Energy Systems for Smart Cities

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***Abstract*— This White Paper has its roots in the two-day workshop held in Trento, Italy, in December 2014 involving representatives from local governance, associations, industry and start-ups. Future Energy Systems in Smart Cities are expected to be based upon distributed energy generation, real-time demand/response and user engagement for a collective awareness about the value of energy resources. In this technological ecosystem, ICT scales up from a commodity to a fundamental pillar to "smartify" the cities. Within this context, empowered communities of users, local governance together with citizens, can perform common actions aimed at maximizing the efficiency of distribution and consumption of energy. Several actions can be implemented with the active engagement of the local communities and stakeholders. This paper aims at presenting how the Municipality of Trento can adopt technological innovations and new end-user engagement policies.**

Keywords - energy efficiency, smart cities, smart grid, policy.

I. Introduction

Energy efficiency is a key challenge for building sustainable societies. Due to growing populations, increasing incomes and the industrialization of developing countries, the world primary energy consumption is expected to increase annually by 1.6%. Hence, issues have been raised regarding the increasing scarcity of natural resources, the acceleration of environment pollution, and the looming threat of global climate change. For these reasons, the European Union is committed to cut 20% of its annual primary energy consumption by 2020.

Addressing energy efficiency means managing the future lifestyle of citizens. In fact, if we look at the impact of technologies related to smart energy systems, it is clear that we are not merely integrating various technological innovation building blocks into the existing systems. Conversely, we are bringing into such scenarios a set of epochal changes. Some of them can be summarized as in the following:

1. Energy consumption will become one part of the bill, as users will turn into prosumers and be capable of producing energy on their own.
2. People will live in more comfortable conditions at their households, at reduced cost and pollution impact.
3. New public lighting with lower ecological impact will be available as pervasive infrastructure for ICT services.

From a technological point of view, the main expected challenges are related to ICT, which will no longer be used as a commodity and will instead become the structural enabler of change. In detail, some challenges are the following: i) technology has to become as transparent as possible to the end users; ii) the dissemination of new technology should be driven not only by industry but also by local and central governments; and iii) the adoption of new technology must be driven by big players, engaging on the front of service innovation, both Small and Medium Enterprises (SME) and start-ups

The paper is organized as follows. In Section II, some of the main innovative solutions applied in future energy systems are described. Then, in Section III, the current situation in Trento is presented, while the action plan and priorities are discussed in Section IV. Finally, Section V concludes the paper.

II. Innovative Solutions in Energy Systems

A. Smart Grid

There are several definitions of smart grids: the IEEE portal on smart grids (http://smartgrid.ieee.org/ieee-smart-grid) specifies that "the 'smart grid' has come to describe a next-generation electrical power system that is typified by the increased use of communications and information technology in the generation, delivery and consumption of electrical energy" [1], while the European Technology Platform on SmartGrids (http://www.smartgrids.eu) defines a smart grid as "an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies.” The general expectation of engineers and researchers addressing this topic is that future electrical distribution systems will be more and more characterized by the simultaneous presence of different types of distributed resources, such as renewable energy sources, storage systems, and loads that actively contribute to the operation of such systems. For this reason, the smart grid will lie on top of an increasingly complex and high-performing ICT-relevant infrastructure.

The adjective ‘smart’ has been introduced only recently, and this was essentially by making reference to the distribution network, which, before the recent massive deployment of dispersed generation (largely of the renewable type), was representing a passive load for the high-voltage transmission network. The result of this major change is that, currently in some countries, electric grids no longer deliver energy in a one-way flow from large de-centralized power plants to end users, and this tendency is expected to further increase and to spread worldwide; producers and consumers will continuously interact at different voltage levels through smart devices and control systems in order to balance the production and demand of electricity. Such a smart grid should include new technologies and infrastructures that will enable new forms of flexibility, thanks to the more interconnected approach of multilayer systems/infrastructures. The lack of flexibility typical of renewable resources, such as wind and solar, and their random nature could therefore be compensated for, combining the electricity, thermal, and transport sectors through appropriate control actions and thanks to the deployment of massive amounts of ICT.

