs and finally paid by end-customers.

It must be noted that VSOs have to pay the distribution service on a monthly basis while customers pay them with an average 3 months delay. Consequently they need to have consistent liquidity to face these 2-3 months delays; the not transparent mechanism of estimates allow VSOs to develop flexible billing policies which allow them to over or under estimate their consumers' consumption in order to face liquidity or operative issues. One such basic policy could be a 10% overestimation of all customers' consumption data until the adjustment invoice is emitted (which of course is not emitted to all customer in the same period) which would result in having 10% extra liquidity throughout the year. Obviously the flexibility of estimate policies (overestimating and underestimating withdrawals) is limited by a trade off with the cost for sustaining customers' claims and complaints.

The introduction of smart meters would for sure shed light on these processes, but the real financial benefit deriving from their introduction can't be assessed as the mechanism and policies undertaken for billing purposes are definitely sensible to both DSOs and VSOs and are difficult to access to. It is also difficult to assess which actor benefits the more by the abstruseness of these processes, but the feeling is that DSOs are favored by the fact they don't deal with the mass market. The benefits related to the transparence of these activities would certainly result in higher competitiveness of the market giving rise to lower prices for end-customers.

Moreover, when assessing the benefits derived from the introduction of smart meters in relation to billing processes, the costs derived by reading errors and rectifications should also be taken into account. Indeed, in the as is situation, a reading error – whether it is not promptly identified by the operator when at customer's household – would imply, if identified at DSO level or VSO level, re-sending the operator at the specific customer household therefore implying a greater. Contrariwise, whether this error is not identified its cost becomes difficult to assess as it could go unnoticed or could derive a customer claim (whose cost becomes relevant).

Some VSO state that the arrears rate may be related to the emission of adjustment invoices. Indeed receiving high invoice adjustment may trigger delinquent behaviors in some customers. Consequently the emission of bills based on actual consumption would reduce the arrear rate as invoice adjustment needs are cancelled.

Another benefit which is directly derived from billing customer on the basis of actual consumption data is related to complaints handling. Indeed, it is widely known that the majority of claims received by VSOs – which are the ones dealing with the end customer and providing customers service through call centers – are related to administrative and commercial purposes. These arise mainly in correspondence of an adjustment invoice (typically too high), or by punctilious customers in case the withdrawal estimate on the invoice differs from the one displayed on the meter. These costs encompass call center costs, and costs for solving contentious. It is estimated on the analysis that the call center costs will be reduced as no information is further required by customers to deal with estimated invoices. However it must be noted, that by analyzing the electricity roll-out case in Italy other sources of uncertainty may derive from the introduction of smart meters which would increase the received calls by call centers, but this is true especially in the initial introduction phase (request of information relative to the meter functionalities, ways of communication, issues faced in the installation, etc.). The costs for solving contentious instead is predicted to reduce significantly as legal litigations with customers related to the emission of distorted invoices and legal litigations with other VSOs related to the switch reading will drastically decrease.

<table>
<tr><th>Enabled benefit</th><th>Type of benefit</th><th>Estimated impact</th><th>Stakeholder affected</th><th>Dependence on other items</th></tr>
<tr><td rowspan="3">Higher transparency and competitiveness of the market</td><td rowspan="3">Recurring</td><td>Low – Medium*</td><td>Distributor</td><td rowspan="3">No</td></tr>
<tr><td>Low – Medium*</td><td>Supplier</td></tr>
<tr><td>Low – Medium*</td><td>Consumer</td></tr>
<tr><td rowspan="3">Reduced call centre costs and provisions for contentious</td><td rowspan="3">Recurring</td><td>Ø</td><td>Distributor</td><td rowspan="3">No</td></tr>
<tr><td>Low</td><td>Supplier</td></tr>
<tr><td>Ø</td><td>Consumer</td></tr>
<tr><td rowspan="3">Reduced arrears</td><td rowspan="3">Recurring</td><td>Ø</td><td>Distributor</td><td rowspan="3">On the remote deactivation of supply</td></tr>
<tr><td>Medium (sc1)
Ø (sc2)</td><td>Supplier</td></tr>
<tr><td>Ø</td><td>Consumer</td></tr>
<tr><td colspan="5">sc1: Telemanagement scenario
sc2: Telemetering scenario
*Intangible; difficult to assess the magnitude of the impact</td></tr>
</table>

Table 18 Billing process and complaints handling benefits

7.2.6 Network balance and efficiency

The distribution network balance presents substantial criticalities which may be impacted by the introduction of smart meters. Indeed, as discussed above the process through which the balance of the distribution network is performed is based on customers' withdrawals estimates which make it difficult to allocate the amounts of gas flowing in the network reliably to their owners (VSOs). The introduction of a smart metering system allows the acquisition of end-customer's withdrawals information which may result useful in different levels of the supply chain. In fact punctually monitoring customers withdrawals allows to accurately profile customer's consumption behaviors with derived benefits for VSOs in relation of their ability to differentiate their offer and provide additional services and for DSOs in relation to more precise gas consumption forecast which allow better planning and maintenance of the distribution grid

- **Better information for Distributors.** Through smart metering systems distributors can have visibility on gas flows in each interval period, therefore theoretically implying more efficient investment and maintenance plans on the grid – e.g. planning network capacity enlargement exclusively in areas where it monitors a peak consumption increase. In regulator's cost-benefit analysis performed in 2007 this was considered a major benefit voice. Through the analysis of the current management policies of the distribution network it appeared that punctual monitoring mechanism are already in place for maintenance planning of the grid. Indeed grid improvement projects involve positioning sensor that continuously monitor the pressure on the pipelines in critical sections of the grid – most high sections, most far sections or sections characterized by higher pressures. The data retrieved through these mechanisms are then entered in simulation models, and critical improvement requirements are identified. Consequently the benefits induced by the introduction of smart meters related to the grid improvement and maintenance can be deemed marginal.

Another improvement on the network management processes emphasized by the regulator in the cost-benefit analysis is the possibility for DSOs to identify leakages and gas theft on the grid. This benefit is purely theoretical as gas and gas distribution grid peculiarities make it impossible to instantly balance gas input and outputs. Indeed the length of the network and smart meter's sensibility don't allow identifying as thefts or leakages measurement fluctuations between entered gas and withdrawn gas – as these depend on the gas state: temperature and pressure. Although thefts and leakages can't be promptly detected given the impossibility to instantly balance gas amounts on the grid, this operation can be done with a temporal delay allowing at least distributor's knowledge on the unaccounted gas volumes (resulting in an input for grid maintenance and improvements).

- **Better information for suppliers.** The benefits derived by the access to punctual data on customer withdrawals allows supplier to better profile their customer base on the basis of consumption behaviors. The introduction of smart meters increases by two orders of magnitude the number of data to be managed both by DSOs and VSOs with obvious consequences in business intelligence output effectiveness. This allow VSOs to better differentiate their offer and to foresee the provision of customized services. The entity of this benefit is difficult to assess as it depends on the business capability of each supplier. A typical value added service could be the provision to end customers of frequent consumption data (for example through web portals). New service creation capabilities depend as well from the frequency with which the meter transmits data to DSOs (and VSOs) as the 155/08 regulatory order mandates that meters should communicate consumption data with a frequency that allows bills to be based on actual consumptions (therefore requiring at least a monthly communication) but many DSO envision the possibility to increase that frequency to a daily communication. In general it can be stated that the more the provision of data is near to a real-time provision, the more new services can be introduced (with an obvious counterpart on the meter's battery lifetime).

  Finally it has to be mentioned that in the French cost benefit analysis for the smart metering roll-out the provision of new value added services implies an economic benefit allowing passing from a null business case to a profitable business case.

Enabled benefit	Type of benefit	Estimated impact	Stakeholder affected	Dependence on other items
Knowledge on unaccounted gas volumes	Recurring	Null - Low	Distributor	No
		Ø	Supplier	
		Ø	Consumer	
Distribution grid maintenance and improvements	Recurring	Low - Null	Distributor	On the above benefit
		Ø	Supplier	
		Ø	Consumer	
Leakage and theft detection	Recurring	Null	Distributor	No
		Ø	Supplier	
		Ø	Consumer	
Customer profiling and new service provision	Recurring	Ø	Distributor	Frequency of data transmission
		Low – Potentially Medium*	Supplier	
		Ø	Consumer	

**Intangible; difficult to assess the magnitude of the impact*

Table 19 Network balance and efficiency benefits

7.2.7 Overall consumption reduction and CO_2 emissions

The provision of actual consumption data to customers in a more frequent manner may foster their energy consumption awareness and trigger changes in their consumption behavior. These changes can be of two different nature: a reduction in the overall consumption and a shift of consumption in periods where gas might be less expensive.

The potential reduction or time switch of gas withdrawals depends on different factors among which:

- ✓ The cross price elasticity of gas demand in different periods, which determines what amount of consumption will shift over time in response to a change in the relative price of gas on different days
- ✓ The variance of gas market prices in different time intervals; the more the market prices are diverse in the different periods, the higher the incentive for consumers to shift their consumption in time. The actual price mechanism doesn't although vary in relation to different time intervals, but this feature may be introduced following the complete smart metering roll-out.
- ✓ The degree of utilization of available transport capacity and storage capacity, determining the economic value of the transfer of consumption over time, in terms of avoided costs of expansion of transport and storage infrastructures.

It must be stated that these factors have a low impact in the domestic consumer market as the usages of gas can be segmented into three main usages: environmental heating, production of hot water and for cooking purposes. The nature of these usages implies a low cross demand elasticity in different periods of the day, or between different days. Considerably different is the demand elasticity referred to industrial customers and thermal power plant, but these are outside our analysis. Furthermore, the price variability of gas is very contained – especially if compared to electricity – given the capability of storing it.

Studies on smart metering deployment, recently undertaken in the United Kingdom, have suggested a reduction of the domestic consumption in the order of 2% (DECC and Ofgem, 2011). Such an estimate was also taken in the cost-benefit analysis of smart gas meters carried out in France (Pöyry and Sopra Consulting, 2011). However, these estimates cannot be transposed to the Italian system as the mechanism through which consumption data is transferred to the customer is substantially different. Indeed, in the UK case consumption information are supplied to the customer through an in-home-display which makes this information easily accessible and provided in a near real-time frequency (maximum 30 minutes delays). In the French case the in-home display is still object of valuations but the provision of information to customers at worse will be performed through a web portal (with hourly consumption rate transmitted with a day delay). Conversely, the Italian regulator didn't foresee a mechanism for providing consumption information to customers in a user-friendly manner, but the only mode of accessing that data – apart from invoices or through customer service call centers – is reading the register totalizer which is shown on the meter display.

To finish a reduction in gas consumption, whether realized would derive a benefit for the country as a whole in terms of reduced CO2 emissions. This objective is particularly sought by European governments which are committed towards meeting the goals set by the 3rd Energy Packet (ERGEG, 2011)

Enabled benefit	Type of benefit	Estimated impact	Stakeholder affected	Dependence on other items
Overall consumption reduction	Recurring	Low - Null	Distributor	Frequency of data transmission
		Ø	Supplier	
		Low – Null	Consumer	
Shift in consumption patterns	Recurring	Low – Null	Distributor	Price variability
		Null	Supplier	
		Low – Null	Consumer	
Reduction in CO2 emissions	Recurring	Ø	Distributor	On the overall consumption reduction
		Ø	Supplier	
		Low – Null	Consumer	

Table 20 Overall consumption and CO_2 emissions benefits

7.3 Benefits of smart gas metering: Quantitative analysis

7.3.1 Why considering the Electric case

Both in the Literature, in the regulatory framework mandating the gas metering roll-out and through the interviews performed with the actors of the gas supply chain, the smart gas metering topic is approached with a recurring reference to the electricity sector. Indeed, the supply chain configuration presents substantial similarities: both sectors are regulated through the same

Authority (AEEG); they have both been affected by the process of liberalization in the last decade; their supply chain result having the same macro structure: generation – transport – distribution – supply and consumption. Both distribution grids cover the entire territory, and have their end nodes in all Italian households (or almost). Also by reviewing the actors of the supply and distribution markets, it is noticed that major players are present in both sectors (e.g. Eni, Enel, A2A, Iren, Hera, etc.). Finally, the operating activities undertaken by the actors of both supply chain (with a focus on distributors and suppliers) present great similarities, and the benefits enabled by smart metering in these activities seem equivalent.

The smart metering roll-out in the electricity sector has now reached 12 years of successful experience, leveraging on the lessons learned from this world primacy seems of utmost importance for the accurate valuation of the impacts on the gas sector.

7.3.2 Electric Vs Gas distribution grids

It is factual that both the electric and gas distribution network are energy grids, they both employ a ubiquitous infrastructure with an extensive coverage of the territory, however their characteristics, features and capabilities present substantial differences.

7.3.2.1 *The object of measurement*

Electricity and gas differ significantly given their characteristics in terms of security issues, storage capabilities and measuring accuracy.

In fact natural gas is a colourless and odourless inflammable substance, and therefore needs to be protected from potential sparks, requiring a set of security measures to be taken when dealing with it. These start from the addition of an odorant to let consumers identify whether there is a gas leakage, to the wide set of home safety measures and controls which distributors should ensure when enabling gas supplies to a given domestic consumer. Conversely, electricity is a non-flammable element, but often represents the root cause of sparks usually given by short circuits. This is the main reason why electricity and gas grids should be accurately separated (and why the smart gas meter shouldn't be powered by electricity).

Another important difference is that electricity has to be consumed simultaneously upon its production and therefore it is not possible to store it (in an economic sustainable manner). This requirement leads to a series of issues for the electricity grid which should always balance its production by monitoring the consumption. On the other hand gas can be stored, and as we mentioned when analysing the supply chain, Italian storage capacity accounts for 14% of its yearly consumption (and new storage sites are being constructed).

Finally, the electricity can be measured instantaneously in terms of energy (kWh), while gas, because of metrological and physical issues cannot be measured instantaneously. This is mainly due to small variation in the quality of gas, to the high distances between the gas delivery points and the measurement stations, and to the different times needed to reach the end-customer given the different flow rates. Also the amount of energy contained in a certain gas volume is not constant, but varies in relation to the temperature, the pressure, and the heating power (calorific values). Therefore smart gas meter – in contrast to smart electric meters – are not able to instantly measure energy consumption.

7.3.2.2 *Provision process*

Until a decade ago the provision process for electricity and gas could be deemed similar as the process was centralized and originated from few sources: thermal power plants for electricity and deposits for gas. These last years although saw the emergence and wide diffusion of distributed energy sources, mostly renewable energies which disrupted the entire electricity system. Consumers became prosumers as they now produce and consume electricity. In fact, the necessity of producing electricity simultaneously with its consumption requires the capability of predicting customer's demand, but this is not enough anymore as customer's distributed generation also needs to be forecasted in order to well balance the system. Towards solving this issue producers' capability to instantly know the amount of energy produced and consumed in different nodes of the grid is essential and is the basic idea of smart grids.

It is important to highlight the difference on the production process of these two energy vectors since electricity distributed generation is the core reason for the development of smart grids, and smart metering is the core element for the development of smart grids. Smart electric meters are therefore required for solving issues that grew significantly in last years, but for which a quick response is needed for the security of the system. This is also why the need of smart electric meters is consolidated in the international community.

The generation process in the gas sector being centralized, these issues are not relevant in the gas sector.

7.3.2.3 *Distribution grid*

Both distribution grids cover the entire territory, and have their end node in all Italian households (or almost). The main difference between the two grids is that the electricity grid can also be used as a vector for the exchange of data through the Power Line Communication protocol, while in the gas network this operation is not possible. This represents a great advantage for the electricity system as a new communication infrastructure is not required to be built. It is however important to say that the limits of this communication protocol which were discussed in the communication section (1.3.2) seem to exclude this technology for new generation smart electric meters given their low bandwidth.

7.3.2.4 *Market configuration*

When analysing the differences between the electric and gas sector it appears essential to investigate on the market structure. In fact, the price configuration of the two markets presents substantial differences which impact on the profitability of the smart metering roll-out. In the electricity sector energy can be bought and sold at spot prices, while it is not possible in the gas sector, as the balance of the network is performed on a daily basis. Furthermore, the longevity of the fixed contracts with supplying countries (over 30 years in some cases and at determined prices) and the storage capacity of the gas sector result in a much weaker benefit deriving from shifting the consumption from a period of the day to another, or from a day to another. This in turn results in a much less volatile price for gas (both at wholesale and in retail market).

7.3.2.5 *Consumers demand elasticity*

The gas domestic consumer market can be segmented into three main gas usages: environmental heating, production of hot water and cooking purposes. The nature of these usages implies a low cross demand elasticity in different periods of the day, or between different days. Significantly different is the electricity sector, where the usages can be driven by many different factors whose usages can be shifted in time with greater elasticity (e.g. washing machine, ironing, dish-washing machine, etc.).

7.3.3 Reduction of operating costs

Following the main operating benefits arising from the smart metering introduction in the gas sector are valued through an item-per-item comparison with the actual results of the electric roll-out case. A model aiming at valuating the benefits derived by the reduction of the burden of operating activities has been developed. This model leverages on the actual results of the electricity roll-out case study, and therefore quantifies the differences in the benefits from operating activities. The operating costs affected by the application can be grouped into five major items which are: costs of mandatory readings; interventions on the meter; billing process; call centre and materials.

Macro benefit area	Benefit	Inputs
Mandatory readings	Cost of mandatory readings	N° of meters
		% of effective readings
		Average manual reading cost
Interventions on the meter	Costs of terminations with deactivation	Average cost of a work order
		N° of deactivations
		% reduction
	Costs for power adjustment	Average cost of a work order
		N° of power adjustment
		% reduction
	Costs for restoring power cuts	Average cost of a work order
		N° of power adjustment
		% of restorations
	Costs of take overs with activation	Average cost of a work order
		N° of take overs with activation
		% reduction
	Costs of switching readings	Average cost of a meter reading
		N° of switching readings
		% reduction
	Verification meter readings	Average cost of a meter reading
		N° of verifications
		% reduction
	Costs for remaining work orders	Average cost of a work order
		Remaining work orders
		% time reduction for a work order

Billing process	Costs of annual balance per customer	Cost of annual balance per customer
	Verified readings (no validation)	Number of validation
		Average cost of validation
		% reduction
	Costs of litigations	Average cost per litigations
		Number of litigations
		% reduction
	Costs for indemnities	Average cost of indemnities
		Number of indemnities
		% reduction
Materials	Costs of materials	Average number of meters in stock
		Average yearly cost of stocks
		% reduction
Call center	Costs of the call center	As-is n° of calls
		Average hourly cost (CC)
		Average duration of calls
		% Reduction of calls' duration
		% Reduction of the n° of calls

Benefits relative to the electricity sector exclusively

Benefits enabled by telemanagement exclusively

Table 21 Model for operating benefits

The pie graph in Figure 30 illustrates the breakdown of the operating benefits resulting from the installation of smart electric meters in 100.000 clients' households. The figure points up how the largest part of the operating benefits result from the elimination of the necessity of accessing customers' household for interventions on the meter. It also emphasizes the low impact, in percentage terms of the elimination of the yearly mandatory readings.

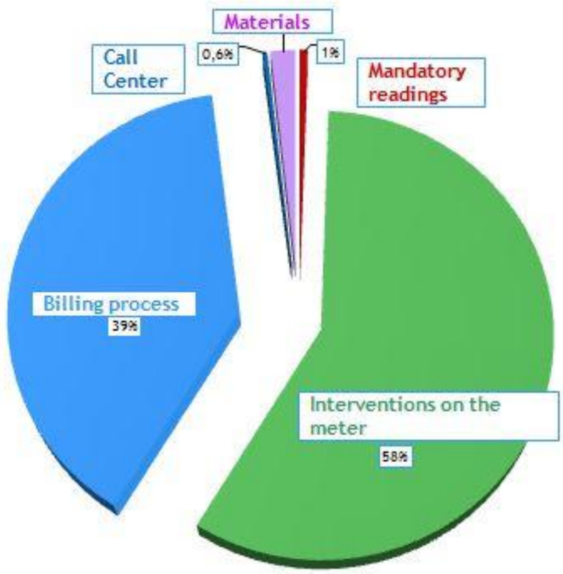

Figure 30 Breakdown of the benefits arisen from smart electric meters' roll-out (*Osservatorio Mobile & Wireless Business, 2007*)

Following, a comparative assessment of each of these cost items will be undertaken, analysing and distinguishing for each of them the main parameters used for their valuation in both sector before and after smart meters' introduction in the electricity and gas sectors.

- **Cost of mandatory readings**

This cost item, given its low impact on the overall operating cost in the pre-introduction scenario – even though completely cancelled (in percentage terms; i.e. the marginal cost of data transmission remains) – accounts for approximately 1% of the total induced benefit. The parameters used for the computation of this cost item are identical in the gas and electricity sector in both scenarios (apart from a slightly major cost for data transmission in the gas industry).

Input description	Unit	Input name
Number of meters	[n °]	Num_met
Percentage of effective readings	[%]	%Eff_read
Average manual reading cost	[€]	Av_read_cost
Output description		**Output name**
Cost of mandatory readings	**[€/year]**	**Num_met*%Eff_read*Av_read_cost**

Table 22 Cost of mandatory readings: Inputs and formula

- **Interventions on the meter**

This cost item represents the major part of the costs considered in the pre-introduction scenarios (65.6%; cf Figure 31). Indeed this voice encompasses the cost of sending operators at clients' households whenever a security issue is detected or a request from the supplier or customer is received. The cost of this operation has been broke down and valued in the above part for the gas sector; particularly similar are the parameters for its assessment in the electricity sector in the pre-introduction scenario. However, the post smart meter introduction scenario presents substantial differences as the electric meter allows augmented functionalities. Indeed, the smart electric meter enables the remote meter readings for commercial purposes (switching or verifications of in the billing process; cf. Table 23), the remote deactivation of supply, the remote activation of supply, it allows the DSO to remotely regulate the power through adjustments (therefore enabling the possibility of reducing the power provision to arrears customer unless they pay the bill); and all these activities are carried out with a marginal cost constituted by the data transmission cost. We further note on the graph of Figure 31 that the cost of interventions on the meter is not eliminated in the post-introduction scenario (accounts for 20% of the impacted operating costs) as intervention for security issues still need the outgoing of an operator at customer's household.

We previously examined the benefit related to the interventions on the meter in the gas sector, and it must be said, in order to accurately compare it with the above figure, that the capabilities offered and the cost for their actuation significantly differ from the electricity sector. In actual fact, the remote meter transactions enabled are the meter readings for commercial purposes and the deactivation of supply (with all the criticalities discussed towards the effective usage of the electrovalve by DSOs and its impact on the battery and consequently on the meter lifecycle).

As in the electricity sector this operative benefit accounts for 58% of the total benefit related to the smart meter's introduction (as depicted in the pie graph on Figure 30) and considering that the incidence of the elimination of the burden of remote readings for commercial purposes is estimated to account for 10% of the total cost of interventions on the meter, it goes straightforward that the major part of the operating benefits of smart meters in the electricity sector is not recovered in the gas sector unless regulatory issues are overcome in what concerns the electrovalve usages (and even then, these would be significantly lower).