The smart grid is therefore viewed as a great enabler for the development of smart cities, which will very likely see the diffusion of smart energy systems. A smart energy system can be conceived as a system involving different energy distribution technologies, such as electricity, thermal and gas grids, which could be combined and managed to exploit synergies among them with the aim of achieving an ‘optimal’ solution for the overall smart energy system.

We have assisted in the widespread use of renewables, wind and solar in particular, which has been enabled by the increasing awareness towards the advantages of a sustainable, carbon-free energy society. A number of government incentives enabling renewable energy diffusion has boosted the relevant industry, e.g., the Italian ‘Conto Energia’ (http://www.gse.it/it/Conto%20Energia/Pages/home.aspx). The number of generating units, mainly owned by users, connected to the distribution network has been impressively increasing. In Italy, for instance, generation plants (hydro, thermoelectric, wind, PV and solar) numbered approximately 4000 in 2004 and now are over half a million, the increase being ascribed mostly to PV plants [2]. In the summer season, renewable energy production in some countries has almost doubled, reaching 40% of the total (this was the case, for instance, in Italy for some days of summer 2014). The impact on the grid is such that conventional power plants fuelled by fossil fuels need to work in conditions different from those they were originally designed and built for and that the cycles that they are subjected to, fast ramp-ups followed by fast ramp-downs, may impair their durability. Grid codes have therefore been further developed to cope with this new technical challenge. Within this context, flexible generating units are becoming a fundamental asset, as they help provide stability to the electric grid by ramping output up or down as demand and system loads fluctuate. Because solar and wind generation can change within minutes, electric grid operators rely on power plants that can provide additional load (or curtail load) on the same timescale as variations in renewable output. Clearly, large storage unit availability would help in this respect, and in addition to hydro pump stations, the development and deployment of secondary batteries with high performances in terms of life cycle and depth of discharge become crucial.

Smart grid technical challenges

In Trento, the main technical challenges that the smart grid needs to cope with are coming from the massive diffusion of dispersed generation at the customer side, especially from renewables and/or the active role that customers may be able to play when their generation plants are connected to the grid. Feasibility and flexibility are most likely the two main issues. Indeed, the injection of energy at the customer side results in:

- the inversion of power flows along the lines,
- the relevant possible violation of ampacity and voltage limits (complex to manage when feeders including distributed generation (DG) are connected to the same bus bar at which feeders not including DG are connected),
- the possible incorrect operation of distribution line protections,
- the loss of inertia of electric power system (which is fundamental to permanently achieve equilibrium between generation and loads) because some types of DG (e.g., PV systems) are connected to the grid through static converters and not through synchronous machines,
- the non-dispatchable nature of some energy sources, such as renewables, which exhibit random availability and therefore call for smarter grid operation and make crucial the role of storage units.

Electric vehicles’ connection to the grid represents another major challenge for the grid capacity and management. Issues relevant to the increase in current and voltage harmonics introduced into the network by power converters will need appropriate filtering means and tools.

Role of ICT in distribution grids’ optimal management

The above considerations imply that the role of ICT in distribution grids’ optimal management is crucial. This point has been very clear since the smart grid concept was thoroughly analyzed (see, for instance, the interesting report issued by the EU Commission "ICT for a Low Carbon Economy. Smart Electricity Distribution Networks” [3]). Concerning particular distribution networks, ICT solutions will need to support and provide some key functions, such as:

- interoperable Supervisory Control and Data Acquisition (SCADA) systems and Virtual Power Plant (VPP);
- monitoring power flow management;
- integration of large DG units;

- real-time communications between power producers, suppliers, Distribution System Operators (DSOs) and end users in order to coordinate the outputs of the various energy resources and loads within the operating constraints to achieve the desired objectives (optimization of voltage profiles along the network, loss minimization, imbalance reduction, etc.);
- real-time M2M interaction in several contexts, e.g., home automation or DSO control centers;
- algorithms to superimpose and maintain a virtual mesh of the desired topology or to guarantee the self-healing capability of the distribution grid after various types of faults;
- intentional islanding;
- cyber security protocols to protect local grids and wider energy networks.

For some of these topics, the development of platforms enabling the simultaneous simulation of electric power and telecommunication networks appears to be an extremely promising tool.

In [4], for instance, the issue of coordinating the outputs of the various energy resources (and loads) with the actions of available control means, such as transformers equipped with on-load tap changers (OLTC), mechanical switched shunt capacitors and static var compensators (SVC), is analyzed. To exploit the above-mentioned coordination function, a Networked Multi-Agent System (MAS) composed of numerous localized controllers with the ability to communicate with each other is assumed. The overall performance is verified thanks to a co-simulation tool that enables the assessment of the quality of communication links when using a shared network that is, in general, characterized by stronger limitations than the communication links adopted for high-voltage transmission network operation.

Smart energy storage

Electric energy consumption is characterized by cyclical patterns explained by consumption seasonality factors and by random spikes, attributable to weather conditions and human behavior anomalies.

Random consumer behavior is the main reason for alternative energy sources' inefficiencies. Another problem is the difficulty faced by conventional power plants in reacting to insufficient instantaneous power demand. The technical problem is the slow speed of reaction to changing load (from ten minutes to hours). Therefore, the consumption surge problem is traditionally solved in two ways: (1) by continuing to generate surplus power and dissipate unused power and (2) by using special equipment (e.g., powerful diesel generators) to cover the transients. In both cases, the consumer pays for the inefficiency of the process with a higher price of electricity. Generation of solar energy and wind power are even harder to manage because peak consumption and peak energy production do not match. In such a situation, a feasible solution is energy storage, the ability to store excess energy and give it back at peak consumption demand time frames. There exist many different technologies for doing so, but the most mature and useful are hydro accumulators and battery storage.

Battery storage yields additional advantages, as it enables a power change response time on the order of second, the ability to install energy storage almost anywhere, and the ability to scale up by adding batteries. The limitation is the higher cost and the strong compliance to operating rules in order to not shorten the battery lifetime. Therefore, to ensure an acceptable Return-of-Investment (ROI), battery systems require proper maintenance. The Battery Management System (BMS) is responsible for both a uniform charge distribution on all cells of the battery (balancing) and ensuring that charge and discharge currents comply with the maximum allowable values.

B. Smart Buildings

Energy efficiency for heating ventilation and air conditioning in buildings

Buildings consume more energy than any other sector of our economy (approximately 40% of the primary energy we use) for heating, ventilating, air conditioning, lighting, etc. Thus, reducing energy consumption and eliminating energy waste are among the main goals of the European Union (EU). Most of the Energy savings in a building must be realized by adequate insulation in its construction, but ICT (and "smartification") plays a fundamental role by adding a technology value to efficiently manage dwellings, delivering an appropriate climate, lighting levels, etc., with minimal energy resources. With this additional step, a *Green Building*, such as those already present in Trento, becomes *Smart*, leading to significant reductions in total energy requirements.

It is widely known that more than a quarter of the energy used in the buildings sector could be saved by providing dwellings with intelligence and automatic energy awareness. Unfortunately, the installations of wired systems can be very expensive (for new buildings, the cost of wiring accounts for approximately 35% of the entire installation, and this contribution quickly rises for hard-to-wire places, such as historical buildings).

To address this challenge, it is currently possible to develop unobtrusive, inexpensive and energy-efficient intelligent electronic systems that can be deployed into people's homes and workplaces and other private and public spaces of everyday life. The recent technologies of *Ambient Intelligence*, *Internet of Things* (IoT) and *Cyber-Physical Systems* (CPS) are widely recognized to be the next generation of ICT technologies to make technology not simply embedded but invisible, fully hidden in our natural surroundings yet present whenever we need it.

Distributed embedded systems (e.g., smart sensors and devices connected to the internet) will collect information and control physical processes (such as automatic heating and ventilation) in feedback loops and will become essential tools for achieving energy efficiency in smart buildings.

Techniques for energy efficiency in electrical consumption

Domestic electricity consumption is continuously increasing and now accounts for more than 60% of the electricity consumed in commercial and public office buildings in Europe [5]. With a typical EU city having hundreds of public buildings, this sector has significant potential for improving energy efficiency.