Input description	Unit	Input name	Reduction	
			Gas	Electricity
Average cost of a work order	[€/order]	WO_av_cost		
Average cost of a meter reading	[€]	Av_cost_read		
Number of power adjustments (power cuts)	[numb]	N°_Padjust		80%
Take over with activation	[numb]	N°_Act		99%
Terminations with deactivation	[numb]	N°_Deact	85%	98%
Switching reads	[numb]	N°_switch_read	100%	100%
Verification meter readings	[numb]	N°_verification	100%	100%
Restoration of power cuts	[numb]	N°_Restoration		80%
Remaining work orders	[numb	WO_ Remain		
Average time for completing a work order	[hours]	AvTime_WO	20%	25%
Output description		**Formula**		
Benefits from intervention on the meter	**[€/year]**	**WO_av_cost*(N°_Padjust*%red_N°_Padjust+N°_Act*%red_N°_Act+N°_Deact*%red_N°_Deact+N°_Restoration*%red_N°_Restoration+WO_Remain*AvTime_WO*%red_AvTime_WO)+(N°_switch_read*%red_N°_switch_read+N°_verification*%red_N°_verification)*Av_cost_read**		

Benefits relative to the electricity sector exclusively

Benefits enabled by telemanagement exclusively

Table 23 Benefits from interventions on the meter: Inputs and formulas

- **Billing process**

As shown on the graph of Figure 31, this macro cost item accounts for 31% of the impacted operative costs in the pre-introduction scenario. This voice encompasses all the costs for customer's withdrawals estimates, validation process, the issue of adjustment invoices and customers' invoice complaints handling processes. The parameters used for its assessment in the pre-introduction scenario are similar in the electricity and gas sector as the processes used for their realization are identical. The average number of complaints to be handled before the introduction of smart meters in the electricity sector is also in line with the one handled in the gas sector (or slightly higher, but not affecting our analysis).

For what concerns the post-introduction scenario, we can appreciate through the graph how this cost item is almost erased as the automation processes resulting by the smart meters introduction eliminate the burden of the activities: elimination of withdrawals estimate; automation of the validation processes (and integration with the invoice issuing process); elimination of adjustment invoices; near nullification of invoice complaints from customers. The resulting benefit voice accounts for 39% of all operating benefits related to the introduction of smart electric meters (as shown on the pie graph in Figure 30) and results significant also in the gas sector (cf. Figure 31).

Input description	**Unit**	**Input name**	**Reduction**	
			Gas	**Electricity**
Cost of annual adjustment invoices	[€/customer]	Bal_annual	100%	100%
Number of validation	[numb]	N°_Valid	98%	98%
Average cost of validation	[€]	Av_cost_Valid		
Average cost per litigations	[€]	Av_cost_Litig		
Number of litigations	[numb]	N°_Litig	90% 50%	90%
Average cost of indemnities	[€]	Av_cost_indemn		
Number of indemnities	[numb]	N°_indemn	90%	90%
Output description		**Formula**		
Benefits from the billing process	**[€/year]**	**Bal_annual+ N°_Valid*%red_ N°_Valid* Av_cost_Valid+ Av_cost_Litig* N°_Litig*%red_ N°_Litig+ N°_indemn*%red_ N°_indemn* Av_cost_indemn**		

Benefits enabled by telemanagement exclusively (highlighted cell: 90% for gas, number of litigations)

Table 24 Benefits in the billing process: Inputs and formulas

- **Call centre and materials**

These items account for the personnel and organizational costs related to the use of the call centre and the costs of materials (i.e. mainly the burden of keeping meters in stock). They represent a marginal voice as they account together for 2.7% of all operating activities impacted, and the introduction of smart meters allow their reduction to 1.2% – representing the 2.6% of the total induced benefits in the electricity sector. This figure is equivalent in the gas sector where both the pre-introduction and post-introduction scenarios are analogous.

Input description	**Unit**	**Input name**	**Reduction**	
			Gas	**Electricity**
Average number of meters in stock	[numb]	Meter_stock	70%	70%
Average yearly cost of stocks	[€/year/meter]	Meter_stock_cost		
As-is n° of calls	[numb]	CC_num_call	25%	25%
Average hourly cost (CC)	[€/hour]	CC_cost		
Average duration of calls	[hours]	CC_av_duration	25%	25%
Output description		**Formula**		
Benefits from materials costs	**[€]**	**Meter_stock*%red_Meter_stock*Num_met*Meter_stock_cost**		
Benefits in call centers	**[€]**	**CC_num_call*CC_cost*CC_av_duration*%red_CC_av_duration *%red_CC_num_call**		

Table 25: Benefits from call centre and materials: Inputs and formulas

The graph in Figure 31 depicts the resulting operative benefits enhanced by the smart meter introduction in the gas and electricity sectors. We notice how their introduction allows a 37% reduction of the burden of the activities impacted compared to the 80% reduction encountered in the electric sector.

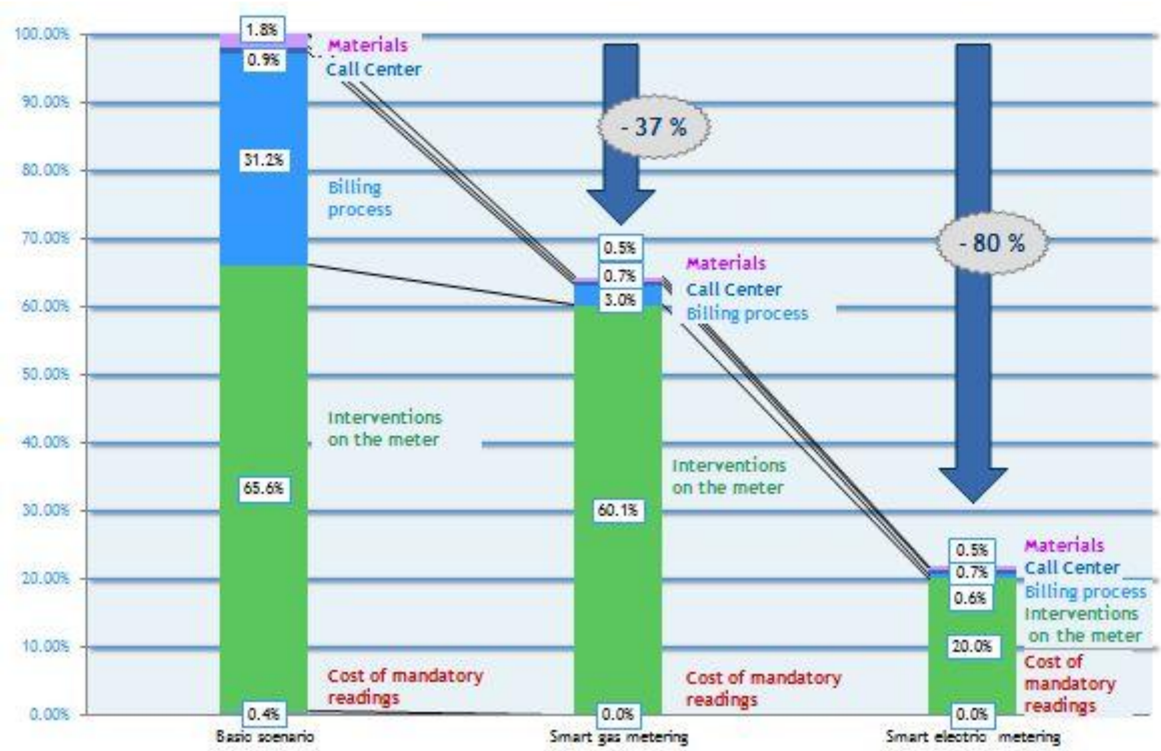

Figure 31 Operating benefits of the smart gas and electric metering roll-out

7.3.4 Non-operative benefits and future options

As widely discussed in the above paragraphs, the introduction of smart meters allow the realization of various – more or less intangible – benefits for the entire supply chain which cannot be reduced to operative activities.

The following part will therefore focus on these benefits aiming at distinguishing the value of their impact in the electricity and gas supply chains. The analysis will tackle item-per-item the main macro benefits enabled.

- **Balance of the network before the diffusion of renewables**

The introduction of smart electric meters allowed all the actors of the electricity supply chain to access real time information of customer’s power consumption. Combined with the fact that the electricity network balance must be ensured instantaneously – the power entered in the grid must be equivalent to the one consumed in every instant – it allows power producers to provide timely and effective responses to the emergency needs of the system by deploying their strategic idle capacity. Indeed 73% of power generated in Italy in average (as it depends from the power generated by renewable energy sources) comes from thermal power plants; these plants are characterized by contained capacity flexibility and reducing their workload derives significant decrease in their energy efficiency rates. Therefore, to deal with this issue, some plants have been stopped – in actual facts thermal power plants are the first energy sources to be arrested whether the power needs decrease as they are the less environmentally sustainable – and are subsequently activated in case of need. This planning and management opportunities are enabled by the use of smart meters to punctually assess the consumption quantities in every instant. Another benefit for producers is the ability, through the availability of customer historical consumption patterns, to better forecast the power needs of the system resulting in an increased efficiency of power plant operating activities.

Furthermore, the smart metering introduction in the electricity sector enabled the instauration of differentiated prices according to the consumption time intervals. This alone enabled a switch of consumption into evening hours and week ends (where the electricity costs less) resulting in a reduction of those peaks. Many studies are tackling this topic within the smart grid concept; indeed it seems that major consumption reduction possibilities may be enabled through the real-time knowledge of consumption data deriving the opportunity of instituting real-time dynamic prices (Allcott Hunt,2011).

Conversely, in the gas sector, the longevity of the fixed contracts with supplying countries (over 30 years in some cases and at determined prices) and the storage capacity of the gas sector result in a much weaker benefit deriving from shifting the consumption from a period of the day to another, or from a day to another. This in turn results in a much less volatile price for gas (both at wholesale and in retail markets). Thus, in this case the provision process doesn't affect the efficiency of major actors in the supply chain – like thermal plants in the electricity sector – but perhaps is limited to the formulation of flexible contracts to increase gas imports or to the storage capacity management.

- **Balance of the network after distributed energy generation diffusion**

The diffusion of renewable energy generation sources, as discussed above, derived significant problems for the balance of the network which requires an adequate a timely response to ensure the security of the grid. At present, in average 10% of daily power consumption energy is generated by renewable energy sources through 300.000 generation systems; and this number is expected to grow (recalling the European targets 20/20/20). The fact that they strongly depend on significant variable external factors makes it impossible to forecast their power potential therefore increasing the variability of the system. In actual facts this variability doesn't provoke issues exclusively in planning decision – eliminating the benefits for thermal power plants' management which were enabled by the introduction of smart meters, discussed above – but most of all in the instant balance of the network and the emergency management. This issue can only be solved through the development of smart grids, able to monitor not only the consumption quantities, but also the one entered in the network. The establishment of this new concept, cannot be confined to merely solving this issue and optimizing the grid management, but allows the enablement of a series further advantages ranging from the provision of value added services to citizens (dynamic tariffs; demand-response paradigm; enabling the development of electric mobility) to the reduction of CO_2 emissions

Towards this issue smart electric meters represent a significant breakthrough, and the noteworthy benefits deriving from the smart grid should partly remunerate the investment in smart electric meters. In the gas sector, this major item of benefit doesn't exist as the provision process is centralized and there is not a smart grid equivalent.

- **Consumption reduction**

The introduction of smart electric meters allowed an increase of customer's awareness on their power energy consumption. This was also emphasized by the introduction of variable prices according to consumption time intervals and through an effective communication campaign. Progresses in household appliances' energy efficiency rates further sensitized consumers towards power consumption effects (both in terms of cost and impact on the environment). Moreover, the diversity of levers on which to act for power consumption reduction – given by the large number of home appliances powered through electricity (ironing, washing machines, dish washing machines, air conditioning, televisions, computers, lighting systems, etc.) – enabled a certain degree of flexibility in consumer's behaviors towards the goal. As a result both a shift of energy consumption quantities towards different time intervals and an overall domestic power consumption reduction were detected. It is important to mention that this trend is going to persist and grow in the next future given the ongoing emergence of smart grids which are meant to transform consumers in active participants of the energy supply chain – therefore enhancing their energy awareness.

The significant benefits reported for the electricity domestic sector are not even comparable to the one envisioned by the smart gas meter introduction – forecasts project a 4-5% consumption reduction in the electricity sector against a 2% reduction in most optimistic gas scenarios – when providing real-time information in a consumer friendly manner (UK case with in-house display discussed in section **7.6**). Indeed the gas domestic consumer market can be segmented into three main gas usages: environmental heating, production of hot water and cooking purposes (whose combinations may vary as shown by the graph in Figure 32 which breaks down gas withdrawals of customers attached to the distribution grid according to their usages). The nature of these usages implies a low cross demand elasticity in different periods of the day, or between different days.

- **Market competitiveness**

As discussed when tackling the market competitiveness on the benefit analysis, the processes which are affected by the introduction of smart meters related to the market competitiveness are similar in both sectors – both in the as-is scenario and in the post introduction scenario; and considering that the switching rates in both sectors are analogous; the benefits related to the enhancement of the market competitiveness can be deemed equivalent

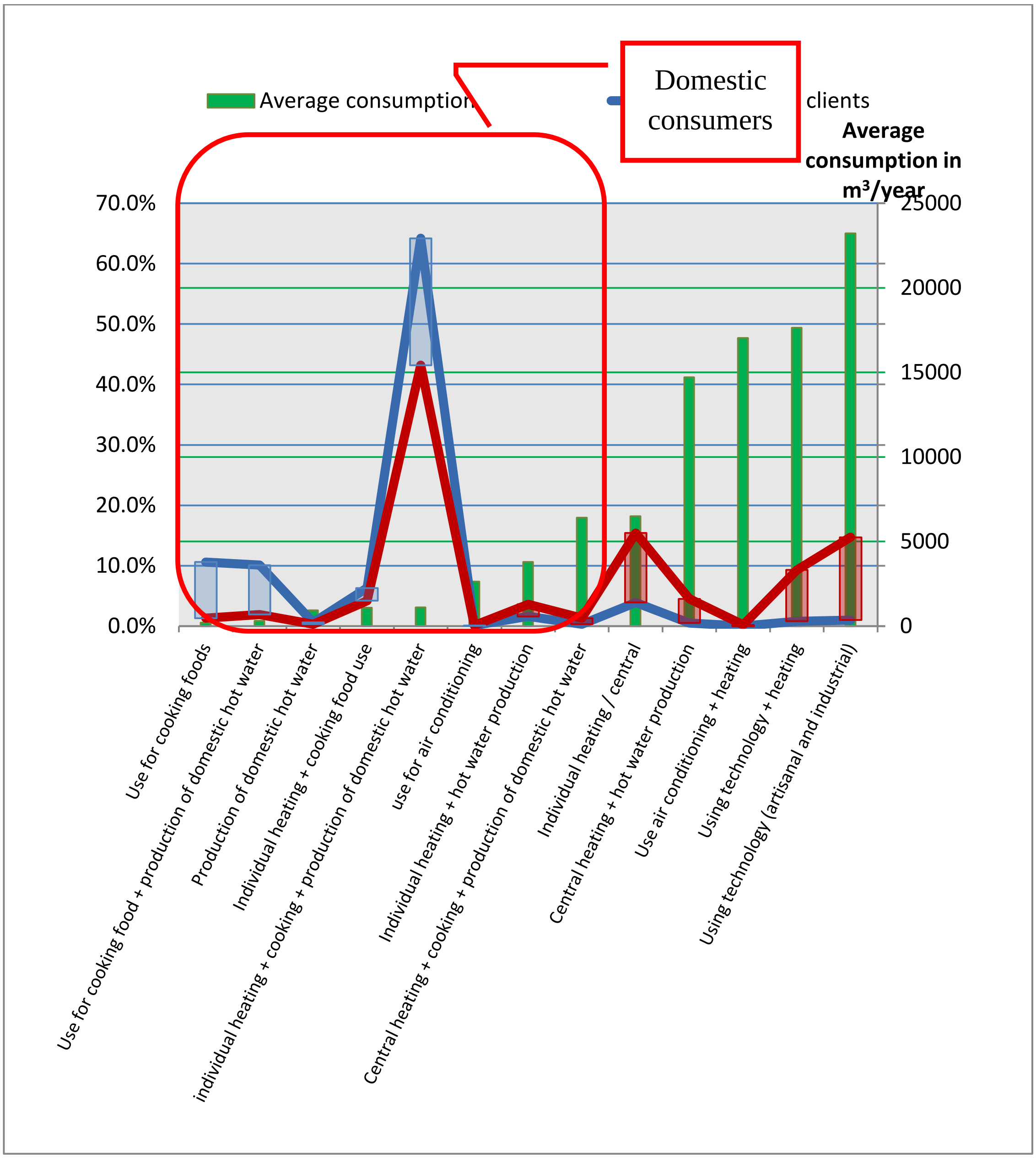

Figure 32 Breakdown of customers' withdrawals by category of use in 2010 (*AEEG, 2011a*)

- **Theft and grid inefficiencies detection**

The real time monitoring of the energy consumed in each node of the grid allows distributors to timely detect inconsistencies and thus detect problems on issues on the grid which imply improving the maintenance of the system and the detection of opportunistic behaviours (thefts). As explained while analysing the benefits, this is not possible in the gas sector given the inability to instantly balance the network

- **Security**

Enhanced security was one of the major goals pursued by electric distributors when deciding to implement the smart electric meters roll-out. Indeed the real time information provided by each meter allows the detection of inconsistencies therefore allowing to punctually identifying whether there is a security issue both in the grid and at customers households. Although circuit breakers allowed the automatic disconnection of electricity even before smart meters introduction, these enable the remote assessment of their causes and effects; thus eventually informing emergency agencies. Conversely, in the gas sector security functionalities are limited by the impossibility to provide real time information and to promptly localize issues on the grid.

To conclude, the performed analysis revealed that facing significant higher costs for the roll-out program (more than doubling them), the smart gas meter induces at most 50% of the smart electric meter's operative benefits and allows the realization of marginal non-operative benefits if compared with the electricity sector.

The electric smart metering shouldn't therefore brought as a model to exemplify the benefits of smart gas metering to avoid misleading conclusions.

7.4 Costs of smart metering

7.4.1 Qualitative assessment

Following, the costs deriving from the introduction of smart gas meter will be identified, discussing for each of them the economic mechanism through which they would be manifested, the actors of the supply chain impacted by these costs, the methodology and main parameters to take into account for assessing their economic value and a qualitative assessment of the impact in relative terms.

The estimation of the costs to be sustained are based on the assumption that distributors aim at merely fulfilling the 155/08 regulatory order, that is not envisioning the extra capabilities of the infrastructure which would result in modifying the entity of the following costs.

Costs
Meter costs
Smart meter acquisition cost
Smart meter installation cost
Information and communication costs
Information technology costs
Communication system costs
Maintenance & Operations costs
Data communication costs
Organizational costs
Skills and know how costs
Administrative costs

Table 26 Overview on smart gas metering costs

7.4.1.1 *Meter costs*

Given the detailed requirement of the 155/08 regulatory order which don't allow accomplishing telemetering through the installation of a retrofit kit to current meters, the roll-out program envisions the replacement of all domestic meters with a new full-functionality smart meter. The main cost items to be taken into account in this section are the costs of the equipment itself and the installation costs.

- **Smart meter acquisition cost.** The cost of acquisition of smart meters is the cost item that the most burdens on the profitability of the system roll-out and impacts directly DSOs. This is mainly due to the detailed and advanced characteristics required by the 155/08 regulatory order which introduced noteworthy novelties in the functionalities the smart meter should provide. In particular the required functionalities which raise the price of smart meters are:
    - The electrovalve: this functionality requires the integration of a valve inside the meter; it further requires installing a sensor in the pipeline following the meter to ensure there is no leakage once the valve is shut down. The cost of this extra feature is meant to cost between €15 and €20.
    - The temperature correction: this element involves the installation of a sensor inside the meter which monitors the temperature of the flowing gas and a processing application which computes at meter level the equivalent volume in standard cubic meters.

  These two elements represent a peculiarity of the Italian regulation which is not required by other European roll-out programs (a part from the electrovalve requirement in UK). Therefore meter producer have to develop a product dedicated to the Italian market, with obvious consequences on the price. Furthermore, the stringent time-schedule for the roll-out implies DSOs to deal with a few producers already present in the market with a low bargaining power. Indeed the production phase of most advanced meter suppliers just entered in the pre-industrialization phase. The regulator itself forecasted a decrease in meter costs of about 40% from 2012 to 2019 as it is shown on Table 27 reporting the standard costs foreseen by the regulator to be reimbursed to DSOs in relation to the year of installation (the costs in the table cover the meter costs and installation costs).

  The cost of the battery also influences the smart meter's cost as this element should leverage on new energy storage technologies and provide the maximum lifetime capabilities. The longevity of the battery, as seen in the technical specification section determines the profitability of the business case.

- **Cost of smart meter installation.** Smart meters' installation cost also represents a significant cost item to be taken into account as it requires specific skills and security procedures to be followed (setup for temperature correction – depressurization of the entire installation – tightness tests – etc.). This cost item is also sustained by DSOs and it encompasses labor costs, work force training costs, and R&D installation costs.

  Organizational issues also need to be forecasted when assessing the cost of installation; these might be related to the inaccessibility of the meter (because inside customer's household when the customer is not present) or customer reticence in allowing operator access their gas meter…

(€/ Meter)	G4	G6
2012	130	180
2013	125	170
2014	120	160
2015	115	150
2016	110	140
2017	105	130
2018	100	120
2019	90	115

Table 27 Smart gas meter standard cost from 2012 to 2019 (*AEEG, 2011c*)

Cost Item	Type of cost	Estimated impact	Stakeholder affected	Dependence on other items
Smart meter acquisition cost	One-time investment	High	Distributor	No
Smart meter installation cost	One-time investment	High	Distributor	No

Table 28 Smart gas meter related costs

7.4.1.2 *Information and communication costs*

These costs encompass the information technology costs, related software and adaptation costs; the communication system acquisition, installation cost and data communication cost; and the operation and maintenance costs of the all infrastructure.

- **Information technology costs.** As we pass from the need of managing one meter reading per year (and one withdrawal estimate per month) to one effective meter reading per day, the quantity of data that the IT infrastructure of DSO have to handle requires a redesign and acquisition of the all software and hardware infrastructure. The costs to be taken into account include costs for IT planning, as well as IT infrastructure for data management and storage, existing IT infrastructure adaptation costs, IT data protection, settlement and communication and retraining employees.

- **Communication system cost.** This item covers the costs for the communication system which is needed to send data from the client to the DSO and supplier. Therefore encompassing the acquisition cost of the required hardware and software infrastructure (concentrators, repeaters, translators, SAC) and their installation costs. This cost item strongly depends on the technology used by the DSO for field communication as this determines the number of concentrator per meter, the need of repeaters and translators, the longevity of the batteries both of repeaters and meters, communication rates...
  The entity of this cost are strictly related to the field peculiarities of the different installation areas and from the network architectures chosen by DSOs. Finally, a great portion of this cost is related to planning activities, as there is not a single infrastructure which can be

replicated everywhere, but the infrastructure should be modeled relatively to the specific area of installation. For an accurate assessment of the cost of the different possible architecture consult the communication section in the technological overview part (section 4.4).

- **Maintenance & Operation costs.** The entire installed infrastructure implies an increase of the maintenance costs of all DSOs' assets. In order to assess their magnitude we can distinguish between field maintenance costs and centralized system maintenance costs:
  - Field maintenance costs encompass the meters, concentrators, repeaters, and the entire field communication infrastructure and are very difficult to assess – even though there impact can be deemed high – as they depend on many external factors which are difficult to predict.

    Meters are subject to metrological regulation and therefore require an inspection once every 8 years for safety reasons. Furthermore the fact that most field devices are powered by batteries (a part concentrators which require higher energy supply and therefore might be powered by the electric grid) involves the cost of changing the batteries whether this expire. As stated in the technology part, meter supplier offer meters with battery which are meant to last up to 15 years in optimal conditions. But from the simulation performed with the Electronic and Information Department of Politecnico di Milano it resulted that accounting 8 years for the longevity of the battery could be realistic (cf. simulations in Figure 34 and Figure 35). Recalling that the metrological lifetime of a meter unit is 15 years, the battery longevity constraint involves a massive replacement operation to be undertaken in the middle of the meter unit lifetime. The replacement of broken meters should also be foreseen.

    For what concerns repeaters and concentrators similar maintenance costs are estimated – apart from security inspections and metrological requirements. In addition – as discussed in the communication part – since these devices are generally placed outside customer's households, the rent for the space occupied should also be considered. Finally, as has been illustrated by a pilot project undertaken by A2A in Brescia, organizational costs related to dealing with the public should be foreseen such as vandalism, or public reticence towards radio frequency communication (in the specific case, the interviewed manager enlightened that they had to face building administrators soliciting an economic counterpart for letting them installing a repeater in front of their building, or vandals who destroyed the concentrator they installed in correspondence of a public light spot with a cost of €300, etc). In the last section of the technological overview part an accurate assessment of the costs related to field issues is elucidated.
  - Centralized maintenance costs can instead be assessed much more reliably as they are independent (or almost independent) from external factors. They generally account for an yearly 10% of the total software infrastructure.

- **Data communication costs.** These costs depend on the frequency of communication, and on the type of technology used, on the DSO bargaining power towards Telcos, and on the rates applied by Telcos. The main costs (and benefit) of each different communication solution which could be taken are elucidated in section 4.3. The cost is entirely sustained by DSOs.

Cost Item	Estimated impact	Type of cost	Stakeholder affected	Dependence on other items
Information technology costs	High	One-time investment	Distributor	No
Communication system costs	High	One-time investment	Distributor	No
Maintenance & Operations costs	High	Recurring	Distributor	Communication system & IT costs
Data communication costs	Medium – Low	Recurring	Distributor	Communication system costs

Table 29 Information and communication related costs

7.4.1.3 *Organizational costs*

The innovation feature of the introduction of smart meters – having the ambition of achieving a world primate given the magnitude of the program – per se derives noteworthy organizational and managerial issues typical of innovation processes. Combining this factor in a context characterized by a highly traditional and conservative nature as can be described the gas sector, straightforwardly reveals the importance of considering organizational and managerial requirements assessing their cost impact. These can be subdivided in skills and experience that different actors in the gas supply chain should acquire and leverage on to efficiently face this breakthrough innovation, and the administrative costs associated to the smart meters roll-out.

- **Skills and know how.** This cost item particularly impacts DSOs which are the responsible of the roll-out program and encompass research and development costs, general management costs, and the acquisition of managerial, information and telecommunication skills. Indeed, distributor's organizational structure mainly leverages on strongly mechanical and technical resources. Managerial skills are also contained given the highly conservative context of operating; this leads to an increase of organizational costs needed to face the roll-out program but their precise quantification is a complex topic as they depend on specific organization's structure and competences, and require a comprehensive project risk analysis to value the impact and costs that a wrong decision in the initial pre-roll-out phase would cause to the system.

  It must be noted that many DSOs, given their organizational structure (60% of them employ less than 10 workers), will not be able to face these requirements and will therefore outsource roll-out activities to ICT companies experienced in the sector (cf. smart metering supply chain in section 2.3)[9].

[9] The interviews performed with leading distributors emphasized this issues, and revealed that major companies are also valuating the outsource option, even though some of those already enrolled telecommunication skilled personnel.

This decision would certainly result in a decrease of these issues, but is counterbalanced by the quality of the commercial offer brought by service companies.[10]

- **Administrative costs.** This item covers all administrative costs associated with smart meters rollout like increased costs from the call centre (detected exclusively in the transition phase), additional information and communication for the customer and general expenses related to the negotiation process with the upcoming new actors of the supply chain

Cost Item	Estimated impact	Type of cost	Stakeholder affected	Dependence on other items
Skills and know how costs	Low – Potentially high	One-time investment	Distributor	Outsource decision
Administrative costs	Low	One-time investment	Distributor	Outsource decision

Table 30 Operational costs

7.4.2 Quantitative assessment and comparison with smart electric metering

Following, the main cost items for smart metering development in the electricity and gas sector are evaluated keeping the same scheme of analysis used in the previous chapter.

- **Meter costs**

- **Acquisition cost:** The meter technology in the electricity sector is widely consolidated and the supply market is composed by many more actors; this makes the supply market characterized by a much greater degree of competitiveness, therefore reducing the price of the smart meter itself. Furthermore the security and legal metrological requirements are much less stringent in the electric meter. The cost of the smart electric meter is of about 45€ while the smart gas meter costs from 3 to 4 times more.
- **Installation cost:** The inspection requirement for higher security standards, the need of trained operators, the need of setting up the temperature corrector, the need of depressurizing the entire installation and of performing tightness tests are the main elements distinguishing the installation process for gas and electricity resulting in a greater burden to carry out this activity in the gas sector (the differential is estimated of around 30% additional costs for the installation of smart gas meters).

- **Information and communication costs**

- **Information technology costs:** These costs can be estimated equal in both sectors as there are no significant functional differences between the required IT infrastructure.

[10] The analysis of the service offer market (mainly performed through interviews to service providers) revealed a low attractiveness of commercial proposals given the high operational costs required (which could be a commercial strategy given small DSOs' low bargaining power). Finally, the reimbursement scheme foreseen by AEEG entails a convenience for DSOs towards the in-house management choice whether than outsourcing, even if this choice would imply a lower efficiency of the supply chain – but this issue has been detected by DCO 40/11 which ensured that adequate adjustment measures will be taken to solve that issue.

- **Communication system costs:** This cost item represents a crucial element of distinction between the two sectors; the fact that the electric distribution grid per se represents a communication infrastructure delineates the dissimilarity. As seen when assessing its impact on the gas sector this cost item depends on many other factors and parameters which need to be set in order to value it; therefore the cost of the communication infrastructure needed to transmit data from meters to DSOs can be 5 to 10 times higher.
- **Maintenance and operations costs:** The main difference between gas and electricity impacting on this cost item is the battery requirement. Indeed in the electric sector, power to feed field devices is provided by the grid itself; in the gas sector instead, the need of battery replacement leverages maintenance and operation costs. Indeed the meter's metrological lifetime accounting for 15 years, a battery replacement in each household within this time period seems unavoidable (probably in the middle of the meter's life: at the 8th year). Furthermore the complex architecture which needs to be foreseen for the transmission of data involves the installation of many more field devices which also impact on the maintenance costs. This can imply a 4 to 10 times higher costs (mainly because a massive battery replacement must be foreseen in the middle of the meter's lifetime).
- **Data communication costs:** Once again, the fact that the electricity grid is also a communication grid makes the distinction on the magnitude of this cost item between the two sectors. Depending on Telcos' commercial offers this difference could burden on the gas metering system, considering the best scenario, twice what it does in the electric metering system. However since this cost item strictly depends on the technical specification of the field infrastructure (e.g. frequency of data transmission, bi-directionality of the communication, distance between meters and concentrators, communication vector used, etc.), a rough estimation would result misleading.

➢ **Organizational costs**

- **Skills and know how costs:** To accurately distinguish the impact of this item in the two sectors it must be noted that the electricity system being more related to electronics than the gas system could be a little advantaged. Although the innovation factor was present in the electricity sector as much as in the gas sector. Furthermore this cost item depends on the organizational structure of the specific company and therefore is difficult to compare it across sectors.
- **Administrative costs:** These costs can also be deemed equal in both sectors as the discussed parameters used for its assessment are substantial similar.

Cost Item	Impact in the Electricity sector	Type of cost	Comparative assessment (gas - electric)
Smart meter acquisition cost	High	One-time investment	++
Smart meter installation cost	High	One-time investment	++
Information technology costs	Medium	One-time investment	=

Cost Item	Impact in the Electricity sector	Type of cost	Comparative assessment (gas - electric)
Communication system costs	Medium	One-time investment	+++
Maintenance & Operations costs	Low – Medium	Recurring	++
Data communication costs	Low	Recurring	++
Skills and know how costs	Medium	One-time investment	=
Administrative costs	Low	One-time investment	=

Table 31 Costs comparative assessment

Letting aside the skills and know how costs – which as elucidated are strongly dependent on the organizational structure of the distributor and on the make or buy decision – the following graph illustrates the comparison between the total Capital expenditures for rolling-out smart meters in the electric sector to the simple cost of acquiring and installing smart meters in the gas sector. Figure 33reports the investment costs for the roll-out of smart meters in 100,000 domestic households. The figure emphasizes how just by considering the cost of acquiring and installing smart gas meters, the investment results 135% greater then the overall capital expenditures needed to roll-out smart electric meters.

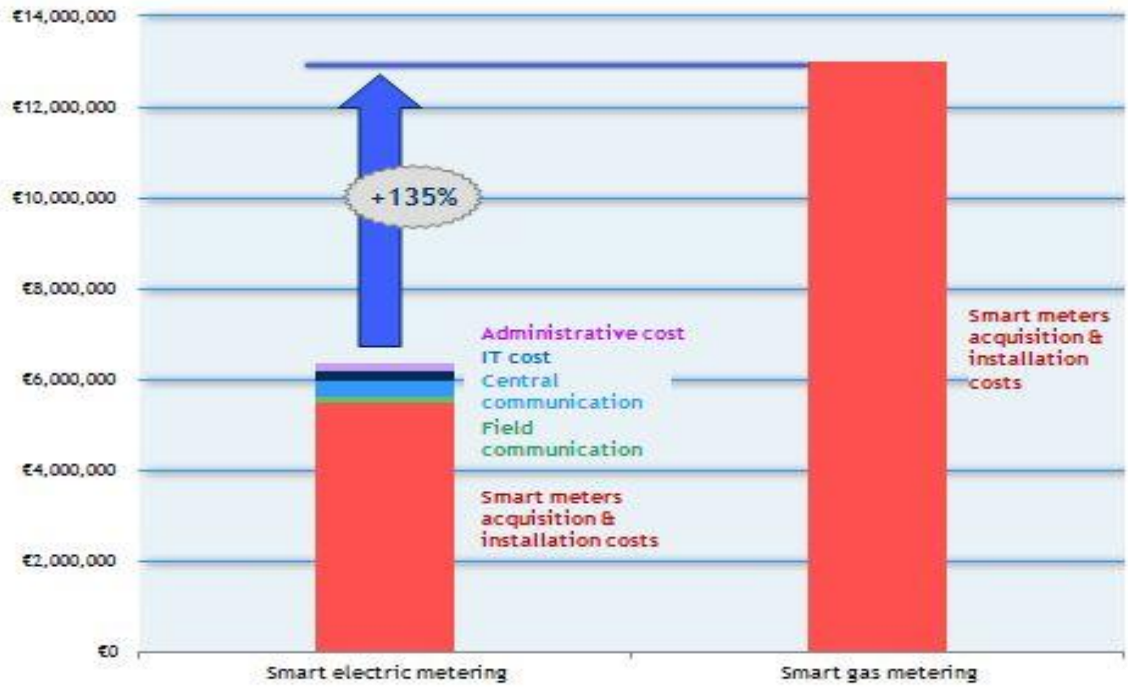

Figure 33: Capital Expenditures comparison between the electricity and gas sectors

In parallel, for what concerns operating costs, these appear to burden significantly on the profitability of the business case. The item which worsens this figure is the maintenance of the equipment, including concentrators, repeaters, translators of signal, and the requirement of changing the battery to the meter in the middle of its useful life (representing a massive project similar to the initial installation). Although this cost hasn't been quantitatively assessed in this analysis through an activity based costing methodology, by reviewing the DCO 17/11 (AEEG, 2011b) it is noticed that the differential operating costs deriving by the introduction of smart gas meters in the domestic market recognized by AEEG on distributors tariff rates accounts for an incremental €10 per metering unit per year.

7.4.3 Considerations and simulations on the battery lifetime

The core critical element for all categories of meters is the duration of the battery**.** In fact remarkable progress are being made in the field of energy storage, representing at the present time one of the key strategic research topics set by the international community (EU 7th framework program, 2007). Conversely at present the most promising technology seems to be lithium batteries which are used by meter suppliers and seem to last up to 15 years in optimal conditions. Batteries lifetime depend on many external factors such as temperature of use, ambient temperature, relative humidity, etc. besides these issues, the many functionalities required and the uses that DSOs intend to make of the meter significantly impact on the battery lifetime: the number of times the radio frequency module is connected for data transmission, the type of communication protocol used, its radius, the use of the electrovalve, etc.

During the analysis various DSOs were interviewed, and the duration of the battery resulted for the construction of the business plan the biggest concern. The leader DSO Italgas performed a pilot project which started in 2009 with 100.000 smart meters installed using different technologies and suppliers, and the battery dead rates (after 3 years from the installation) were surprisingly high, conversely to suppliers meter specification. This issue led the analysis to focus on the battery lifetime and some simulation were performed considering different frequency of communication and different communication technologies in order to get a more complete view on the topic (not just relying on suppliers meter features).

The simulations were performed with the Electronic and Information Department of Politecnico di Milano considering two scenarios in order to appreciate the impact on the battery lifetime of increasing the frequency of communication windows. Scenario A considers a communication with the meter through a communication window of 3 minutes per day, while scenario B considers a communication window of one minute each hour. The analysis has been performed considering a bidirectional communication, a lithium battery of 4A/hour of the dimension of 3.5cm x 5cm x 1 cm (the battery which will most probably be used by meter suppliers) which resulted in a cost of approximately 20 Euros. Simulations have been carried out considering four different communication vectors:

1) Mod. WM-Bus RF 868MHz (25mW / 1.5Km – 100Kbps)
2) Mod. WM-Bus RF 868MHz (500mW / 4Km – 38.4Kbps)
3) Mod. WM-Bus RF 169MHz (5Km – 38.4Kbps)
4) Mod. GSM-GPRS Qb (4Km – 250Kbps)

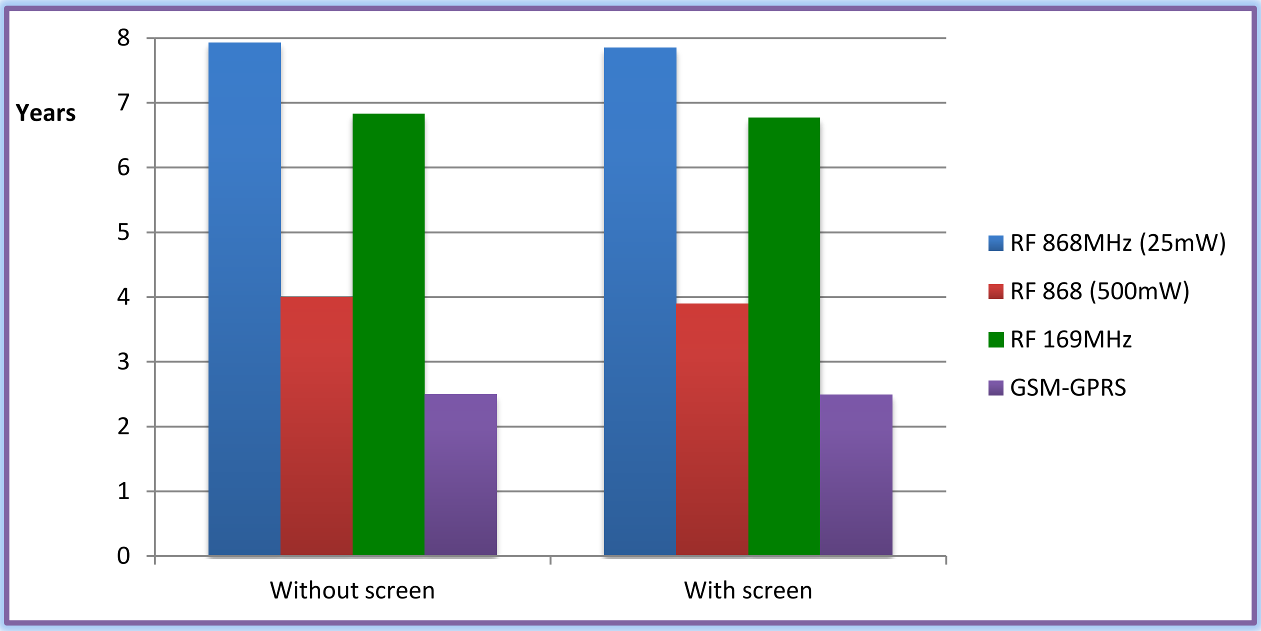

Figure 34 Battery lifetime in scenario A

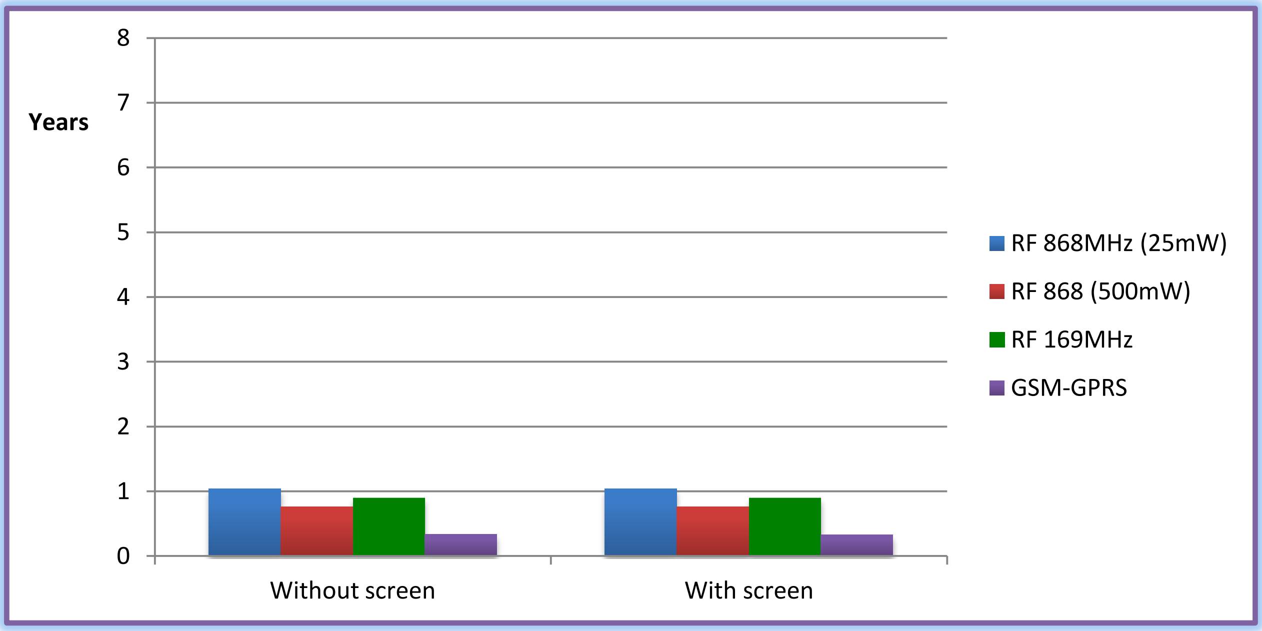

Figure 35 Battery lifetime in scenario B

Figure 34 and Figure 35 show how communication vectors 1) and 3) present a lower battery utilisation rate and therefore result as being the most suitable communication vectors for gas metering. Scenario B clearly elucidates why a real time communication can't be foreseen; this would require a change of batteries each year, with obvious effects on the sustainability of the business case. The performed simulations also underline the marginal impact that feeding the screen has on the longevity of the battery.

7.5 Conclusions and qualitative comparison between costs and benefits

Table 32 illustrates the major benefit and cost items impacting on the different actors. This table emphasizes the misalignment between actors perceiving the benefits of the roll-out and the ones required to sustain its investment. To this respect, a clarification needs to be done, indeed the actors sustaining the direct investment are DSOs; however, this cost will be reimbursed through higher tariffs, therefore reversing the cost on to consumers. Hence the better-off result to be suppliers.

	Distributor	Supplier	Consumer
Benefits			
Lower mandatory reading costs	X		X
Elimination of the auto-reading process		X	X
Reduced switching procedures and other commercial readings	X	X	X
Remote deactivation of supply	X	X	
Remote enablement of activation	X	X	X
Higher transparency and competitiveness of the market	X	X	X
Reduced call centre costs and provisions for contentious		X	
Reduced arrears		X	
Knowledge on unaccounted gas volumes	X		
Distribution grid maintenance and improvements	X		
Leakage and theft detection	X		
Customer profiling and new service provision	X		
Overall consumption reduction		X	X
Shift in consumption patterns	X	X	X
Reduction in CO2 emissions		X	X
Costs			
Smart meter acquisition cost	X		
Smart meter installation cost	X		
Information technology costs	X		
Communication system costs	X		
Maintenance & Operations costs	X		
Data communication costs	X		
Skills and know how costs	X		
Administrative costs	X		

Table 32 Cost and benefit impact on the various actors of the supply chain

The analysis revealed that the benefits of the smart gas metering shouldn't be sought in the operating activities of the distributor. Indeed, the study revealed that the roll-out of smart gas meters, besides implying massive capital investments from the distributor, increases the operating costs of the activities impacted by the smart metering introduction. Figure 36 depicts this issue with the standard costs provided by the AEEG in what concerns operating activities. The graph shows how in the electricity sector, conversely, the attractiveness of the investment is derived by the significant reduction of operating costs (68% reduction as shown in Figure 36).

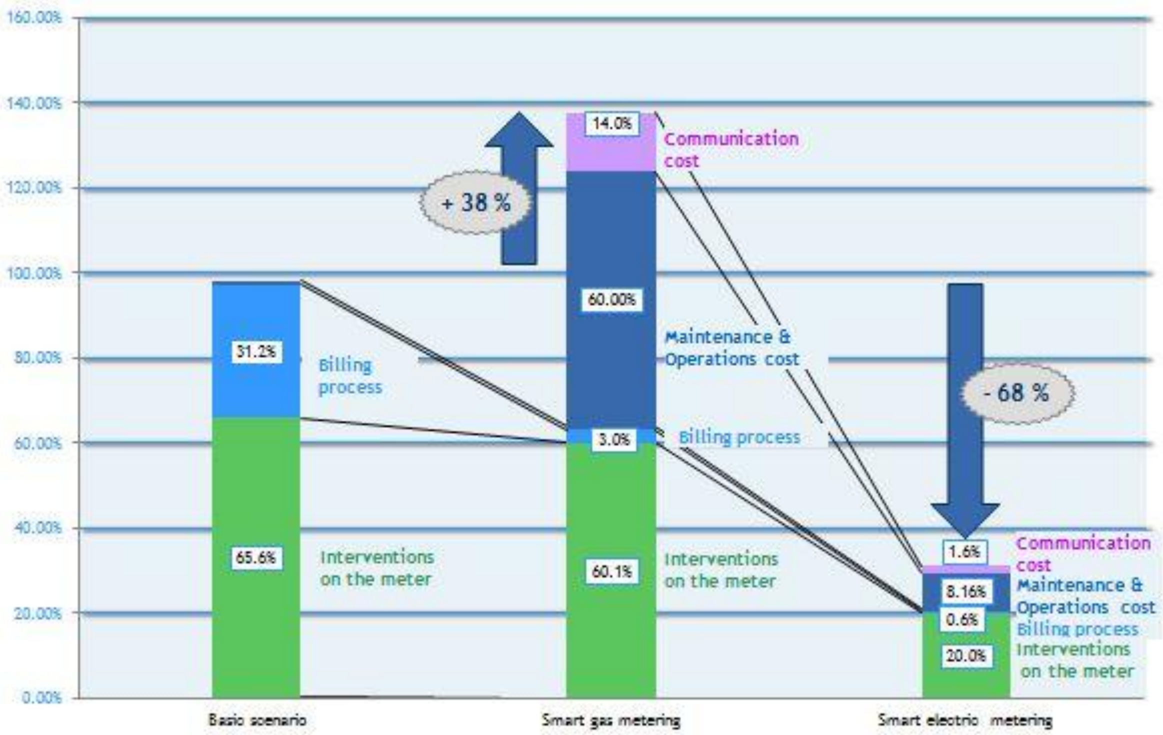

Figure 36: Operating costs and benefits of the smart metering roll-out in the gas and electric sectors

The cost-benefit analysis undertaken by the Authority (AEEG, 2008) focusing on the costs and benefits related to the distributor, as responsible for the metering service therefore seems to limit the boundaries of the analysis. Conversely, the value of the smart gas metering introduction should be sought considering the system as a country (including suppliers, distributors and consumers), with a particular emphasis on consumers. Indeed, the qualitative assessment exposed the potential positive impact of triggering a change in consumers' gas consumption. However, to enable this trigger, an appropriate interface with the client should be deployed, but the obligations of the AEEG do not consider this phenomenon.