Regarding residential buildings, many individuals would be interested in efficiently scheduling their own energy consumption to reduce electricity bills. However, people lack information on their consumption amount and patterns and on how these could be optimized. Typically, end users receive feedback on their household electricity consumption every month through electricity bills. Via this monthly feedback, people notice how much electricity they have consumed in the entire month, but they have no means of knowing their details, such as the amount of electricity used for specific applications and particular purposes (e.g., washing machine, lighting) and their occurrences during the day.

The vision of smart grids has been introduced to make the power grid more efficient and reliable. The main challenge is to convince consumers to participate actively in the supply/demand interactions and convince the utilities to invest in the smart grid infrastructure. Local government may encourage, facilitate, and empower consumers (particularly residential consumers) to participate in the response/demand-side management program through home energy management schedulers, which have already been studied [5]-[7].

A range of sensing devices is readily available to monitor all aspects of the environment, such as temperature and energy consumption, and to detect events such as movement. Smart meters are inherently distributed [8], [9] and heterogeneous [10], as sensor technologies have evolved independently, providing limited opportunity for integration. End-user programming is needed to control the devices and empower residents, addressing concerns of devices controlling their lives [11].

Role of ICT for smart buildings

Data comes from various sensing equipment, which differs in terms of the manufacturer, the format used, and the values returned by the equipment. The problem is how to provide a unified interface through which the end user can access the data. The trend is to use ubiquitous infrastructure to support context-aware applications that make sense of data received from diverse sensing devices and enable end-user programing and aggregation of data from disparate sensors [12]. A significant amount of research effort has been devoted to developing algorithms for automated analysis of various data from residential users. The role of ICT is envisioned to investigate the enabling mechanisms of data fusion, as well as the optimal cooperation schemes between the IoT and smart sensors placed in buildings. Innovative IT-enabled solutions for energy systems are emerging. Smart plugs are capable of accurate monitoring/profiling, thus enabling energy disaggregation at the device/appliance level, while multichannel smart sensors can measure load demand at the building or area level, as well as major energy consumption due to heating, cooling, lifts, etc. Innovative real-time data analytics will correlate smart meter data to uncover new energy insights, such as live anomalies (wastage, savings and failure) and long-term trends. Social networks, gamification, IoT and mobile applications will be employed to exploit this information for novel real-time feedback to end users to motivate them in an attractive and enjoyable way towards major energy-saving opportunities.

C. Smart lighting

One-eighth of primary energy is used for electricity generation, accounting for approximately 19% of the global electricity consumption [13]. The energy used for lighting equals two-thirds of the electricity production in the US and accounts for greenhouse gas emissions equaling 70% of the emission by passenger cars. Although the overall impact of lighting on the global energy consumption is limited to approximately 2.5%, the impact of lighting on energy use is much larger when focusing on environments with a high density of buildings.

Indoor lighting

The domain of indoor lighting is mainly divided between home/residential (consumer) and office (professional) markets. According to a study by the US Department of Energy (DoE) [14], the impact of lighting equals 12% in residential buildings and 25% in commercial buildings. This number equals nearly 40% for office buildings, making it the target application to develop lighting solutions to improve energy efficiency.

ICT-based LED technology is the most appropriate technology to generate light and to guide light deployment in an efficient way. In office buildings, lighting consumes as much as 40% of the total energy. By applying intelligent lighting systems, based on presence detection and the blending of electrical light with daylight, the lighting energy consumption can be reduced by 70%. The real energy saving challenge for Europe, however, is to transform the existing building stock, particularly in view of the low building replacement rate. Although lighting control systems have been around for two decades, their market penetration is still limited. In addition to the initial cost, the complexity of installation, commissioning and maintenance represent critical obstacles. Even more importantly, the behavior of current lighting control systems is often perceived as counterintuitive by the users. Over the last few years, sensor technology has progressed to such an extent that the end user no longer has to be confronted with non-intuitive system behavior. LED lighting technology is much more suited for integration with sensors and embedded software than today's technology, resulting in a superior cost-performance ratio with respect to the current lighting control systems. Moreover, to optimize lighting energy use, prompt feedback on actual energy consumption is relevant, as is a seamless integration of the lighting control and the building management systems. Due to the lack of open standards, many hardware components are needed to allow for the integration of different systems and solutions.