Furthermore, the analysis emphasized that the business case has to be carried out on a long time horizon (15-20 years) deriving significant repercussions on customer's bills, therefore suggesting to reconsider the timing of the roll-out plan. Indeed, the cost benefit analysis of the AEEG doesn't evaluate the sensitivity of the obtained results to the timings of the roll-out plan. In particular, being the first movers in this technological innovation process – conversely to the electric sector where operative benefits justified the early implementation – doesn't derive any benefits for the country. In fact, the spontaneous technological research trend is expected to produce in the next future a new generation of metering devices with augmented capabilities at lower costs. In addition, the smart metering investments undertaken in foreign countries would certainly derive positive impact on the technological development of the smart metering infrastructure as learning economies are generally relevant in the initial of introduction of a new technology. Thus projects launched later can leverage on the experience and know-how gained from the first movers. Finally, as the technology matures, the competition on the supply market of metering units should increase, thus reducing the overall cost of the project (recalling the great incidence of the meter acquisition cost on the overall Capex investment).

Finally, it can be stated that the electric smart metering case shouldn't be brought as a model to exemplify the benefits of smart gas metering to avoid misleading conclusions.

7.6 International comparison

Undoubtedly there is still little experience and availability of information regarding the use of smart meters both in Italy and abroad, especially in the gas sector. It therefore reveals crucial investigating whether – and how – other countries are preparing the introduction of a national smart gas metering roll-out, for example through consultations, pilot projects or cost-benefit analysis.

At present, only Italy and the United Kingdom have set a clear plan for the roll-out of smart gas meters, while 4 other countries (France, Ireland, Netherlands and Slovenia) are still discussing on the opportunity to do so. Others – the vast majority of European members – yet didn't accomplish the cost benefit analysis to determine whether this option results economically sustainable or not. A first quick analysis suggests that, compared to Italy, other countries are moving with greater caution regarding the timings and the methods set in place to achieve the smart gas metering roll-out. In fact Italy seems to be the only country which set a roll-out time schedule so detailed and ambitious.

Following, the on going initiatives in the two most advanced countries in the smart gas metering implementation after Italy will be analysed, discussing their cost and benefit analysis.

7.6.1 United Kingdom

The United Kingdom is the only country apart from Italy which has already scheduled a roll-out program. Indeed the decision-making process started in early 2006 by the two regulatory bodies OFGEM (Office of the Gas and Electricity Markets) and DECC (Department of Energy and Climate Change). The required functionalities of installed gas meters are less stringent than the Italian ones as the temperature correction is not foreseen to be integrated to the meter – the correction will be performed through sensors in the household and the information will be elaborated through the In-house-display. However UK is the only other member state which foreseen the obligation of installing an electrovalve on future gas meters.

As for the communication system, DECC intends to create a new regulated company for the acquisition of data in the field and transmission to all parties with relative credentials (DataCommsCo or DCC). The DCC will be responsible for the provision and management of both smart electric and gas meters' data and services communication. The creation of such a body is expected to significantly reduce the cost of the roll-out program as economies of scale and of scope will increase efficiency and effectiveness of the activities.

To support the decision making process OFGEM mandated the realization of a pilot project with the objective of assessing the appropriateness of providing to each household an In-House-Display (IHD). This device is a user friendly display to be located inside each household which is directly connected to both the electrical and gas meter and provides consumption information feedbacks to the user. The pilot project involved installing both gas and electric smart meters in 18.000 households between 2007 and 2010, and proved that household's owners where an IHD was installed allowed an average 2% reduction in overall gas consumption; it also underlined that these results were achieved only in households where the energy consumption was provided in terms of its cost and that whether the information was provided through an internet portal, no significant results were revealed.

The roll-out program foresees a joint roll-out for both electricity and gas (Dual Fuel) to leverage on synergies for the installation process (installing only smart gas meter would cost 49£/meter and exclusively a smart electric meter 29£/meter; while the joint installation is estimated to cost 68£/meter resulting in a reduction of 10£/meter) and the communication system. The outcome of the cost-benefit analysis emphasized an economic loss for the gas domestic sector only (of 1.412£ between 2011 and 2030), while if considering the entire gas and electricity system the picture changes significantly (net benefit of 5.070£ as shown on the Table 33 Cost-Benefit analysis results in the UK (*DECC and Ofgem, 2011a*); DECC and Ofgem, 2011a, DECC and OFGEM, 2011b). As a result, in 2011 the regulator mandated the roll-out (DECC and OFGEM, 2011c) which should start in 2014 and involves the installation of 53 millions smart meters both electric and gas within 2019.

		Domestic sector	Non-domestic sector	Total
Gas only	**Benefits**	9.345	612	9.957
	Costs	10.757	574	11.331
	Net benefits	**-1.412**	38	-1.374
Dual Fuel	**Benefits**	15.827	2.84	18.667
	Costs	10.757	574	11.331
	Net benefits	5.070	2.266	7.336

Table 33 Cost-Benefit analysis results in the UK (*DECC and Ofgem, 2011a*)

7.6.2 France

The French position in what concerns smart metering in the gas sector was expressed through the resolution of 3 September 2009 of the Commission de Régulation de l'Énergie (CRE, 2009) and in the recent consultation (Pöyry and Sopra Consulting, 2011), emitted after the availability of the first results of the trial launched in 2010 involving 18.500 domestic consumers, which involved the use of four different communication technologies and meters pertaining to four different vendors. A further large scale pilot project (involving 100.000 domestic consumers) is planned and will be undertaken by the biggest French distributor – covering 96% of the market – which will end in 2014. Depending on the results of this project, the decision whether to enact the mandatory roll-out plan which would involve completing it by 2020, will be taken or not.

So far, the French configuration presents significant lower functionalities than the Italian one as no electrovalve will be requested, and neither the temperature correction; while the sustainability of the IHD for the business case is currently being assessed. It should be noted that, whether the IHD will not be required, the French regulator envisions the provision of information at most on a daily basis through an appropriate web page.
The cost-benefit analysis performed by Poyry Consulting in 2011 within next 20 years outlines how without the involvement of the final consumer – and therefore the reduction in consumption – the business case would result significantly negative (passing from -€150 millions to €7 millions as shown on the graph of Figure 37 Outcomes of the french cost-benefit analysis (*Pöyry and Sopra Consulting, 2011*)). Finally even if economic models are not yet developed, the French analysis envisions the possibility of creating a major benefit item through the provision of new value added services (resulting in a further increase of €305 millions).

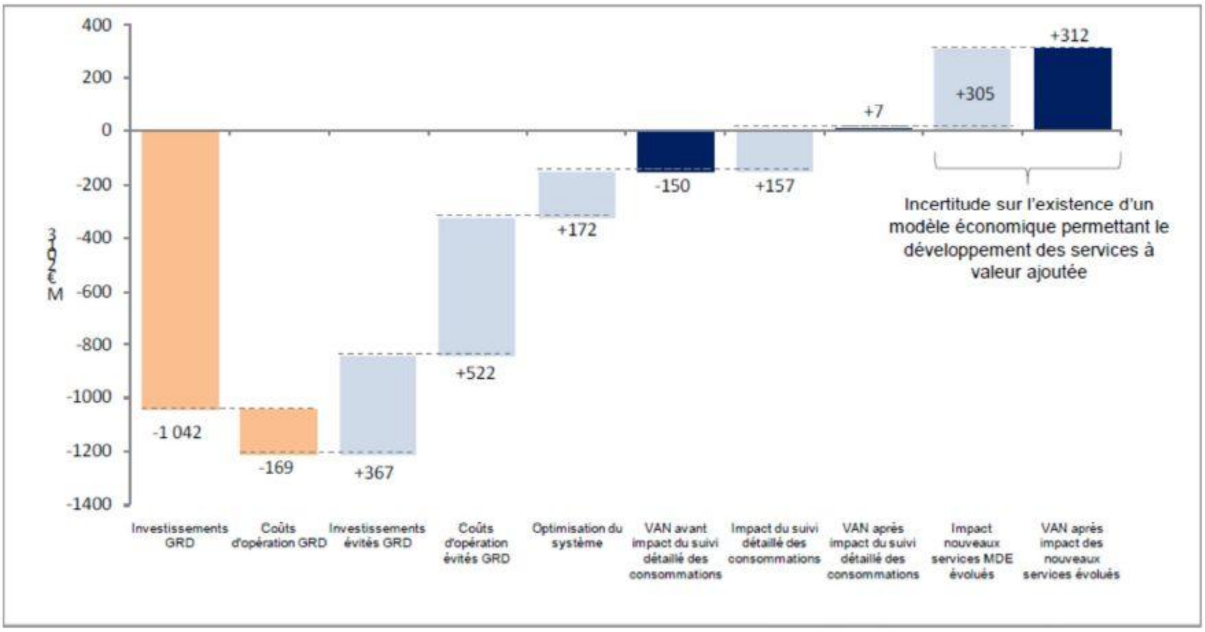

Figure 37 Outcomes of the french cost-benefit analysis (*Pöyry and Sopra Consulting, 2011*)

The following table reports the differences between the three most advanced countries in what concerns smart gas metering activity to better understand the resulting differences in the cost benefit analysis above discussed.

	Italy	France	UK
Compulsory	Yes	To be defined following results of pilot projects	Yes
Timing	Roll-out mandated in 2008 To be completed by 2018	Whether the assessment results positive; roll-out between 2014 and 2020	Roll-out mandated in 2011 To be completed by 2019
Investment	Borne by Distributors (presence of many small distributors: 245)	Borne by distributors (market very concentrated)	Borne by the supplier

	Italy	France	UK
Meter characteristics	• Electrovalve • Temperature correction • No constraint for the IHD	• No electrovalve • No temperature correction • IHD presence under assessment	• Electrovalve • Temperature correction undertaken through LAN • Mandatory IHD provision
Integration with the electric smart meter	Under assessment after the emission of consultation paper 40/11	No integration	Joint roll-out
Data communication	Depends from distributors decision whether to outsource	Will be defined through the currently pending "construction of the solution"	Regulated created company to manage all meter's data communication

Table 34 Comparison of smart metering initiatives in Italy, France and UK

Chapter 8 - Internet of things: an enabler for Smart Cities

This chapter will first illustrate the importance of the "smart city" concept towards solving major issues and criticalities characterizing our time. Following, a comprehensive investigation of the main IoT fields of application encompassed by the smart city concept will be pursued. The analysis is based on the case study tool – both direct and indirect – with the objective of assessing the state of art picture of each field of application's development, judging their adherence to the IoT paradigm and their maturity and diffusion to better value their future growth opportunities.

8.1 Premise

To quote Wellington E. Webb, former mayor of Denver: “The 19th century was a century of empires. The 20th century was a century of nation states. The 21st century will be a century of cities.”

Indeed the emerging needs and trends characterizing current times – the increasing urbanization, the continuous quest for economic growth, the emerging sensitivity towards environmental sustainability, the breakthrough technological development – foster the attention on the capabilities, functionalities and services that future cities should be able to provide to their citizens.

Urban performance currently depends not only on the city's endowment of hard infrastructure (the so called 'physical capital'), but also, on the availability and quality of knowledge communication and social infrastructure ('intellectual and social capital').

Forrester defines the smart city as:

“The use of Smart Computing technologies to make the critical infrastructure components and services of a city — which include city administration, education, healthcare, public safety, real estate, transportation, and utilities — more intelligent, interconnected, and efficient.”

While for Smart Computing, it intends:

“A new generation of integrated hardware, software, and network technologies that provide IT systems with real-time awareness of the real world and advanced analytics to help people make more intelligent decisions about alternatives and actions that will optimize business processes and business balance sheet results.”

This quote clearly emphasizes the opportunities and possibilities offered by the Internet of Things paradigm which represents a necessary requisite to facilitate the development of smart cities. Indeed Internet of Things paradigm allows the realization of a ubiquitous infrastructure made of objects aimed at sensing the needs of cities and citizens through their real-time context awareness.

The current chapter will consequently first illustrate the importance of the “smart city” concept towards solving major issues and criticalities characterizing our time. Coherently with the scope of this work, the aim is not to examine the smart city model at 360° but understand whether there are opportunities for the smart gas metering infrastructure to exploit synergies in what concerns the communication infrastructure. Therefore, a comprehensive investigation of the main IoT fields of application (all characterized by the need of a communication infrastructure) encompassed by the smart city concept will be pursued. The analysis is based on the case study tool – both direct, through interviews to project personnel and indirect, mainly through projects’ information available on the web – with the objective of assessing the state of art picture of each field of application’s development, judging their adherence to the IoT paradigm and their maturity and diffusion to better value their future growth opportunities.

8.2 An increasing sensitivity towards smart cities

8.2.1 Increasing need of smart cities

An urgent need is characterizing cities worldwide to become smarter in the way they manage their infrastructure and resources to deal with the existing and future needs of communities. Concurrent trends in urbanization, economic growth, technological progress, and environmental sustainability are the drivers for this spanking urgency.

- **Urbanization**

  At present, more than 50% of the world's population lives in cities. By 2050, this number is going to increase to 70% due to growth in the current cities and migration from rural areas, according to the UN forecasts. Some of this growth will be in 27 megacities with greater than 10 million people, but more than half of this growth will occur in cities that currently have fewer than 500,000 people. The need to become smarter therefore involves every city, which is called at setting its strategic objectives to face long term urbanization as urban infrastructure is increasingly experiencing noteworthy stress (just think to traffic congestion, pollution, economic downturn, etc.). Existing cities will be hard-pressed in renewing their infrastructural components in order to provide value added services to their citizenry, while emerging cities will face green field development challenges.

- **Economic growth**

  The top 100 urban conglomerations currently account for 25 percent of worldwide's gross domestic product. By aggregating people in the same area while providing them with services and opportunities distinguishing the urban environment cities fuel creativity and entrepreneurship, which further encourage the economic activity. While the developed world has underinvested in its cities, the developing world by some estimates will need $40 trillion by 2030 for its new urban infrastructure, which presents remarkable innovation opportunities.

- **Technological progress**

  ICT advances have revolutionized all aspects of life. Two billion people use the Internet, and more than five billion are mobile subscribers. There are 30 billion RFID tags embedded in our world and a billion transistors per human, each costing one ten-millionth of a cent. Figure 38 The three cycles of technology growth and digestion (*Forrester Research, 2009)*shows the three cycles of technology growth and digestion highlighting the increased importance of the upcoming technological smart computing cycle in terms of investments-to-GDP ratio

  This convergence of pervasive sensing and networking, wireless connectivity, and cheaper, faster, smaller computers are enabling the emergence of the internet of things paradigm, which – as discussed in the first chapter of this thesis – is not a vision anymore, but represents a reality of our times in full development (even if in its initial phase). These progresses make it easier for city actors to intelligently control systems and empower people.

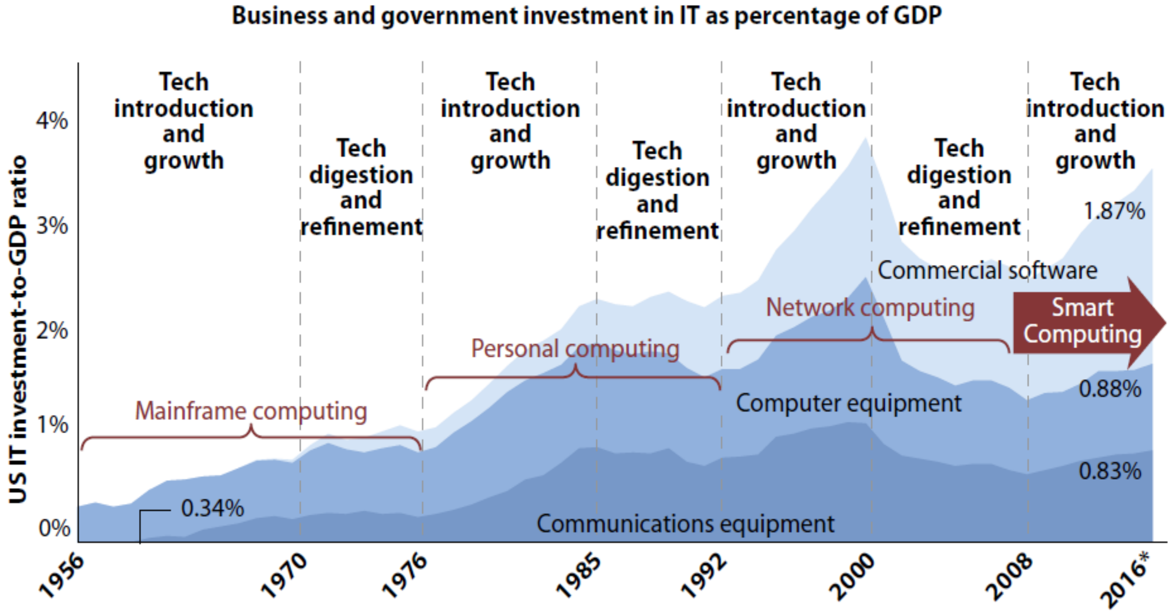

Figure 38 The three cycles of technology growth and digestion (*Forrester Research, 2009*)

- **Environmental sustainability**

  There is evidence that human activity has caused unprecedented environmental change, and population growth will soon stress the world's natural resources to the breaking point. Global warming, air pollution, land degradation, declining per-capita availability of fresh water, food shortages, and reduced biodiversity are some of the starkest challenges. The need for better controlling human's impact on the planet is increasingly stringent and induces cities – which play a crucial role in mitigating the effects of climate change, all the more so when considering that 80% of energy consumption and CO2 emissions is associated with urban activity – to rethink and redesign the processes harming the environment at the base of their conception. Some priorities that current cities are pursuing for tomorrow's sustainable development are the sustainable mobility, the sustainable and efficient use of energy and the sustainable citizens living patterns (through a citizen's responsabilization and awareness of environmental issues)

8.2.2 The environment as the driver for a cascade set of initiatives: from intergovernmental institutions to local administrations

International organizations and governments, being the entities most devoted towards the long term human's sustainability result concerned about the issues harming our environment. These concerns are translated into initiatives and directives set at various levels of the world's leading actors which we will analyze in this section: from UN and international organizations (G20, OECD, etc.), to Europeans initiatives, to government directives, until regional and local administration plans.

Countless intergovernmental initiatives and discussion have been undertaken in last decade addressing environmental issues. From the millennium development goals set by the UN where the environmental sustainability represents one of the 8 priorities to overcome global issues, translated into actions for its various organizations (UNEP – UNIDO – UNDP – WB funding – etc.); to the G20 Washington summit in 2008 calling for OECD countries to join discussion table for a coordinated answer to environmental issues.

At EU level, considerable effort has been taken to formulate policies for the translation of the world's priorities into directives in what concerns environmental issues. These goes from the setting of the 20/20/20 goals which involves a reduction of 20% of emissions, 20% improvement in energy efficiency and 20% increase in renewables by 2020, to the formulation of the Third Energy Package setting in details the instruction for sustainable energy processes and usages. The formulation of the 7th Framework Program was also developed around this issue, and marked the appearance of the smart city model – leveraging on the information and communication technologies progresses – to face those issues through projects and research funding in the area. In fact, it allocated €12 billion for the realization of 25-35 smart city projects which aim at reducing their CO_2 emissions of 40% by 2020. The upcoming 8th Framework Program will further power and foster the development of that model by providing drastically increased funds.

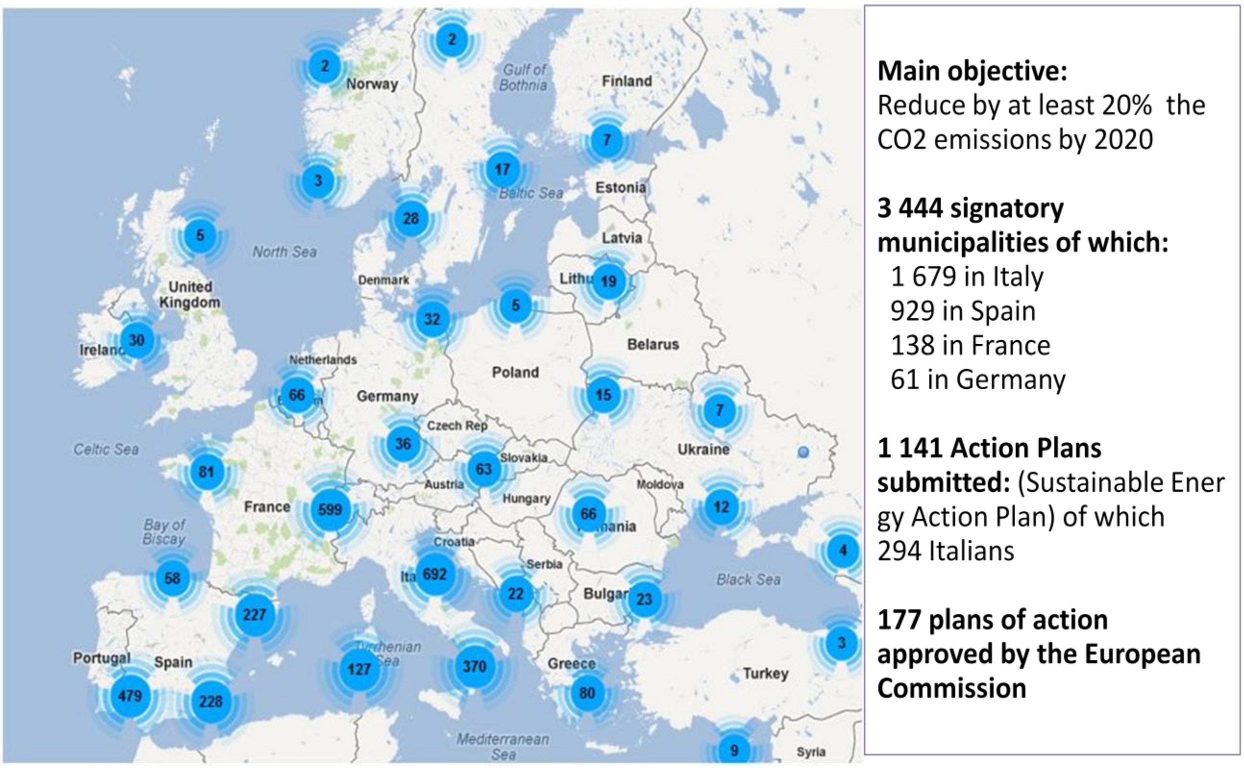

Figure 39 Covenant of Mayors map (*Source: www.eumayors.eu*)

A major initiative which was launched by the European Commission after the adoption of the EU Climate and Energy Package in 2008, is the Covenant of Mayors to endorse and support the efforts deployed by local authorities in the implementation of sustainable energy policies. It represents the mainstream European movement involving local and regional authorities, voluntarily committing to increasing energy efficiency and use of renewable energy sources on their territories. By their commitment, Covenant signatories aim to meet and exceed the European Union 20% CO_2 reduction objective by 2020. The map in Figure 39emphasizes the magnitude and incidence of this covenant in Europe.

At country level, smart cities initiatives are led by a combination of environmental concerns and economic growth opportunity. The long term infrastructural and investment projects envisioned in US, Japan, China and fast growing economies (Singapore – South Korea – Dubai – Indonesia – etc.) for building new intelligent cities (Figure 40 illustrate some examples of brand new constructed cities) or city district clearly reveal the strategic importance of focusing on the urban context.

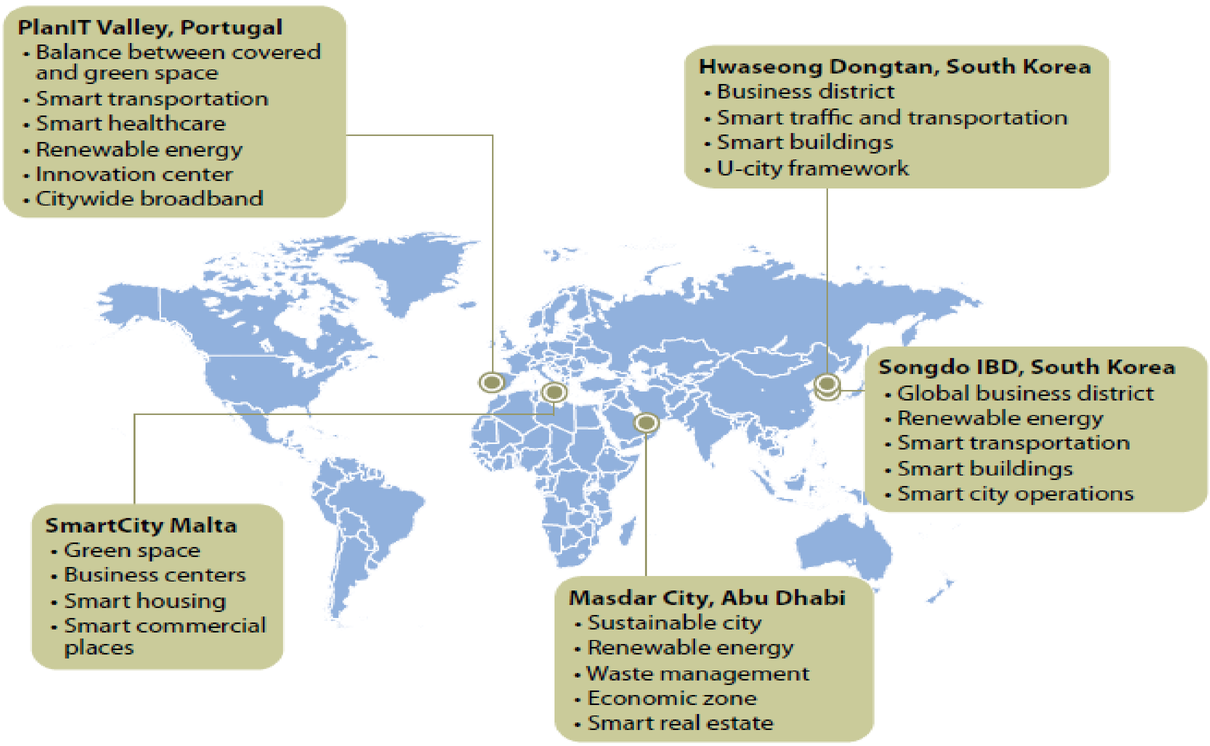

Figure 40 New intelligent cities built using the smart city concept

In Italy, the degree of development of the smart city model presents some significant differences among regions and cities, mainly due to difference in the infrastructure endowment although it is the European country with more signatories to the Covenant of Mayors (at present, signatory cities are 1807). This issue was emphasized with the emergence of the new government in Italy (Mario Monti’s government) and seems to be a result of the absence of a detailed digital agenda for the country. To overcome this issue, the Infrastructure and Economic Growth Minister Corrado Passera issued in January 2012 a consultation paper through the Italian Authority for Communications Guarantees AGCOM (Autorità per le Garanzie nelle Comunicazioni) stating the upcoming issuing of a detailed digital agenda. In the consultation paper emerges the centrality of the smart city model for the design and realization of the strategic objectives for the country. (Passera, 2012)

8.3 IoT in the smart city: application fields

A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rail/subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens. Emergency response management to both natural as well as man-made challenges to the system can be focused and rapid. With advanced monitoring systems and built-in smart sensors, data can be collected and evaluated in real time, enhancing city management's decision-making. Internet of Things solutions are therefore a precious enabling factor for the realization of smart cities. Following the different smart city fields of application will be analyzed with the objective of assessing the state of art picture of each field of application's development, judging its adherence to the IoT paradigm and its maturity and diffusion to better value its future growth trends. This analysis has been carried out through the case study tool, 62 projects have been analyzed (17 of which through direct interviews) for a total of 84 Internet of Things applications.

The adherence to the Internet of Things paradigm is evaluated on the basis of:

- Use of open technological standards for the communication between nodes and between nodes and the network
- Accessibility of the data (to the highest number of users and developers, within data confidentiality constraints) and reachability of the object, not just to its relative data
- Multi-functionality, i.e. the '"intelligence" of the application

While the maturity of a given field of application could be:

- Consolidated: technological solutions are available on the market and their value was demonstrated
- Experimental: technologies are yet to be developed, and/or the impact on processes and value is yet to be appreciated
- Embryonic: the concept is being developed, trials or completed projects are missing or are limited

8.3.1 Smart energy and smart utility

The inefficient use of energy is a primary cause of excessive CO2 emissions. The Internet of Things paradigm allows monitoring and controlling its uses from generation to consumption in different sectors.

- **Electricity management**

The interest in this sector is driven by strong public investment related to national or supranational objectives (use of renewable sources, reducing consumption, reducing greenhouse gases, increasing network efficiency, etc.) and can be subdivided into two major categories – not distinguishable in nature as the first is a requisite for the second one.

  - **Smart metering:** The smart meter enables telemetry – which allows invoicing customers on real consumption, setting different prices in different time slots, etc. – and thanks to the actuating function the remote meter management (e.g.enabling or deactivating the electricity provision remotely). The electric Smart Metering is already a reality in Italy since several years and puts the country in the forefront in Europe and the world on this topic boasting over 32 million smart meters.
    In the smart metering projects undertaken abroad – as well as in pilot projects undertaken in Italy for the design of the second generation smart metering solution to be enrolled in 2016 – there is a growing attention to integration with the domestic world

  - **Smart Grid:** This field of application is still in its embryonic stage of development. The transition towards smart grid is a long and complex process which requires the collaboration of different actors in the electric supply chain (distributors, power plants, consumers, power suppliers, etc.). Smart grids are enabled by the presence of smart meters, and are meant to manage the distributed generation; automate the demand management; introduce large-scale electric mobility.
    Although in a small scale, we are witnessing the first smart grid pilot projects both in Italy and abroad (eg Isernia in Italy and Rome Malagrotta, MeRegio in Germany, UKCustomer Led Revolution in networks, NiceGrid in France). In parallel numerous initiatives to test and promote electric mobility are emerging (e.g. Mi Muovo Elettrico in Emilia Romagna, eMobility in Rome, Pisa and Milan, e-Vai in Lombardy, ZEC – Zero Emission City in Parma). The proper involvement of consumers resulted to be a key element for the success of projects (e.g. Google Power Meter is an example of failed initiative because the information to consumers was provided with delays and variable frequencies)

- **Water management**

Smart Metering projects meant at supporting the management of water supply are less common than the several initiatives in the electricity or gas sector. This is mainly due to the lower cost of the resource (water). However the major inefficiencies characterizing the Italian water grid might trigger the Authority to pursue some regulatory initiative. In the (few) projects undertaken, the focus is placed on the overall network efficiency and losses reduction as well as on the effective billing system based on actual customers consumptions (e.g. Outsmart - Cluster of Trento, Wide Bay Water Corporation - Australia) Smart Gas Meter may be a strong force for the deployment of smart meters for water, whether the communication infrastructure chosen can be shared.

- **Heat management**

In this case the Internet of Things enables both to monitor and control the heating distribution grid, and to remotely measure energy consumptions; the following subdivision of the undertaken initiatives can be performed:

- **Smart metering:** The smart heat meter enables telemetry – which allows invoicing customers on real consumption, setting different prices in different time slots, etc. – and thanks to the actuating function the remote meter management (e.g.enabling or deactivating the electricity provision remotely). A powerful stimulus towards its roll-out can be given by the legislation, which provides in some regions (e.g. IX/2601 resolution of the Lombardy region of 30.11.2011) the requirement of punctually measuring the heat used for heating and for hot water from each individual household that share the same thermal system with other users.

- **Smart grid:** In the heating sector there is a smart electric grid equivalent as the heat generation can be distributed (perhaps through solar thermal panels) therefore implying the need of an intelligent network management to balance demand with available resources. The interest towards Smart Thermal Grid arises from the aspiration at reducing the amount of "valuable" energy used for the production of heat. Indeed this suggests the use of innovative production processes (cogeneration, recycling heat produced in industrial processes, solar thermal, etc.). District heating systems are spreading in different Italian cities (e.g. Torino heats 70% of the city through cogeneration thanks to its major industrial plants; Brescia), but projects of Smart Thermal Grid are still at an embryonic stage although there are great expectations on their outcomes (e.g. Politecnico di Torino-Iren; Smart Grid per la Sapienza in Rome)

- **Waste management**

Within this field of application, the Internet of Things presents substantial opportunities as it can enable the identification of bins and rubbish sacks (e.g. automatic identification and simultaneous weighing of bins for control or reporting activities); it can monitor the waste level inside garbage cans and communicate it to collection trucks or control centers (through a sensor measuring the filling level or an odor sensor); it can enable fleet management opportunities (perhaps verifying the actual performance of different activities). As a result it allows utilities to assess the quantity of waste contained in each garbage can, thus enabling:

- Route optimization of garbage collectors (reducing costs, improving service quality by avoiding the persistence of full bins in the streets)
- Correct waste reporting, perhaps combining it with differential charging tariffs
- Monitoring actual collection operations

The analyzed projects suggest a wide diffusion in what concerns the garbage can identification functionality (e.g. Consorzio chierese in Torino which uses low frequencies RFID tags for bins identification), while advanced solutions are rare (e.g. Comune di Duino Arusina - Trieste). The real value of these applications has yet not been explored as all initiated projects are pilot or small scale projects.

	Smart metering (electric)	Smart grid (electric-heat)	Smart metering (not electric)	Waste management (bin Identification)	Waste management (bin content)
Field of application maturity:	Consolidated	Embryonic	Experimental	Consolidated	Embryonic
Adherence to the IoT paradigm:	Medium-High	High	Medium	Low	High

Table 35: Smart energy and smart utility fields of application

The project Milan WiPower is an initiative of A2A with the collaboration with the Politecnico di Milano, subsequent to the resolution 39/10 of the Authority for Electricity and Gas, aimed at encouraging the development of smart grids. The objective is to improve the distributed generation management by testing performance, reliability and applicability of different communication systems to allow communication between a primary cabin and the interface devices of a distributed generator on the medium voltage grid. They intend to create prototypes to be applied in two primary stations - one in Milan and the other in Brescia for a total cost of 1.6 million - and to link them to the actual distributed generation units already existing on the network (one being located at Politecnico di Milano in Bovisa). The engineer Salvatore Pugliese, ICT manager of A2A Reti Elettriche, notes that this initiative may give life to a series of new features "*including the tension adjustment on the medium voltage grid, also exploiting the capacity of the generation to adjust reactive power; this infrastructure would also be able to give signals or regulate the active power, which today is prohibited, but in case someone decides that the distributor must take the dealer's role at the local level, it can be enabled*". Finally, in addition to the need for a clearer regulatory framework, Pugliese points out the need to "move faster" and to address problems - whose effects are already visible on the distribution networks - caused by the rise of distributed generation (given the substantial incentives in this area).

Box 1: Milano WiPower

"Mi muovo elettrico" is a project guided by the Italian region of Emilia Romagna. It is implemented, as well as funded by Enel and Hera, involving Bologna, Imola and Modena and will soon be extended to other cities in the region. The market for electric mobility has been greatly discussed, but finds notable difficulties in taking off, mainly because of low demand, and of the lack of infrastructure. To overcome this issue – the vicious circle implying that the infrastructure is not installed because of the inexistence of electric cars' demand and that the low demand is a result of the lack of infrastructure – this project proposes the installation of over 100 electric charging stations characterized by a uniformity of the operating mechanism. In fact, users throughout the region will have access to the recharging points using the service card integrated with the transport services in Emilia Romagna, which communicates via radio frequency with the charging station, enabling the charge and communicating the user's credentials to the operator for the billing (a full recharge will cost around two or three euros). This is a medium to long term project because of the low incidence of electric vehicles in the private sector, nonetheless, the local government/public administration already has a fleet of over thirty electric vehicles at their disposal.

Box 2: Mi Muovo Elettrico

The development of the distributed power generation brought the necessity to change the way the network is managed to handle the flow of energy, that is no longer a one-way flow from large power plants to the suburbs, but can be inverted, causing a series of problems to networks such a risk of blackouts, security or network instability. The goal of Integris - European project worth 5 million euros, and involving 5 different countries and companies such as Endesa and A2A - is to explore different communication vectots from those in use today, providing booth communications mainly through the GSM network in order to shed light on the possible solutions, increase the automation of the network and provide input to regulatory systems. Also, it looks at integrating and optimizing the control and monitoring equipment found in secondary cabins/substation, in order to integrate all possible functionalities (also including future features such as the activation of the demand-response systems).

The project involves the implementation of two pilots, one in Brescia and the other one in Finland to test these new solutions. In Brescia, the test has been launched in February 2012, with the aim of assessing the point-to-point communication channel with WiFi connections which, differently from the meshed networks can reach longer distances enabling communication up to 2km (typically the maximum distance between two secondary cabins).

The engineer Salvatore Pugliese, head of ICT in A2A Reti Elettriche, remarks how the advent of smart grids revolutionized their business traditionally known as very "operational", and confronts them with new challenges, creating the need to acquire new resources (in particular in the ICT field), build up skills and change their strategic vision. S. Pugliese also stresses the need for a clearer regulatory framework regarding the roles, tools, capabilities, standards and timing of the development of smart grids; "*This is definitely a barrier to the generation of strong investment by operators and actors. That's why we're a cautious when we say that we want to build the network in a way that allows us certain features, because it might not be the distributor the actor responsible for the investment or the reference framework may be different from the one we expected.* "

Box 3: Integris

The Consortium for Chierese Services is a supra- municipal authority the main objective of which are the collection of waste and its pricing. The territory in which it works is composed of 19 municipalities in the province of Turin serving a total of 115,000 residents. Its revenue is approximately € 15 million per annum.

Following the introduction of home garbage collection, the Consortium Chierese created a system which provides for differentiation of taxes based on household waste production.

The application of RFId technology by the company consists of the utilization of containers with tags for non-differentiated waste. Each container identified by its individual "code number",

while each transponder, operating with frequency LF, has a unique serial number associated with each box and its household. By combining the dimensions of the container with the number of times it is emptied (as indicated by a sensor on the truck), it is possible to calculate the amount of waste produced by each household.
Once the emptying has occurred, the data of each user is sent in real time by the truck to the central system via GPS.
The information collected in the system is then re-processed by a software: if a user produces less undifferentiated, emptied trash this means that he has done a better job in differentiating his trash, which will subsequently be evidenced through a recognition rate. Overall, the Consortium has distributed 30,000 containers equipped with tags in 19 municipalities , and in five of these municipalities, which make up 72% of the population, data collected will be used for accurate pricing.
The main reasons driving the company towards the introduction of this type of system were principally the ability to achieve fair tax contributions, increasing the level of customer service, and ensuring compliance with legislative requirements under the so-called Ronchi Decree of 1997 and the subsequent Presidential Decree 158 of 1999.
The major benefits that this new collection system allow us to reach are primarily linked to incentivizing good behavior from the user, creating greater transparency between the waste collection authority and the user, and finally increasing ability to plan and manage the collection of waste.

Box 4: Box Consortium Chiarese

8.3.2 Smart mobility (or transportation)

As a third of the energy consumed in cities is related to transportation, the accurate management of citizens' mobility needs through an intelligent public transportation systems, road infrastructure management and other mobility services results in a major opportunity towards reducing human's footprint as well as increase citizens' quality of life. The Internet of things paradigm enables the punctual (perhaps real-time) monitoring and control of various city components; although the real breakthrough happens through the integration in common platforms of the different data collected by different actors, allowing these to extract much more relevant information. Thus the information collected by fire-fighters' monitoring systems on a fire in a house could automatically be shared with ambulances and police man, and perhaps with citizens who may plan an alternative route for their daily journey.

- **Road network and traffic management**

Internet of Things solutions allow monitoring the status of road infrastructure (roads, streetlights, bridges, parking, traffic lights, etc.) and traffic conditions. Thus they consent to reduce the costs (maintenance, operating costs and investment costs) while improving the quality of existing services and perhaps enabling the creation of new services.

The main contexts of use are relative to:

- **Parking management**: Thanks to ad-hoc sensors powered through batteries embedded in the asphalt or conceivably positioned on a lamppost, clear indication to car drivers can be provided on the status and location of a free parking (car parks within or along the closed roads). This application is very developed in the US due to the success of the Parker (Streetline) project whose actual diffusion encompasses 80 cities.
- **Traffic Management:** This subfield of application incorporates traffic light management to reduce congestion or facilitate the mobility of particular vehicles categories (e.g. police, ambulance) perhaps through a dynamic change of the duration of traffic lights based on the actual level of traffic; access management of restricted areas; identification of anomalous events (e.g. abnormal trajectories)
- **Public transportation:** The main applications here are enabled through the monitoring and control of public transportation assets (buses, stations, taxis, subways), and allow both a punctual management of actual activities (performance measurement and planning) and the provision of value added services to citizens, perhaps providing waiting times through mobile apps or through information poles at bus stations.
- **Management of street lighting:** This activity is enabled by fitting sensors on the lampposts to monitor control and adjust the light power according to real visibility conditions. The technology here is already mature, and economic benefits are clear for local administrations given the rapid pay-back time of these investments – street lighting may impact up to 40% of local administration operating expenses – therefore allowing a rapid diffusion (cf. Smart Town Nettuno study case).

More advanced applications – with higher adherence to the Internet of Things paradigm – are still in their embryonic phase or even in the field of scientific research given the few field trials (and therefore the success history). The fact that benefits are not easy to be translated in economic terms represents a further barrier to the justification of the investment.

- **Smart cars**

An ubiquitous wireless (or wired whether possible) sensor network – characteristic of the internet of things paradigm – allows the punctual monitoring of real time road infrastructure conditions and status and whether combined with information which may be provided by infrastructure users (cars by sharing their in-vehicle hardware and software abilities) results in a powerful tool for optimizing city transportation management. The smart car field of application is therefore strictly related to the road and traffic management and could be subdivided into:

- **Infomobility:** The provision of timely – possibly real-time – geo-referenced information on traffic situation and road conditions to citizens is a powerful tool for reducing congestion levels. Indeed the elaboration of this information by intelligent devices – such as smart phones or GPS navigators – combined with other parameters allow the provision of route optimization services to citizens. In some cases the provider of the information and the supplier of the device for its elaboration are combined (e.g. Tom Tom Live, Covel). Most recent projects are characterized by an increasing degree of openness and standardization, which is a necessary requisite for the collection and integration of different types of data – such as position, air pollution, weather conditions, etc. – coming from different sources or objects – such as cars, public transports, taxis, cameras, sensors, etc. (cf. Singapore Live; Pegasus)

- **Connected Vehicles:** This field of application incorporates the connection between vehicles (vehicular ad-hoc networks – VANETS) and between these and the surrounding infrastructure. The interest towards this innovation field is driven by the need of safety given the critical death rate on streets. Indeed there are several public and private initiatives all over the world in terms of accident prevention and detection (e.g. European Union eCall project; Vehicle Safety Communication Consortium - VSC - in USA; Advanced Safety Vehicle Program in Japan). Another major driving factor towards connected vehicle's development is related to the opportunity of new service provision such as new insurance models or vehicle's assistance and diagnosis services, perhaps enabling the remote equipment repair or automatic message transmission whether an accident occurs. Furthermore it presents significant synergies with other smart city services as smart car is a further ubiquitous source of information on the infrastructural condition; and its intelligence could be combined with intelligent infrastructural components through V2I – vehicle to infrastructure communication (e.g. Travolution is an Audi small scale pilot project which was launched in Germany and involves the communication of cars with traffic lights aimed at suggesting car drivers the speed at which to go to get the green light).

  Italy is characterized by a leading position in this field of application boasting the presence of over 900.000 online connected vehicles. However more advanced projects (in terms of complexity, multi-functionality and adherence to Internet of Things paradigm) are still in embryonic stages of development

	Road network and traffic management	Road network and traffic management (advanced)	Smart car	Smart car (vehicle network V2V & V2I)	Street lighting management
Field of application maturity:	Experimental	Embryonic	Consolidated	Embryonic	Experimental
Adherence to the IoT paradigm:	Low	High-Medium	Medium	Medium-High	Medium-Low

Table 36: Smart mobility fields of application

Smart IP is a European project which falls under the Seventh Framework Programme coordinated by the city of Manchester and responds to the challenge of the transformation of public services involving the so-called "smart" citizens who are able to co-produce innovative services (internet enabled) within the European smart cities (Ghent - Manchester - Bologna -Cologne). In Bologna has the objective to establish a multi-channel Internet service for citizens and officials to provide insight into the real state

of mobility within the city (via mobile) so as to reduce congestion. The data are collected only by the networks of sensors placed in the territory - cutting edge systems already before the start of this initiative – from third party sources such as incidents control systems of police, firefighters, reports by citizens etc… With the support of Engineering Technology Partner these data are transferred in real time in a centralized database that make them available to the control rooms and to the users via a dedicated web portal.
Engineer Giovanni Farneti, contact person for the Information Technology sector of the city of Bologna has highlighted that a "success drivers was the establishment of the living labs that aim to involve the public throughout the development of the project - not just in the initial phase for the definition of the targets and in the final stage for the evaluation of results." In this perspective, the Emilia Romagna region has already completed over 20 interviews with managers – operating in the field of mobility, communications and police – and is responsible for citizen's involvement on the issues brought forward by the project. Chiara Mancini – Directorate General organization, Personnel Information Systems and Telematics of the Emilia-Romagna area of online services – explains: "we have already started the activity of community engagement identifying two generalist on-line communities and five communities focused on mobility issues to which we administered a questionnaire to try to identify the needs of citizens on issues of mobile information - so far we received 688 valid questionnaires. Moreover it is starting [early December] a CATI survey of 1,400 citizens in which we investigate what are the mobility needs of the wider population - both because it is numerically larger and because the type of sampling better reflects the actual population not taking into account only the most active and available online."
Among the difficulties encountered - explains the engineer Farneti – "there is a lack of funds, characteristic of this economic period for the development of smart initiative, and a culture of politicians that should be sensitized about these issues and educated to a systemic approach typical of smart cities.

Box 5: Smart IP Bologna

The Smart Town Nettuno Project is an initiative of Telecom Italy, in partnership with UMPI, and carried out by some other Italian municipalities with the goal of developing an "intelligent" public lighting. These Smart Town projects are easy to implement (fast and cost effective) because they are simply incorporated to the existing services on infrastructure. In fact, to smarten up light poles, all it takes is a simple electronic device on the lamp and other one in the cabinet for monitoring purposes. So far it has been implemented on a third of the town of Nettuno. The Power Line Communication technology is used, leveraging on the electrical energy transmission channels to transmit data signals. This technology allows the implementation of an integrated set of services to the smart lighting function such as video surveillance, traffic control, free parking space spotting, garbage spotting, WiFi hot-spots, mobility/tourist information , chargers for electric bicycles so on.
However the actual implementation of these services is marginal because of the issues regarding funding by public administrations. The town councillor Flavio Biondi explains; "*Once we capitalize the cost of the project, we plan to extend it to the entire area of the municipality of*

Nettuno, until then we won't be implementing new integrated services on the infrastructure,". Being a self-financed project, which pays for itself through savings resulting from the implementation (decrease in energy consumption - on average of 30%; and more effective maintenance - faults and failures reported in real time), adding new features to lighting management system is postponed to later stages in order to perceive the economic return.