Outdoor lighting

Lighting in a city is everywhere. Street lighting in many EU cities is of antiquated design, resulting in wasteful use of energy. It is treated in a very tactical manner, evidenced by the aging assets that exist and the volume of citizen complaints. It is too often on when not needed, wasting power and money and also sometimes resulting in light pollution. Lighting is a significant budget line item. Quality low-energy lighting offers savings on energy bills and supports 'place-making,' public safety and security. The lamppost is also typically a single-purpose asset; however, that is not necessarily the only role it can play. New ICT technologies can help transform the role of the lamppost as a fixed asset for CCTV, Wi-Fi, parking, etc.

Lighting can deliver early rewards for cities. First, in significant financial terms: as lighting can represent some 20% of a cities electricity budget, savings in energy costs and maintenance costs of 20% and 70% are not uncommon. This is therefore a “quick win” for smart cities. Second, by using the existing physical infrastructure enhanced with digital infrastructure for multiple purposes, synergy across additional smart city services can be unlocked.

For example, there is a promising niche made feasible by technology development, including the emergence of energy-efficient LED lamps for street lighting, the advent of autonomous mesh networks and the sharp price decline of wireless connectivity hardware (Wi-Fi or otherwise). By combining every LED lamppost with a network access point, all the lampposts become access points, forming a mesh network. This infrastructure both allows remote control of each individual light point and provides wireless network connectivity covering almost the entire city. Smart remote lighting control allows for adjusting brightness and/or color and for efficient use of energy for lighting. In addition, the interaction with sensors further allows selective lighting on a city scale.

D. From Waste Water Management to Environmental Quality

Integrated water resource management

Waste water management is strictly related to energy savings. The European-wide shift in water policy is marked by the 2000/60/EU Water Framework Directive (WFD). This Directive creates the possibility of changing the planning process on a European scale through sustainable strategies. Such strategies provide a much more integrated (river-basin) approach to European water policy, explicitly recognizing the interdependencies between ground, surface and coastal waters. Additionally, they introduce key elements in water policy, such as the concept of “good” and non-deteriorating “status” for surface, underground and coastal waters. Moreover, the hydrological planning on a river basin scale of pollution-control measures is the best approach to reduce impacts in coastal areas [15]. The adoption of a ‘Program of Measures’ in the context of the WFD requires an integrated approach that combines principles of ecology, economics and sociology. Specifically, the WFD aims to preserve water resources by fixing quality objectives for all water bodies. At a European level, the WFD requires all countries to achieve specific water quality objectives (WQOs). However, it is not clear how these WQOs should be achieved.

Environmental Quality Standards (EQS) and waste water management

The integrated management of water resources includes the complete water cycle from water supply until the waste water is dumped in the receiving water body. Efficient water management requires an effective treatment of waste water. The Waste Water Treatment Plants (WWTPs) are of crucial importance to achieve water quality objectives (WQOs) and to maintain adequate environmental quality standards (EQS). Among the challenges that municipalities will have to face in the accession to the Covenant of Mayors (besides the reduction in CO_2 emissions), an upgrade of WWTPs is envisioned to reduce the impact on ecosystems, to save energy and to optimize waste disposal (sewage sludge). In particular, the high energy consumption due to the management of the aerobic component of conventional biological systems and to a high production of sludge is a critical point for the design, the upgrading and the management of WWTPs. The societal benefits associated with a reduction of the sludge and with the related energy consumption are also mentioned in the Horizon 2020 priorities, as it is stated that "eco-sustainable innovations will reduce pressure on the environment.”

The energy consumption associated with the treatment of urban waste waters at the municipality level is often not considered in SEAPs because the municipal WWTP is managed externally (e.g., by a private company). The high energy consumption associated with the operation of a WWPT is often considered as “necessary” to achieve high efficiency and to reach adequate environmental quality standards (EQS). Therefore, the main problem is just to recover the costs due to this consumption.