Box 6: Smart Town Nettuno

Octo Telematics is a company founded in 2002, specializes in providing systems and telematics services for the insurance and automotive market, with a focus on sustainable mobility.

The services offered by Octo Telematics is based on a device, called "clear box", installed on board the vehicle and equipped with GPS and accelerometer, which transmits a series of data (such as location, route, sharp accelerations and decelerations) to the service center of the company. The comunication is on GPRS network, except in a few cases (example: alarms), when the need to rapidly transmit data makes the voice and SMS channels more reliable. Given the importance of optimizing the communication when the number of vehicles involved increases, the company has built a dedicated communication protocol allowing to manage this diversity while ensuring the reliability of the service. Octo Telematics currently runs a large stream of data: in fact, private vehicles monitored are about a million in Italy, which traverse a total of about 50,000 kilometers per minute. Based on this data, several services are provided:

· Info Traffic, i.e. real time information about traffic on highway and beltway networks, thanks to the data transmitted from the fleet Octo Telematics (Floating Car Data analysis), through its subsidiary Infoblu. This data is made available to users via iPhone and Android applications;

· Insurance Services, i.e. the profiling of driving styles (mileage, type of road, time of actual use of the vehicle) for car insurance customization, as well as accident analysis (analysis and reconstruction of the dynamics and kinematics of the incident) to ensure proper investigation and proof of liability;

· Remote diagnostics, i.e. remote sensing of vehicle defaults, through the integration of the vehicle on-board computer with the clear box;

· Fleet management, i.e. the management of the company fleet (ex: location, stolen vehicle recovery), mainly for car rental companies.

With regard to the activities of Research and Development, the company is working on further accident detection and analysis to support the insurance (ex enabling the detection of attempted fraud, determining the risk profile of the motorist, or incentivizing safer driving habits) and at the same time provide services for the safety of motorists (for example the determination of the severity of the accident or the automatic call to 118 - service "eCall").

Another area of interest is the analysis of frequented urban routes to predict expected traffic in the short term and support the planning of urban mobility (for example through roadwork); for this the company is collaborating with several research institutions and is involved in this project, which is financed by PEGASUS.

Octo Telematics is also working with the National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) to determine which driving habits and styles can be classified as "eco-driving", seeking to evaluate how best to reduce CO_2 emissions through the adoption of such behaviors.

Box 7: Octo Telematics (Interview with provider)

A significant share of traffic, according to some experts even up to 30%, is caused by drivers looking for a parking space. To counter this phenomenon, the Hollywood district of Los Angeles is adopting technological solutions aimed at providing support in the search of free parking along city streets.
The solution applied in Hollywood, as proposed by Streetline, provides that the motorist looking for parking use an application. The application, originally launched for iPhone users (in February 2011 over 1,400 had already been downloaded to the application in Los Angeles), has also been available for Android devices since August 2011. From a hardware point of view, the solution (marketed as real-time software-as-a-service) can detect the presence of vehicles parked along the road. The sensors communicate via a wireless mesh network through a receiving system, which in turn connects to the central data center (located in Dallas), which houses a dynamic map of the parking situation of the city.
The solution has proven very useful in improving public services in finding parking. The town is also considering the possibility of introducing in the future a criteria of pricing based on the actual demand of parking.

Box 8: City of Los Angeles: Parkings

In the city of Cagliari, which counts about 350,000 inhabitants, more than 180,000 vehicles transit each day.
CTM - a company operating in the field of local public transport in the wide area of Cagliari - along with the municipality of Cagliari, in the early 2000s, have seen the need for a more accurate and operational management of traffic in the city. This being said, the project "Muovetevi" was initiated with goal of creating two fully integrated control quarters, one for the management and supervision of public transportation and the other to control private mobility. A set of devices were therefore installed in the territory - such as environmental sensors and sensors for detection of traffic, control lights on parking spaces, cameras (for traffic detection or access control to restricted traffic zones) - networked with a fiber-optic infrastructure or GPRS systems using the standard protocols. The centralization of data from these devices has allowed the implementation of a series of new applications and services to citizens, such as centralized traffic light (by implementing priority systems for public transportation at traffic signals), the communication of the traffic situation in real time using information poles, parking management (notifying users of the number and location of free parkings) in addition to an increased operational efficiency (timeliness of intervention and better punctuality, reducing travel time of public transport by more than 15%).
A implicit benefit, nonetheless stressed by the interlocutor, was the change in the mentality within the municipality that, "*handling the mobility according to a more managerial, and not limited to mere planning - which took five, ten years - has achieved a much more direct and operational management.*"

Box 9: Muovetevi Cagliari

8.3.3 Safety, security and environmental monitoring systems

This field of application presents significant synergies with other smart city’s field of application discussed above as it involves the installation of advanced monitoring systems and built-in smart sensors all over the city both in natural contexts (rivers, woods, mountains) and man-made artificial infrastructural components (dams, buildings, roads, etc.). The information retrieved through these ubiquitous monitoring systems can then be used in other contexts, perhaps adding major functionalities to the installed devices whether necessary. According to the scope of the retrieved information we can further subdivide this field of application into:

- **Environmental monitoring**

Internet of Things solutions enable – via sensors distributed on the territory – to capillary monitor the pollution level in the city. In particular, it allows monitoring weather conditions – by temperature sensors or humidity sensors, etc; monitoring the air quality – through sensors measuring the concentrator of air pollutants (e.g. CO2 – Sulfur dioxides – Nitrogen oxides – etc.); monitoring water quality – by measuring the concentration of water pollutants (e.g. heavy metals – chemical wastes – fertilizers – etc.), by monitoring the conditions to preserve the ecosystem (e.g. coral reef), or by monitoring pollution levels on sewage streams flowing into seas or rivers.

Italy is characterized by a great diffusion of traditional solutions (not IoT) for measurement of the main climate parameters and polluting factors, mainly administered by regional ARPAs. More advanced application solutions, with greater adherence to the IoT paradigm are currently very rare and mainly represented by small scale pilot projects. Although these solutions seem to ensure greater capillarity and whether in “difficult” contexts (e.g. drains, glaciers, oceans) greater robustness, the business case is complex (need of demanding risk analysis) and technologies – while promising – are not yet ripe for all context of use.

- **Safety and security monitoring**

This field of application uses the information retrieved from the ubiquitous monitoring system to enhance citizens’ safety, prevent both natural disasters and man-made challenges and provide both focused and rapid emergency responses. For example, resources can be committed prior to a water main break, salt spreading crews dispatched only when a specific bridge has icing conditions, and use of inspectors reduced by knowing condition of life of all structures.

It can be further subdivided into:

- **Safety:** The monitoring infrastructure is used mainly for preventing adverse events and for managing emergencies in an effective and efficient manner. The main context of application are therefore related to flooding: by monitoring the level of streams to detect flooding threats in advance; fires in critical urban areas (subways, underground car parks, CBD areas, etc.) and forests: perhaps through temperature sensors, by promptly detecting fires and monitoring their real-time propagation; soil stability and landslide risks; collapse structures: perhaps by measuring vibrations in historic buildings; etc.
  This subfield of application presents strong interest shown by the presence of numerous applications, which can often be multi-functional (e.g. application for monitoring flooding of underpasses integrated at the traffic light management system to block access in case of danger). However, with few exceptions the majorities of projects undertaken

are in a small scale (tens of sensors), generally focused on a single feature and using proprietary and closed communication protocols, limiting the degree of integration at the information level (databases) and not objects.

- **Security:** Within this field of application are encompassed all application meant at enhancing citizen's safe living like surveillance, explosions identification, gunfire identification, screaming, etc. Traditional surveillance solutions are much diffused both in Italy and abroad through the use of safety cameras. Although more advanced solutions are very rare.

	Environmental monitoring	Environmental monitoring (advanced)	Security monitoring	Surveillance	Safety monitoring
Field of application maturity:	Consolidated	Embryonic	Embryonic	Consolidated	Experimental
Adherence to the IoT paradigm:	Low	High	Medium	Very low	Medium

Table 37 Safety, security and environmental monitoring systems fields of application

The Parco Urbano di Castel Fusano covers 1,000 hectares between the urbanized areas of Lido di Ostia Casal Palocco, Infernetto and the Presidential Estate of Castel Porziano. The natural environment is composed of Pinewood and typical Mediterranean fauna, representing one of the last remaining coastal forests of Latium.
The City of Rome implemented in 2009, in collaboration with the Italian-Swiss start-up EnvEve, a system to effectively and rapidly identify the outbreak of fire in the park of Castel Fusano. The solution, currently active in one area of the park, is based on a wireless sensor network: 1,000 "sentinels" have been put in place to send an alarm in case of fire. This alarm is conveyed through the gateways and installed repeaters in order to reach the central system and then be transmitted to qualified operators within seconds via phone and / or internet. Key aspects of this type of solution are the limited environmental impact and its reliability in terms high effectiveness and absence of false allarms. To ensure a good performance, the installation requires an accurate preliminary classification of the area to protect, identifying levels of risk: the risk of the area determines the density of the sensors, which can vary from 0 (little or no risk) to 25 per hectare (high risk).
The advantages of the installed solution are two: first, accurate and timely identification of outbreaks of fire allows to act with higher effectiveness, therefore reducing the damage caused by them. Secondly, the information collected can be used to facilitate fire fighting operations by constantly updating the operators with the spreading of the fire.

Box 10: City of Rome: Parco di Castel Fusano

Recently, we have unfortunately experienced firsthand how weather events pose a threat to many hydro-geologically at-risk areas. In these cases, the speed with which one can detect a critical event, such as flooding, landslides or fires, and the speed by which the alarm is issued following the event, is of vital importance. Technology can assist in this respect: there are now several projects concerning the application of sensor networks for environmental monitoring, though few have actually been implemented. An example of this is offered by the city of Imperia, which has adopted the system of Minteos FloodAlert for monitoring levels of the Impero stream that runs through some quarters of the city.

In fact, streams that cross urban areas are often poorly monitored, despite presenting a danger of flooding if significant rainfall occurs, which may cause the closure of major roads and pose a major inconvenience to the public.

The system consists of wireless sensors, calibrated so as to trigger the alarm when it reaches a critical threshold, positioned along the bed of this small stream and a gateway. The sensors send to the operation center the collected data, where they are made visible through the interface NaturAlert through gateways. In addition to searching the real time data-level the system provides access to an historical record of data and sends an alarm via web, SMS and phone call if pre-set thresholds are exceeded, promptly alerting institutions and teams for preventive interventions, such as evacuations or closures of any roads and bridges.

Box 11: Imperia (Interview with provider)

8.3.4 Entertainment and tourism services

The internet of things enables various objects in the city, such as monuments, museums, lampposts and bus stations to communicate with citizens providing various kinds of information. This represents an enabling factor towards enhancing tourists' experience in the city. The technologies enabling this functionality are mainly NFC and QRcode. Near field communication (NFC) is a set of standards for smartphones and similar devices to establish radio communication with each other by bringing them into close proximity, usually no more than a few centimeters, therefore enabling the exchange of data. While the QRcode is the trademark for a type of matrix barcode (or two-dimensional code) first designed for the automotive industry. More recently it became common in consumer advertising and packaging, because of the dissemination of smartphones given their capacity to read barcodes. The barcode redirects the user to the given website, consequently enabling the provision of information to citizens or tourists.

QRcode is characterized by a high degree of maturity although the functionalities enabled are limited as there can't be a bidirectional exchange of data (very low adherence to the internet of thing paradigm) – cf. project TagMyLagoon in Venice.

NFC instead, is an emerging technology whose development is in full growth and its diffusion seems undoubted. Its functionalities can be leveraged-on in various smart city fields of application (transport payment, micro-payments of services offered by public administration, infomobility, etc.) – cf. Cityzi project in Nice.

	Entertainment and tourism services
Field of application maturity:	Experimental-Consolidated
Adherence to the IoT paradigm:	Medium

Table 38 Entertainment and tourism services field of application

8.3.5 Smart Home and Building

This field of application involves the transformation of current homes and buildings into intelligent infrastructural component able to sense the presence and needs of their inhabitants, therefore automating various functionalities of the home, and enhancing the creation and provision of additional services. The main subfields of application are:

- **Energy Management:** This application enables the load management, the dynamic management of appliances for energy efficiency. Europe pushes towards the development of integrated solutions for energy efficiency both in buildings and in homes (Energy-efficient Building – EU funding, FP7, Smart Cities and Communities in the initiative; Beaware) which is also reflected in the interest of Italian companies (e.g. Intesa San Paolo)

- **Management of scenarios:** It involves the combination of different parameters (e.g. temperature, light) to increase inhabitants comfort. These solutions are widely consolidated, and don’t present technological issues

- **Security:** This encompasses video surveillance, intrusion detection. As the previous field of application security solution are widely consolidated and diffused although they don’t present a high degree of adherence to the Internet of Things paradigm

- **Safety:** This incorporates the monitoring of losses (e.g. gas, water, etc.) and possible actions which could be implemented to solve safety issues (e.g. automatic closure of gas; sprinkler activation). This field of application also represents an important driving factor given the derived EU funds especially in the building sector to enhance workplace safety and structural integrity.

- **Maintenance facilities:** reporting failures, centralized management and monitoring of the functioning of key equipment for buildings (air conditioning, centralized heating, etc..)

- **Personal Assistance:** this field of application involves providing not medicalized services to facilitate the home living of people with physical disabilities or with cognitive issues.

These fields of application present technological solutions that have traditionally been developed according to a "closed" logic which doesn’t allow interoperability between solutions from different vendors, although there is a growing interest in exploring the additional benefits which could be offered to customers through open solutions. This could help giving a new impetus to this sector.

For what concerns smart homes, the consumer knowledge of these solutions is very limited therefore giving rise to misleading preconceptions both in terms of costs of the solution and of its capabilities; a clear consumer communication and understanding of the real benefits of these solutions – for example in terms of energy consumption reduction capabilities, in terms of costs, etc. – are essential to overcome barriers towards adoption. Furthermore, the analysis revealed that the use of an interface already known to the consumer may help enhance their experience, perhaps a smartphone or a tablet.

	Smart Home & Building	Smart Home & Building (advanced)	Home Safety and surveillance
Field of application maturity:	Consolidated	Embryonic	Consolidated
Adherence to the IoT paradigm:	Medium	High	Very low

Table 39 Smart home and building fields of application

E-Cives is a project started in early 2011 by Greenerg, (a provider of energy services), Cooperative Societies COOSS Marche and Maze (dispensing social services and social-health) and Techno Habitat (engineering cooperative that managed the project), in collaboration with HomeLab (see Box Home Lab). energy

The project aims to build a platform ("CIVES") for the integrated management of various home devices (ex: appliances) and communal (ex: boiler), which enable services for the management of the energy in the building, optimizing energy consumption, maintenance and management of electrical (including photovoltaics), heat and water systems. To this end, the various devices installed in the dwelling, using standard as Connex and Zigbee, are interfaced with a gateway of flat, provided with input WiFi and Zigbee, which in turn transmits the collected information to a platform open IP. With this logic is to enable interoperability of systemic solutions, allowing the entry in stages to more service providers.

The project involves the implementation, starting in November 2011, management solutions and control energy consumption in five buildings in the province of Pesaro. The implemented features cover monitoring of the consumption of centralized systems of apartment buildings and their distribution between individual apartments; perspective is also provided an indication of consumption on a per appliance. The consumption data are available through the web portal with various degrees of detail depending on the user profile (administrator, condominium, energy supplier). The project also includes the study of solutions for selling surplus energy to the grid from renewable sources.

Box 12: E-Cives

Intesa Sanpaolo is the leading Italian banking group present in Italy with 5,600 branches, in addition to more than 1,600 branches worldwide.
In 2002 the group launched a project to monitor energy consumption of its subsidiaries in 2007 that led to the inclusion of this budget in the contract for renovations and new branches: there are currently around 1,500 branches of which the consumption is monitored total electricity and you are making a gradual extension. The initiative has also led to implementation of a solution, in collaboration with Team Energy and Telecom Italy, working on a group of 24 branches, designed to monitor in addition to the total electricity consumption including those related to lighting, air conditioning and other utilities (eg PCs, printers, copiers). The project also includes the collection, via environmental sensors, information relating to the internal temperature of the premises to monitor the conditions of comfort. The data on consumption, both total and partial, are detected using "logger", on average one to three per building depending on the size and structure of the electrical system, which communicate with a central GPRS: Due to the requirements of safety of an environment such as banking was in fact necessary to implement a solution independent of the corporate network. The processed data can be accessed remotely with different levels of aggregation (single branch, the group of branches).
The ability to monitor the actual consumption of the branches, combined data analysis of monthly electricity bills, has enabled Intesa Sanpaolo to create performance indicators for energy reference cluster divided into geographical area, type of system (autonomous boiler fuel / heat pump) and size of the branch, on the basis of which have been defined target consumer updated annually. The comparison of performance of each branch of the indicator with the target value, highlights the critical energy level.
The reduction in energy consumption is achieved by acting on two fronts: firstly by reducing waste due to failure and / or operational inefficiencies, with the ability to detect it early, the other implementing adaptation actions on the basis of targets for improvement, thanks to ability to identify potentially critical sites on the basis of the comparison between actual consumption and the values of the target cluster. Recently, the branches are equipped with "logger" which, in addition to detect the consumption, also run times of operation of the main systems, dramatically.
These initiatives have led to Intesa Sanpaolo get progressively lower in 2011 compared to 2008 baseline, approximately 10% of annual electricity consumption of its main branches, more generally, all the environmental initiatives that Intesa Sanpaolo aims over time, in 2011 only made it possible to avoid the release of CO_2 to 11,495 tons compared to 2010, which is equivalent to the amount of CO_2 absorbed in a year from 383,167 trees.

Box 13: Intesa San Paolo

Agrindustria is a 'company which specializes in various processes of re-using discarded raw food materials from food raw materials, with a focus on plant-based products.
In 2011 the company implemented at its production site in Cuneo a monitoring system for fire protection based on Wireless Sensor Networks (WSN) made by Minteos. The project was initiated from the need to ensure adequate fire protection in an environment marked by a high number of flammable materials and the presence of dust, aspects which make the traditional smoke detection systems (eg via infrared or aspiration) unreliable due to the high number of false alarms.

The system, in operation from June 2011 in a warehouse and a silo of about 200 m^3, is based on environmental sensors used to detect carbon monoxide (CO) produced during combustion and communicates the collected data through wireless sentinels to a central gateway. The gateway then sends information via GPRS to a central system, allerting management via SMS when predetermined thresholds are exceeded.
The critical issues in the implementation of this solution involved the proper configuration of alarm thresholds: the presence of particules machinery in the warehouse way increase the level of carbon monoxide. Following proper calibration and defined alarm thresholds, the system is now operational and has led to a drastic decrease at the number of false alarms, while increasing fire safety as, for example, it was possible to extend the monitoring to areas (e.g. silos) that previously could not be monitored by traditional systems.
Given the project's positive results, Agrindustria plans to extend the installation to all environments containing dust, so as to cover 100% of their areas through between traditional and WSN solutions

Box 14: Agrindustria

In the following Figure 41 the main smart city's fields of applications are located into a matrix according to their maturity and adherence to the Internet of Things paradigm.

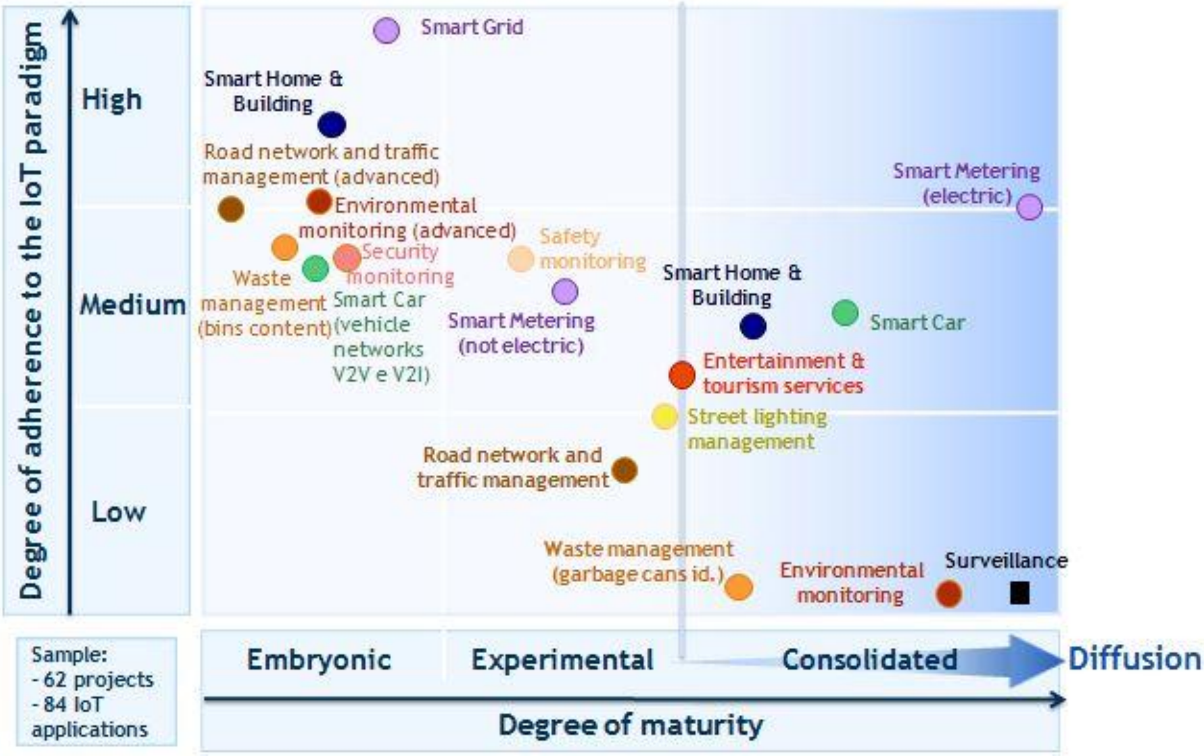

Figure 41 Smart city's fields of application maturity and adherence to the IoT paradigm

Chapter 9 - A Smart city solution for gas metering

This chapter first aims at rationalizing the main drivers to take into account for the realization of a smart city. Once the smart city recipe has been defined, the adherence of the Italian smart metering roll-out program towards the identified model will be discussed by evaluating the infrastructural requirements and costs to adapt the smart metering solution as a component of a wider smart city infrastructure. Finally, based on the comprehensive analysis of the smart city's fields of application analyzed in the previous chapter, the research of exploitable synergies among those fields of application will be pursued aimed at providing a multi-service architectural solution.

9.1 Premise

The analysis of the main fields of application led to the identification of a large number of smart city projects characterized by a wide diversity in terms of maturity, technological innovativeness, impact on the society and diffusion. The previous study was structured in a vertical research analysis of each field of application; however, the disclosed definitions of Internet of Things and Smart City clearly express their transversal and multi-functional characteristic encompassing different specific industries and sectors. Indeed through the Internet of Things paradigm different objects, owned by different actors, meant for different purposes can communicate to each other building an infrastructure which results cross-industry and cross-sector. Using the same rational, a smart city application meant for public light monitoring can be leveraged-on for traffic monitoring or for security purposes; a smart home energy manager can be used as an interface with the electric grid for enabling the demand-response functionality of smart grids; a building surveillance system can detect whether a parking in front of the building is free or not and communicate it to the building's inhabitant coming back from work and looking for a parking.

The term "smart" actually underlines the cross-functional and multi-purpose feature of city applications. (Hassan et al., 2010)

The following chapter first aims at rationalizing the main drivers to take into account for the realization of a smart city based on the analyzed case studies and on worldwide best practices. Once the smart city recipe has been defined, the adherence of the Italian smart metering roll-out program towards the identified model will be discussed by evaluating the infrastructural requirements and costs to adapt the smart metering solution as a component of a wider smart city infrastructure. Finally, based on the comprehensive analysis of the smart city's fields of application analyzed in the previous chapter, the research of exploitable synergies among those fields of application will be pursued aimed at providing a multi-service architectural solution.

9.2 Identification of the smart city recipe

9.2.1 The importance of a global strategic vision: planning is crucial

The wide set of players required for the realization of smart cities suggests the need of coordinating the efforts undertaken by different actors in the city. Indeed the complexity characterizing the urban environment is distinguished by a multitude of different actors with contrasting needs and interests like people: families, students, tourists, expatriates, citizens; public entities: local administrations, schools, hospitals, transportation companies, public safety entities (police - fire-fighters); or private entities: national or foreign companies in services, industry, utilities, real estate, etc. (Nelson, 2010)

Each city is therefore unique in relation to their inhabitant's needs and cultures, infrastructural resources and constraints and consequently needs – once it has decided on transformation – to undergo an assessment process which involves evaluating its needs and innovation opportunities, set clear objectives, prioritize development efforts, and establish metrics that let city actors (local administrations, ICT companies, residents, etc.) assess progress. The assessment process should therefore be flexible enough to let planners choose the domains most important to them and provide some means of projecting costs and measuring progress—for example, how well various agencies are integrating operations and sharing data. (Bellavista, 2011) Indeed one of the biggest hurdles in making infrastructure smarter is the lack of adequate funding. This issue emerged in all smart city projects analyzed through direct interviews in Italy, and is mainly related to the economic crisis affecting current times; governments cut funds for local administrations, and these face budget deficits.

This issue further enhances the importance of an accurate planning process which starts by the identification of city needs and opportunities in order to correctly allocate resources: cities need to develop a long term strategic vision, communicate it and share it**.** Indeed citizen’s inclusion in the planning process is crucial both to understand their priorities, and to sensitize them towards the issues their city is facing. (Naphade et al., 2011)

To do so, planners should have a higher perspective encompassing all subsystems composing the city with the objective of seamlessly integrate and optimize them to achieve a new level of effectiveness and efficiency. These systems are increasingly both producers of information and consumers of one another’s information, although interactions can also be indirect. Hence, a smart city can be viewed as a “system of systems.” (Gann et al., 2011)

To let smart cities emerge, a cultural change needs to be initiated in all the actors composing the city. Indeed, the transversal nature of smart city projects involves different actors with different interests often contrasting to become partners towards the realization of a common goal. Partnerships are therefore essential and collaboration is crucial. (Huestis and Snowdon, 2011) To reach effectiveness, different actors should be aligned with the city vision and coordinate their efforts. Coordination can be facilitated by open data: by providing cross-agency visibility of planned interventions different actors can exploit synergies. For example, the electrical utility’s replacement of a cable under a street intersection might offer traffic managers an opportunity to save money by replacing a signal at the same location.

Indeed the aggregation, integration and openness of multiple data sources allows representing the interdependence of different urban domains and subsequently the provision of new intelligent services to citizens. For example, electrical utilities can combine sophisticated models of near-term demand based on historical usage patterns (day of week, holidays, local weather, major events, and so on) with real-time traffic information that could impact future demand. Thus, awareness of a major delay in outbound traveller traffic in the early evening could let the utility project a delay in demand because those travellers will arrive home late. The utility could likewise use real-time weather data to predict the location of cables damaged in a rainstorm and so on.

Furthermore, open data allows citizens get involved on the smart city realization both by allowing them to get access to information that could result precious to them (thinking about the worker which by knowing the real traffic situation can reduce the time spent in the car, or decide to take an alternative mobility solution) and by enabling the open innovation paradigm. (Debnath et al., 2011) Definitely, by aggregating data in common open platforms, the information which can be extracted and retrieved could benefit different actors enabling the creation of services by a multitude of different users. This is the base for the success of the Internet 2.0, whose capabilities and opportunities have been widely studied and leveraged on by companies (smart phones' application stores clearly exemplifies that paradigm).

9.2.2 The core role of the Public Sector

In the previous section we emphasized the importance of developing a powerful long term strategic vision for the city and sharing it with all city actors. It is evident that the endorsed actor to perform this activity, give development priorities, and coordinate the efforts undertaken by different figures in the city can only be a public entity and in particular local administrations. (O'Connell, 2008) Their role is crucial in planning activities as they should put together and consider all major – and minor – actors of the city in order to reach a global view and share it with those. We can see that this good practice has been more or less absorbed by Italian forward looking city initiatives – e.g. Genoa, Parma, Bari, Bologna, Firenze, Piacenza all created smart city consortiums enclosing utilities, ICT consultants, transportation companies, service companies, public safety (police, fire-fighters, etc.).

Furthermore, the massive adherence of European cities to the Covenant of Mayors, involves each of these to develop a comprehensive long term plan to meet the covenant's goals: the Sustainable Energy Action Plan (SEAP). This is the key document in which the Covenant signatory outlines how it intends to reach its CO2 reduction target by 2020. It defines the activities and measures set up to achieve the targets, together with time frames and assigned responsibilities. It is a strategic document which empowers local administration to take initiatives and plan their progress. Figure 42 represents the Italian adherence to European initiatives for smart cities.

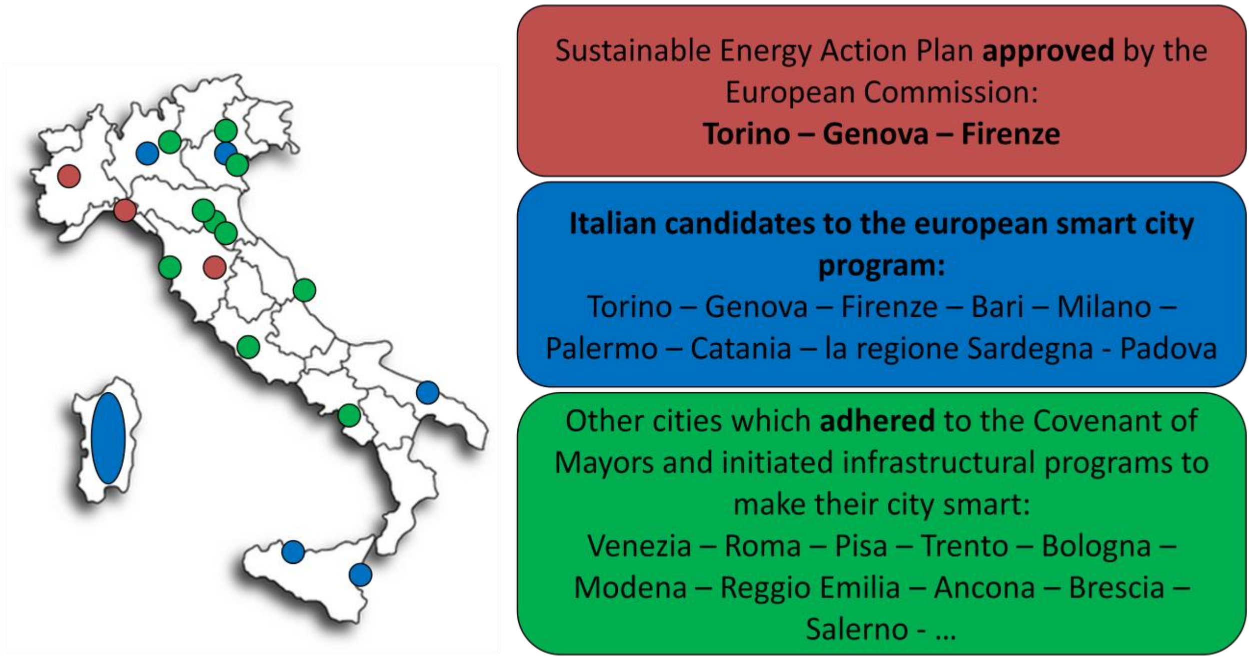

Figure 42 Italian adherence to European smart cities initiatives

The public sector is thus crucial for the launch of smart cities, it is the operative planner; a major funding source; and it fuels and coordinates subsystem initiatives through local administrations.

The transversal peculiarity of smart city projects regularly requiring different actors with contrasting interests to collaborate towards the realization of the same mission often derives a misalignment between the actors required to sustain the investments and those benefitting from it. (Nelson, 2010) (Eger and Maggipinto, 2010) (Saha and Paterson, 2008) This represents a substantial barrier to the realization of smart city projects – that frequently emerged during our interviews – and can be overcome through the public sector ability to redistribute profits of investments.

Another lever to solve this issue is the realization of Public Private Partnership (PPP), which are deemed crucial for the success of smart cities as they allow to leverage on private's resources, experience and know how to solve public issues allowing as well the transfer of these abilities to public entities. (Harrison et a., 2010) (Eckman et al., 2010) This collaboration schemes were also strongly set in motion through the Italian Infrastructural and Economic Growth Minister Corrado Passera (Passera, January 2012) as their value towards the realization of the smart city concept is undisputed. Indeed the private sector is characterized by an economic value orientation which results precious in the identification of the most economically sustainable projects for smart cities. Another major private sector's asset to be leveraged on for the realization of smart city solutions is their creativity whose contribution in innovation processes is acknowledged. (Kuk and Janssen, 2011)

Finally, considering the higher level of analysis, the public sector has the regulatory role which influences all city's subsystems, as it can – through norms and regulations – affect each actor's interests and operations. From this derives the importance of an intelligent and forward looking governmental regulatory activity which should leverage on all the characteristics discussed for local administrations, but through effective cross-city directives facilitating and coordinating the efforts undertaken in different cities. (Harrison et al., 2011) Technical norms and regulations represent a remarkable instrument for development as they can direct and mandate investments and projects; however, it is a double-edged sword, as an error in the regulation may derive noteworthy extraordinary costs for the entire society. (Moya, 2012)

The smart metering regulation in the gas sector is a prime example of the complexity of issuing a comprehensive regulation mandating a technological development.

9.2.3 The central role of infrastructure

Infrastructure has several meanings depending on the context the term is used in. In terms of utility and facility functional operations, the infrastructure represents the underground and aboveground cables and pipes networks supported by all related assets. While for civil engineers, involved in other urban contexts infrastructure can be related to other functions such as road networks, bridges, train and bus stations, schools, hospitals, universities and other public services.

Infrastructure represents the first layer of an intelligent city upon which different services can be provided to citizens, companies, tourists and all city actors. (Streitz and Norbert, 2011)

The smart city model implies providing a comprehensive and integrated infrastructure able to sense people's needs and act as a consequence of those. Towards this goal the Internet of Things development plays a crucial role. Indeed to make an infrastructure aware of its context, a wide set of sensors needs to be deployed in order to make the assets composing the infrastructure able to sense and communicate with each other and with their environment: monitoring and controlling becomes crucial.

In relation to that, already since early 2001 Thomas C. O'Reilly stated that "the conventional infrastructure networks are composed of main and major assets connected to pipes or feeders; however, the majority of these assets are not talking to each other and have very limited control and monitor operational functionalities. This issue can, at present, be overcome by the actual state of art technological development in hardware, software, information and communication technologies enabling the emergence of the Internet of Things paradigm. (O'Reilly et al., 2001)

To transform current cities infrastructure endowment and make them intelligent, the distribution of a sufficiently ubiquitous number of sensors to be deployed in association with infrastructural components is a necessary requisite; these sensors then need to be able to communicate to ensure the needed level of assets connectivity and control; this derives the need of deployment of a secondary parallel infrastructure associated with the physical infrastructure: the communication infrastructure. (Al-Hader and Rodzi, 2009)

In effect the communication infrastructure represents the recurring infrastructure needed to enhance every other infrastructure's abilities.

A communication infrastructure will therefore have to be deployed for city monitoring or security purposes; for managing the transport infrastructure; for managing public lighting; for managing the electricity distribution grid; for managing the gas distribution grid; for the enablement of smart buildings development; and so on (for each smart city's field of application).

The recurring nature of the communication infrastructure in all major smart city fields of application suggests the importance of tackling its deployment in an integrated manner by exploiting possible synergies.

9.3 Smart metering infrastructure: a call for smart cities?

Now that we have distinguished and analysed the main fields of applications, and we have identified the requirements and good practices for undertaking smart city projects, we can evaluate the adherence and adaptability of the smart metering infrastructure realization into a smart city intelligent infrastructure.

9.3.1 Requirements for a multi-service architecture

The smart metering infrastructure, to be exploited as a component of the larger smart city infrastructure needs to present some features and characteristics which need to be planned and foreseen in the initial roll-out phase with a forward looking approach. (Macagnano, 2009) Indeed, in the vast majority of Italian cities, the smart city infrastructure is not yet a reality; many components of it are still missing and as seen in section **8.3** these components are characterized by different development trends. However, the long term longevity of the smart metering infrastructure (smart meters have a metrological validity of 15 years) should take into account the development of other components of infrastructures, especially those upon which synergies could be exploited. If not, this opportunity will be turned into a further constraint towards smart cities evolution. This said, accurate development forecasts for each of these synergetic fields of application should be carried out punctually (referring to the specific area of implementation) to measure the potential of the option.

The general requirement which need to be envisioned for a multi service metering infrastructure can be summarized by:

- **Increased interoperability**: Interoperability is a crucial requirement which has already been discussed while assessing the technological requirement of the infrastructure (cf. section 4.4). Indeed, the regulation envisages that interoperability should be ensured considering the standards that have or will be published for the gas sector. However, whether envisaging to share the communication infrastructure with further actors of the city, extra standard interfaces should be foreseen especially for the concentrator. Figure 43 depicts the extra communication interfaces which should be foreseen for an increased interoperability. The current requirement increases the cost of field devices, in particular of the concentrator which can impact up to 20% extra cost of each concentrator.

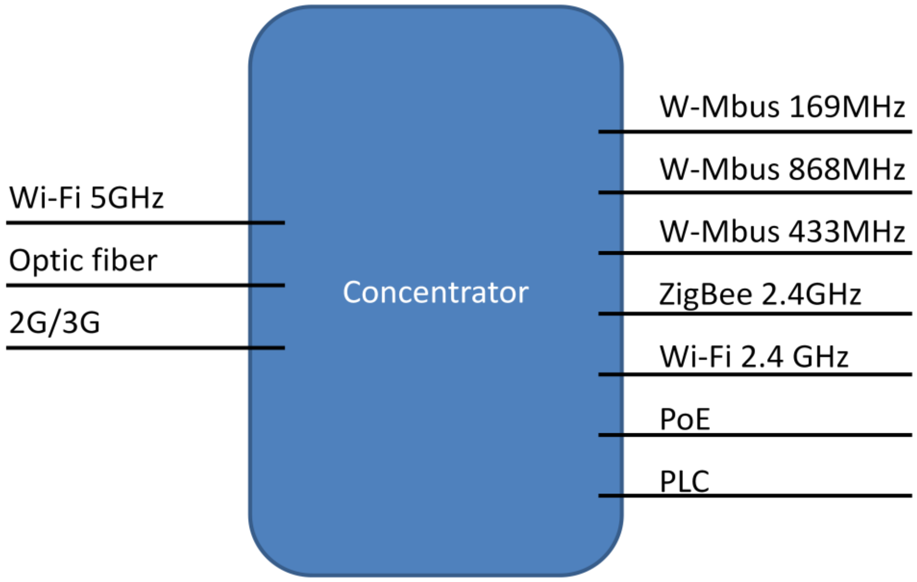

Figure 43 Extra communication interfaces for an increased interoperability

- **Scalability:** This requirement is needed because all other smart city infrastructural components are yet not present (or partly present) and therefore the installed communication system needs to ensure the subsequent increase of communicating devices (which could be other smart meters – electric, heat, water, etc – or cameras, home devices, etc.). This feature implies that the field communication architecture has to be modular, with different communication modules to be added with a marginal incremental cost. This requirement has a marginal cost on field devices as they are usually produced through the assembly of different modules. In addition, it implies that the central acquisition centre (SAC) is also conceived in a modular and enlargeable manner to manage future increasing quantities of data; this implies an incremental cost which can account up to 10% of the SAC cost (considering also the necessity of idle capacity).

- **Flexibility:** The solution must be flexible to enable future service customization in relation to the different needs contrasting different data users in terms of frequency of data communication (monthly, daily, hourly, real-time), transfer rate, number of users, type of data required, etc.

- **Appearance of an independent actor:** to facilitate the integration of different services through the same communication infrastructure, it is strongly suitable that the management of this infrastructure is left to an independent actor. First to increase economies of scale and scope in operations and maintenance activities, but above all to better customize the solution for the diverging requirements of the different actors sharing the same communication facilities. Finally, because utilities are not keen to let their data flow through a channel managed by a competitor (i.e. another utility). (Guo et al., 2011) The applicability of this requirement to the smart metering roll-out in Italy will be discussed in details in the following §9.3.2

9.3.2 Importance of an independent actor

The analysis of the gas distribution market considering their organizational structure, their resources and their traditional core business pointed out the difficulties that those actors will face when planning and implementing the smart metering roll-out. This suggests the opportunity of outsourcing the metering activity to an actor which can better leverage on its resources, experience and know-how, perhaps an ICT service company.

Following, the main differential drivers impacted by the outsource decision will be identified; these are divided into cost drivers and strategic drivers:

Cost drivers:

- **Cost of meters:** This cost item is strongly influenced by the volume requested by utilities given the early stage of the market development: the production is often initiated downstream the received order (Made to order). The complexity of the device and the opportunity to customize it for utilities emphasizes this issue.

- **Cost of communication:** This cost item can be divided in two separate communication costs: the cost of communication between the concentrator and the SAC, which is slightly impacted by the bargaining power of utilities to lower the price set by Telcos (both for SIM acquisition and for transfer rate tariffs); while the cost of field communication is composed by different modules and depends strictly on the field infrastructural constraints and barriers. The bargaining power of utilities would result heightened whether a GPRS/GSM communication is foreseen for each meter, indeed Telcos should design a customized SIM machine to machine solution given the peculiarities of its uses for the gas sector: low data traffic but need of absolute coverage reliability; however this vector is not suited for the domestic market (unless in rural areas with low density rates).
- **Cost of the central acquisition system:** This voice item strongly depends on the number of metering units for which the central infrastructure is shared. Indeed those software systems are characterized by strong economies of scale both for maintenance costs and for management cost.
- **Cost of computer and telecommunication skills:** Switching to an automated meter reading system causes a rearrangement of the skills required by distributors for managing the metering service.

Strategic drivers:

- **Importance of measurement service as a driver of competition:** Since the service distribution is a de facto monopoly, competition between different distributors is limited to the acquisition of new distribution concessions; the extent to which the metering service offered impacts on distributors' ability to win new concessions is definitely marginal.
- **Attitude towards collaboration:** This driver depends on the distributor's culture, and organizational structure. We can distinguish between traditional and conservative distributors (the large majority of the actors as emerged during the interview with the regulator AEEG) and innovative distributors – often these utilities are parts of major groups interested in different businesses
- **Ability to create new items of profit:** The smart metering roll-out could result in an opportunity for distributors for enlarging their core business, assessing the opportunity of creating new value added services, perhaps to be sold to suppliers or other interested parties.

However for an accurate valuation of outsourcing the segmentation of the distribution market should be performed given the diversity of the actors composing it (cf figure Figure 13).

We identified three main categories of distributors which may present different inclinations towards the outsourcing decision given their organizational structure, dimension, and number of services provided:

- **Large mono-utilities:** which can leverage on higher resources, and reach economies of scale
- **Small mono-utilities:** which are often unable to face the smart metering complexity with available resources, can't reach economies of scales, and can't leverage on synergies with other service provided
- **Multi-utilities:** which can leverage on synergies and economies of scope with the different service provided

The following table expresses the impact of each outsourcing driver on the different actors in relative terms.

	Large mono-utility	Small mono-utility	Multi-utility
Meter cost	Low	High	Depends on the dimension
Cost of communication	Medium	Medium – High	Medium
Cost of the central acquisition system (SAC)	Medium - Low	High	Depends on the dimension
Cost for ICT skills	Low - Medium	High	Low (also depending on the dimension)
Strategic importance of the metering service	Low - Null	Null	Medium
Attitude towards collaboration	Depends on organizational structure and culture	Depends on organizational structure and culture	Depends on organizational structure and culture
Ability to create new profit items	Medium	Low	High

Table 40 Impact of each outsourcing driver for each distributor's category

The service company – likely an ICT provider – would enjoy both the benefits resulting from economies of scale, providing the service for different distributors and reaching higher bargaining power; and economies of scope by leveraging on its expertise and resources and by exploiting synergies in providing the service to different utilities – gas, water, electricity, etc. – or other actors of the city.

It is the solution which would result in reaching higher efficiency considering the entire supply chain resources; however, misalignment between bargaining powers and the fact that distributors are facing a regulatory order (they are obliged either to perform the roll-out in-house or to pay for the outsourcing) creates opportunistic behaviours among service company, consequently leveraging the price of the outsource.

To avoid these issues in UK the regulator envisioned the creation of a new Public-Private-Partnership service company: the meter company which will manage the acquisition of all meters' data both of electricity and gas, and then redirect it to each utility's meter data manager. This solution results in being optimal for the containment of the roll-out costs but needs an active regulatory Authority which defines its functional processes and punctually regulates its management processes to avoid inconsistencies and ensures the competitiveness of the supply chain.

The majority of the market, which are small mono-utilities – recalling that 60% of distributors employ less than 10 workers – will envision the outsource decision as the cost of the in-house management would result too burdensome. However it must be said that the reimbursement mechanism proposed by the regulator AEEG (cf. section **3.3** Italian Regulation) currently privilege the in-house management, but this issue was revealed in the last resolution paper (DCO 28/12) and is said to be solved by autumn 2012 with adjustments on the reimbursement scheme.

Finally, whether envisioning the smart metering solution as an infrastructural component of a smart city, the management of the communication infrastructure should be left to a third actor unless a large multi-utility or a major mono-utility foresees an opportunity in providing metering services to other utilities, but this would involve a major enlargement of their core business (the interviewed major distributors although consider this scenario unrealistic given its complexity and divergence from the core business).

9.3.3 The smart metering adaptive approach: a solution to overcome the smart city's fields of application development diversity

The analysis of each IoT field of application encompassed by the smart city concept pursued in the previous chapter revealed a great diversity not only in the level of maturity and diffusion of these fields' projects, but also relatively to the region and city (or district) considered. Gas distributors however face an obligation which has to be fulfilled in the whole Italian territory therefore envisioning a solution which can easily be replicated across regions and cities. Thus, the diversity in the level of maturity and future diffusion of IoT fields of application across cities seems to represent a barrier to the design of a multiservice solution as this should be customized for each city depending on the real synergies opportunities. However, as will be demonstrated in this paragraph, the smart metering infrastructure is subject to specific field and infrastructural constraints which involves the need of a solution which is intrinsically flexible and customizable according to the specific area of implementation.
This suggests the use of an adaptive approach which is a methodology that identifies homogeneous assemblies and for each of those defines a technical solution optimizing the field context.

Two major characteristics of the field context which may drastically impact the efficiency of the envisioned solution have been identified. These are relative to the location of meters: distinguishing between those that are positioned inside the household's property and those that are outside; the number of closely combined meters: distinguishing between those that form a set of more than 10 meters, and those that are individually positioned or that form a set of few meters.