The link between the 20-20-20 objectives at the European level and both residential and industrial purification is very clear. In the case of Trento Municipality, the WWTPs of the urban area are property of Trento Province. Even if they physically lie within the boundaries of the municipal territory, their management is delegated to a specific treatment agency. Thus, in this case, the SEAP of Trento Municipality does not provide any measure for the reduction in energy consumption relative to the WWTPs. This is a gap in the regulatory framework: there is no connection between the Climate-Energy Legislative Package "20-20-20" and the Water Framework Directives 2000/60, particularly as far as the processes of integration between the strategic environmental plans is concerned. Who is responsible for the CO_2 emissions due to the energy consumption caused by a WWTP? Trento Province has an energy plan, but WWTPs are not mentioned. Thus, no measure is planned.

Considering that the WWTPs dissipate more energy at the municipality level than any other type of activity, the reduction in energy consumption and energy waste should be one of the main goals of both public administrators and water managers. Most energy savings could be achieved by adopting adequate plants and ICT-based smart solutions to manage the biological processes and to reduce the energy consumption of mechanical parts. Many technological solutions could be applied and tested in collaboration with the University of Trento and the Laboratory of Sanitary and Environmental Engineering (LISA).

III. The Situation in Trento

With the 2007 document "Energy for a Changing World," the European Union formalized the challenge to reduce its CO_2 emissions by 20% by 2020 while increasing by 20% both energy efficiency and the share of renewable energy resources. In 2009, the EU itself adopted the Climate-Energy Legislative Package "20-20-20," which requires EU member states to meet such goals by 2020.

On January 29, 2008, the European Commission introduced the Covenant of Mayors (EUSEW 2008). The

Municipality of Trento joined the Covenant of Mayors on April 8, 2014 by activating procedures to involve the entire citizenry in the development and implementation of a sustainable energy action plan, as is customary in best practices [16]. The accession to the Covenant is expected to generate a virtuous loop in spreading the culture of energy savings and environmental sustainability all over the territory while keeping a good balance with other instruments.

In particular, the plan consists of two parts:

1) The Baseline Emission Inventory (BEI), which provides information on current and future CO2 emissions, quantifies the amount of CO2 to be reduced and identifies the critical issues and opportunities for sustainable energy development of the municipality, along with the potentials of renewable energy resources;

2) The Sustainable Energy Action Plan (SEAP), in a strict sense, identifies the actions that the administration intends to pursue in order to achieve the CO2 reduction defined in the BEI. The SEAP includes a Counselor for Mobility (political reference), an Environmental Service Manager, an Integrated Solid Waste Project Manager, an Energy Manager, an Enterprise and Citizens Desk Manager, a Planning and Urban Mobility Manager and an Officer for Research and Statistics.

The SEAP of Trento addresses the following areas:

1. *Municipality buildings*, especially kindergartens and schools;
2. *Public lighting*, which has already been the subject of a project started in 2012 to reduce light pollution and consumption by 15% and to improve safety and quality of life.
3. *ICT-based services* for citizens and tourists (e.g., through smartphones). These in turn include:
   a. instruments capable of gathering energy consumption data;
   b. systems capable of computing and optimize energy consumption in real-time;
   c. certified databases regarding buildings;
   d. dashboards to manage and to analyze energy efficiency in public lighting and buildings.
4. *Health and University infrastructures.*
5. *Training of employees.*

On the basis of the Smart City Index indicators, Trento is currently at the forefront of energy efficiency and, in particular, the implementation of smart buildings, smart grids and smart lighting. Given the particular climatic conditions of Trento, the issue of smart energy systems is crucial, especially as far as the building energy efficiency is concerned. Additionally, the heritage of public properties of the City of Trento is quite complex and includes a relevant number of institutional structures dedicated to education and sports facilities. Currently, the energy dissipation of such structures is handled by an Energy Manager. The next step will be the introduction of automatic ICT-based Building Management Systems (BMS).