	Meters positioned outside the household property	Meters positioned inside the household property
Set of more than 10 meters	The meters will be associated to one concentrator also flanked on the same set of meters. It represents the optimal solution as the connection requires a low transmission power potential and could be done through a wired solution. The meter management is simplified as it is the installation process.	The concentrator will be positioned side by the meters' set. The solution can be either wired or wireless with a low transmission power needed. In this case a contract has to be formulated with the client where the meter intervention modalities are defined, and the energy consumed by the system reimbursed.
Single meter or less than 10 meters' set	The meter(s) are connected either through a cable or wirelessly to a signal translator and repeater which wirelessly transmits the data to a concentrator positioned on a public street – perhaps on a public lamppost – in the optimal position for reaching every repeater on the public street.	The meter(s) are connected with a repeater flanked by, which then transmit the data to the concentrator positioned on the public street. A contract with the client has to be formulated to define the modalities of intervention on the meter and of energy consumption reimbursement.

Table 41 Field configuration clusters

An exception to these four major clusters of field configuration, for which the installation of smart meters results particularly burdensome has been identified:

- Meters positioned on the balcony facing a public street or inside apartments. Whether the meter is positioned on the balcony facing a public street the connection is contrasted by the balcony itself (which represents a barrier for the communication) and by the fact that in this case meters are usually positioned in niches. The effectiveness of repeaters is therefore contrasted by infrastructural barriers, and positioning the concentrator on the public street could involve not reaching some meters, especially if in the higher floors. The option of not telemanaging these meters should be valued and balanced with the cost of installing repeaters on the side façade of buildings with all resulting installation and maintenance costs. While if the meter is positioned inside the apartment, the situation worsens, implying higher costs for telemanagement as the access to the meter, both for installation and maintenance purposes would result very high. Distributors are considering the fact of installing them after all other configuration scenarios are rolled-out

Finally, power availability represents a major constraint which needs to be considered when planning the positioning of concentrators. Indeed the cost of realizing an electric connection (whether possible) and of power consumption to be negotiated with the electric distributor needs to be balanced with the cost of batteries. Moreover, the option of feeding the batteries of the concentrator through a photovoltaic panel needs to be considered.

The infrastructural constraints shaping the smart metering roll-out case suggests that distributors will not be able to build a solution which results optimized for each field context; conversely they require a flexible solution optimized for each single location. Hence, allowing the opportunity of envisioning a solution which exploits synergies with other smart city components, whether these are available (at present or in the future).

9.4 Integration with Smart City

Now that we've defined the adaptive approach needed to face the smart metering roll-out which opens a window of opportunity towards the customizability needed to envision a smart city solution; that we've identified the requirements and costs of a multi-service infrastructural solution, and that we assessed the inclination of distributors towards an outsourcing decision (which is a necessary requirement for a multi-service solution), we can analyze these synergies.

The analysis starts from the state of art picture of each smart city field of application's development (i.e. the output of the previous chapter). The investigation focuses on the fields of application which resulted to have a certain degree of maturity (i.e. experimental or consolidated), implying that their diffusion might experience a significant growth in the next future (within the lifetime of the smart gas metering investment). Furthermore, the fields of application which result having a low degree of adherence with the IoT paradigm are left out of the analysis as this implies that their communication infrastructure doesn't present the requirement for integration with other services (i.e. custom communication solutions, reduced interoperability, no multi-functionality, etc.). Figure 44 shows the resulting selected field of application suitable for the integration with the smart gas metering infrastructure.

The actual electric smart meters has been left out of the focus in Figure 44 as, although having a great level of adherence to the IoT paradigm, don't present the interoperability and scalability requirements to be integrated with another communication infrastructure – however the second generation smart electric meters to be deployed in 2016 will present those requirements as they are required to enable the smart grid paradigm. The "smart car" field of application, although diffused, doesn't appear in the red area of Figure 44 as is often based on custom solution, and intrinsically doesn't present any synergies with the smart metering infrastructure (i.e. the communication network can't be shared).

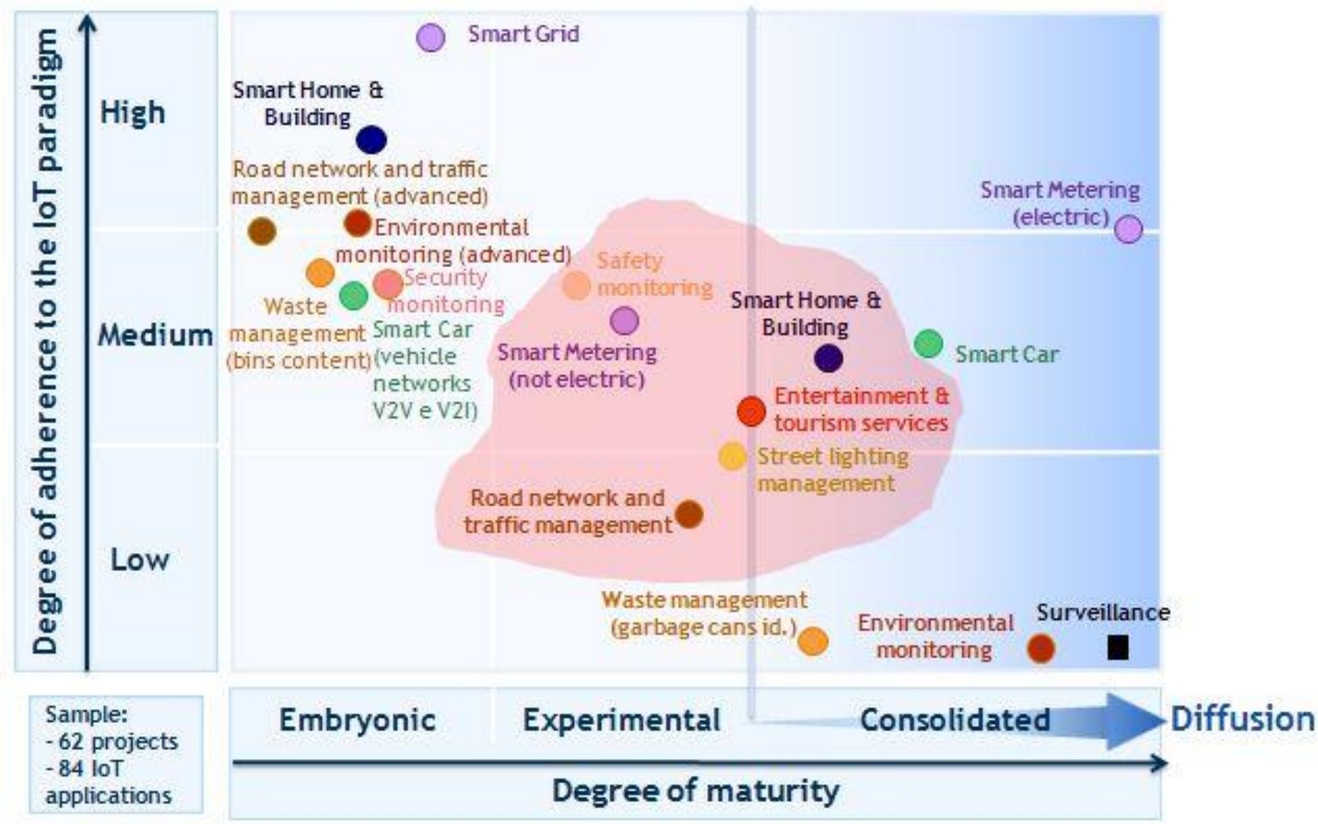

Figure 44 Smart city fields of application suitable for an integration with the smart gas metering infrastructure

Based on these fields of application, three service architectures have been studied characterized by increasing levels of integration but lower feasibility rates (considering the current infrastructural development):

- integration with other utilities;
- integration with other smart city infrastructural components;
- integration with other smart city infrastructural components and smart homes.

9.4.1 Integration with other utilities' services:

This solution has been discussed in the technological overview and involves sharing the infrastructure with other electric meters, water meters and heating meters (whether these are available). The resulting technological architecture doesn't present substantial issues and can leverage on the same standards designed for gas (cf. scheme in Figure 45)

Although as mentioned before, the current smart electric meters can't be adapted into a component of this infrastructure and therefore to be added to the system next generation of smart electric meters should be deployed (foreseen for 2016).

For what concerns the water meters, the needed infrastructure present requirements equivalent to those in the gas sector, therefore allowing the full sharing of the communication architecture. However these are not required by the Italian regulation, although it seems that this option could be envisioned in the next future given the high inefficiencies characterizing the Italian water grid (and water regulation authority has recently – January 2012 – been assigned to the same gas and electric authority AEEG).

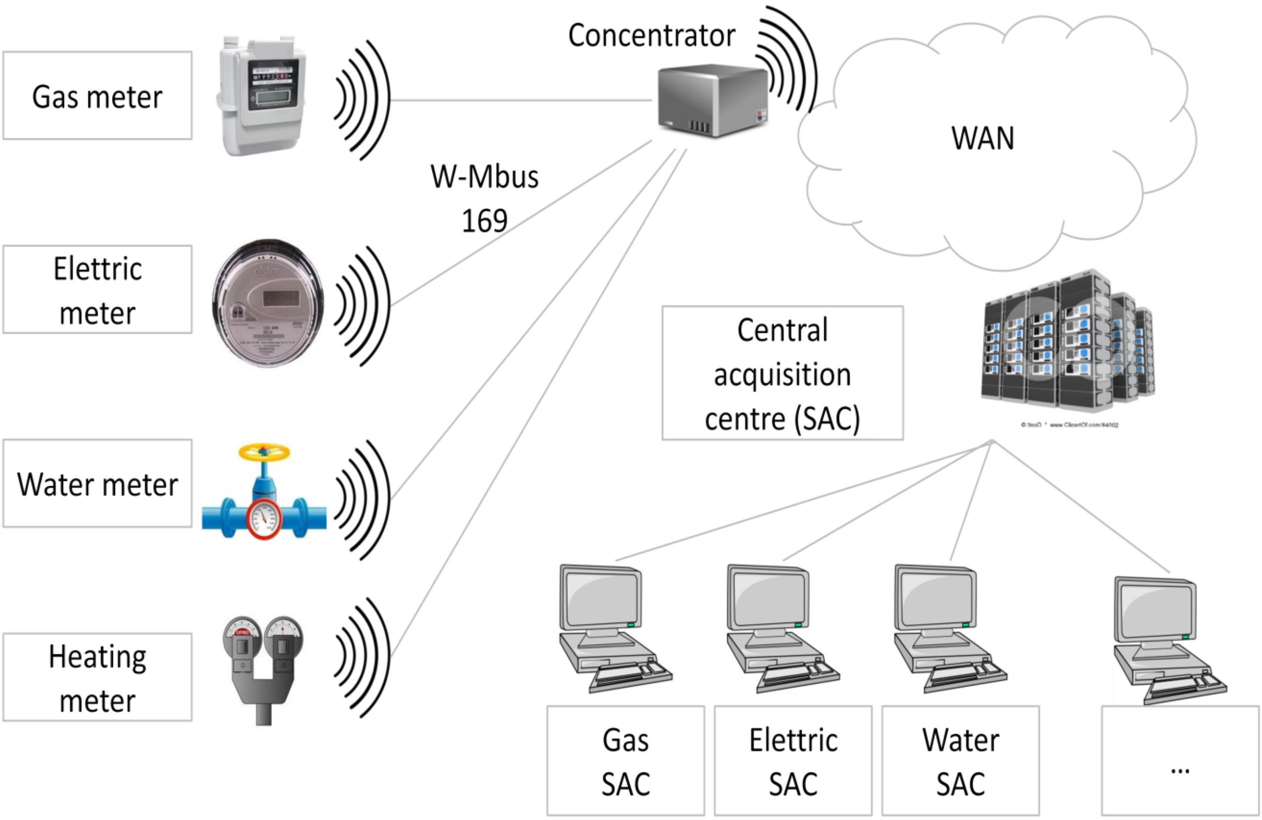

Figure 45 Integration with other utilities architectural scheme

For what concerns heating systems, these present the same requirements of the other meters previously discussed, however heating meters are subject to local or regional regulations and present substantial differences among different cities in the country. In Lombardi for example the recent regulatory order N° IX / 2601 mandated the installation of thermoregulatory and heat accounting systems for thermal system shared by a plurality of users.

9.4.2 Integration with other smart cities infrastructural components

As seen in the previous chapter when analysing the different smart city fields of application, the lamppost management represents a quite consolidated application field whose diffusion is significantly growing given the rapid return on investment. Its capillarity and presence around many city households combined with the power availability of exploiting such a synergy makes it an excellent component to be added to the communication infrastructure.

Safety monitoring sensors are also appealing towards the envisioned infrastructure as well as sensors for traffic monitoring. These components are more sporadic, but their integration requires an insignificant incremental cost. Furthermore the quantity of data they require to transfer allows the containment of the concentrator functionalities (interfaces, supported standards, etc.).

For what concerns entertainment and tourism services, it has been showed how these application usually make use of the NFC technology or to QR codes. These technologies don't present any similarities with the smart gas metering needed infrastructure and therefore won't be taken into account for the construction of the architectural solution.

The integration of security cameras or cameras for traffic monitoring can also be envisioned, although they require a higher bandwidth, therefore implying the need of using different communication standards (perhaps zigbee), deriving higher costs for the concentrator as previously discussed.

The public sector's role into enabling this level of integration is crucial as many of these services are managed by public entities and as the cost of the investment should be split among the different infrastructure's users.

Figure 46 illustrates the general infrastructure resulting from the integration of these smart city services.

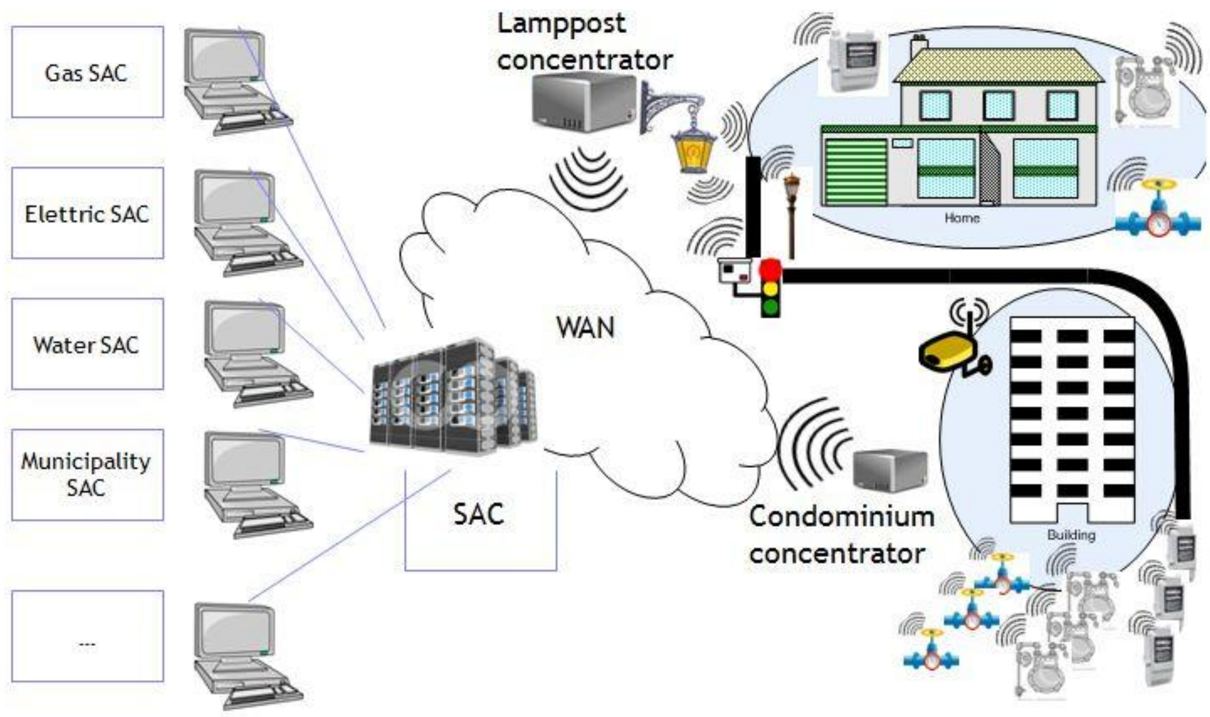

Figure 46 Integration with other smart cities infrastructural components

9.4.3 Integration with smart city and smart home

The most advanced integration level is the enlargement of the communication infrastructure until customer's households. Indeed this solution enables the provision of timely withdrawal data to customers through the communication with a home modem (or in-house-display) or simply through an internet portal. It enables the creation of additional value added services to customers, but presents some major criticalities and costs.

Although in the majority of household there is an internet connection which could enable the communication of the meter directly towards the central acquisition system, this cannot be leveraged on because of maintenance and reliability issues. Indeed, the household connection (often WiFi) is not reliable enough to be used for the metering service as for example whether the customer is not home this connection could be switched off. To overcome this issue the previous communication infrastructure should be installed, and whether the customer's HAN (Home AreaNetwork) is available this channel could be used by the meter (resulting in a marginal operating cost decrease). This although increases the complexity of the roll-out program, and doesn't seem too realistic in the short run.

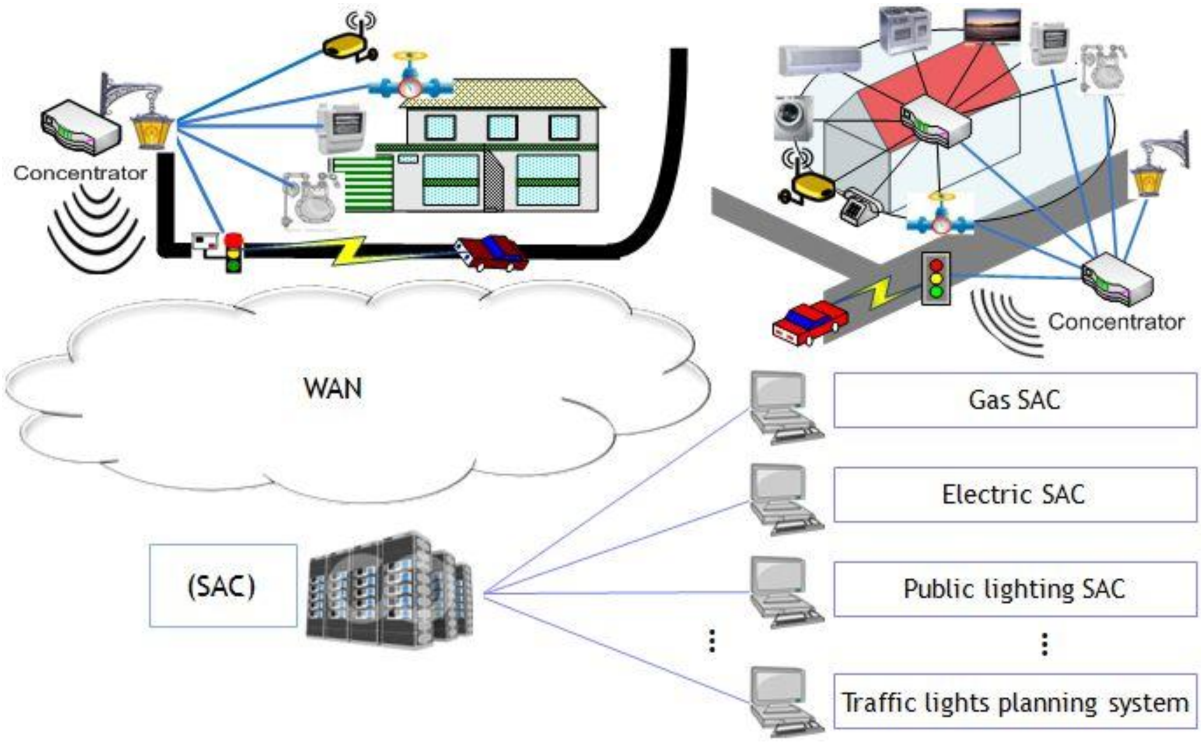

Figure 47 Integration with smart home

The only home application which could leverage on the installed communication infrastructure is safety monitoring systems (alarms) which need a separate communication vector from the HAN given their high reliability required. However, as seen in the previous chapter, safety monitoring systems although consolidated are often based on custom communication networks and thus, in the present state of art don't represent good candidate for the integration with other services.

The low number of synergies to be exploited with the smart home suggests that distributors will not envision this alternative. Perhaps the enlargement to smart home could be enabled in a subsequent period given the low incremental costs (just need a connection between the home modem towards the meter and towards the concentrator as shown on Figure 47 representing the scheme of the advanced integration level). It is important to mention that this architecture will most probably be implemented when second generation smart electric meters will be rolled out given the importance of home device management and demand-response schemes for the smart grid enablement.

9.4.4 Strengths and weaknesses

The benefits of the multiservice architectures previously analyzed strictly depend on the number of services for which the communication infrastructure is shared. The resulting infrastructure however presents the following strengths:

- **Coherence with European mandate M/441** and with last AEEG's resolution papers calling for pilot project proposals (DCO 40/11 and DCO 28/12)

- **Scalability:** A multi-service solution allows exploiting the communication infrastructure for subsequent needs. Indeed it tolerates the extension to other services to be provided through the same infrastructure with marginal incremental costs. The solution can be installed in the present exclusively for smart gas meters, but can be extended for electric meters, water meters, heat meters, but also to other smart city services such as traffic monitoring, environmental monitoring, managing public lamppost, etc.

- **Flexibility:** The solution can be customized for different users' needs and requirements

- **Effectiveness:** The solution enables an effective transmission of consumption data to the customer therefore satisfying the European directives aimed at increasing customer's awareness of their energy usage

- **Efficiency:** A unique communication infrastructure – and in particular a single concentrator – is sufficient to implement the system

- **Possibility of new service creation:** This solution enables the opportunity of providing value added service to customers through a simple communication with its local area network

- **Economical:** By optimizing field devices configuration, it allows reducing the costs of operations and maintenance as the unitary costs of each operation will decrease. Furthermore the cost of the service for each user should decrease as the number of users increase.

While the main criticalities of the multi-service infrastructure are:

- **The investment costs**, as analysed in the previous section is higher, particularly in the initial phases given the higher potentiality of the system

- **Natural monopoly** might emerge, which may impact on the metering services and create dominant positions (to contain this issue, a strong regulatory authority is needed)

- **Organizational and planning costs** are also higher given the relatively higher complexity of the communication system and the different actors involved. Forecasts on the future users of the system need to be performed in all different locations to assess the value of this option in different areas

- **Need of local administrations support** in fostering the adoption of the system by different actors of the city (lamppost management – utilities – regulations for building access – etc.)

Chapter 10 - Future research issues

The structure of the analyzed business case for introducing smart gas meters revealed a certain degree of uncertainty regarding the real amount of benefits derived by the provision of timely feedback to domestic consumers. Indeed, although the minimal functionalities required by the 155/08 regulatory order don't foresee an effective interface for providing actual consumption feedbacks to consumers, the analysis of the major international initiatives as well as the recommendations of the European Commission highlight the need of future academic research on the topic to assess the real potential of changing domestic consumption patterns.

The analysis of the state of art picture of each "Internet of Things" field of application encompassed by the smart city concept, also presents some limits as being based on the case study tool, doesn't pretend to be exhaustive. Increasing the dimension of the case study sample through further research would definitely consolidate and refine the results obtained through this work. In particular the analysis revealed the presence of innovative and forward looking projects (although in their embryonic stage of development) characterized by a high level of adherence to the IoT paradigm in different smart city's fields of application. Monitoring the development of these application fields is of utmost importance for the accurate assessment of the value of exploitable synergies for the smart gas metering infrastructure.

Finally, the realization of pilot projects to test and study the resulting shared communication architectures would further shed light on the operative, technical and managerial complexities of the multiservice metering infrastructure requiring an active participation of the public sector.

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