Several redevelopments of building envelopes, installations, and municipal buildings (120 of them are responsible for approximately 90% of the total energy consumption) have already been planned and implemented on a yearly basis. The analysis of the solutions applied in recent years on building envelopes and installations shows a reduction in consumption of at least 30%. This can be further increased with effective and integrated electronic monitoring solutions. By simply replacing old boilers, energy savings on the order of 10%-20% can be obtained. As far as the central heating systems are concerned, 65% of the total power is produced by high-efficiency condensation generators.

Various initiatives to train municipal employees and to promote good practices and guidelines for sustainability are currently ongoing. The Municipality estimates that, by making its employees aware of the impact of their own habits on energy, paper and water usage, energy consumption can be reduced by 2%, corresponding to 115 MWh/y.

Important actions are, and will be, performed by the City Council for Energy Efficiency and Smart Building. To this purpose, a new single and "certified" information database (the registry of the municipal property) will be created from the aggregation of various existing databases held by different subjects.

The assets of private dwellings estimated during the 2011 census consist of approximately 50,000 units. The same survey shows that a significant percentage of the building stock (over 45%) dates back to 1960-80. The presence of buildings with an appropriate thermal insulation and a BMS is therefore somewhat reduced because only in recently built constructions are such features actually present.

The residential sector is the most energivorous. In 2013, it accounted for 36.5% of the total energy consumption, with a reduction of just 2.6% compared to 2006.

Thus, a table of discussion on these issues with the participation of both authorities and stakeholders is still needed. At the moment, the following types of actions are planned by the Municipality:

- *Regulatory actions*, such as the definition of building regulations or other planning tools;
- *Compulsory energy* certification of buildings, both for sale and for lease;
- *Pilot actions in significant sectors*; in particular, studies should be performed for the identification of the best operational methods in large buildings with centralized HVAC systems;
- *Construction of new city infrastructures* and retrofitting of old ones (e.g., street lighting systems);
- *Promotion of meetings with financial institutions* in order to identify products and tools able to support the implementation of energy efficiency measures;
- *Advertisement and communication plans* to make the end user aware of the opportunities offered by new technologies;
- *Support for the identification of solutions* to reduce energy consumption in the residential sector;
- *Measures* to promote energy savings and the diffusion of systems based on renewable energy resources.

The actions outlined above are expected to save approximately 25,000 MWh/y of Municipality energy consumptions. However, the actions involving citizens directly can bring overwhelming results. In fact, higher energy efficiency in private households, wider adoption of renewable energy resources at the domestic level, efficiency policies in the tertiary industry and smart mobility strategies can provide results 10 times better than those achievable with Municipality projects alone. As a consequence, effective communication plans to increase citizen awareness and engagement have been strongly suggested by all parties involved in the workshop.

IV. Strategic Priorities and Challenges

A. Integration with other smart city objectives

A modern city can be regarded as a living body. Like an organism, every part of the city system is deeply coupled and interrelated with other parts through a complex network that is reactive to external and internal stimulations. Keeping the same analogy, the smart city layer consists of a set of sensorial organs (the sensors), muscles (the actuators), the neural system (the communication layer) and the brain (the hardware-software processing elements controlling the smart city systems).

Unfortunately, the smart city layer is not as interconnected and "organically" responsive as the physical city is. The smart services are seldom implemented in an organic manner. They tend to focus on specific tasks, completely ignoring the contextual events that may potentially affect them [17].

Smart city services should start to "think" and "act" in a more organic way. This means that they should be designed according to a federated scheme. This approach can introduce considerable optimizations to the existing services, thus achieving a leaner infrastructure and important cost reductions [18].

A good way to reduce the complexity of a federated scenario is the "smart district" entity, a subset of the larger smart city, usually coincident with a physical city district. Inside this smaller entity, it is possible to test and to introduce new smart services that can show their economic advantages and can be fine-tuned at an early stage to be delivered more effectively at a larger scale in a following phase.

Many infrastructures (such as storage systems or renewable production plants) make more sense if they can be delivered at the district level, as they improve efficiency and assure better economic returns over a wider scale (this is also a moral obligation given that the investments in smart city infrastructures are mainly public).

It is essential that the federated services are based on open standards and widely accessible to third-party integrators. This could create a potential marketplace for the services developed by private companies and freelancers. The citizens could significantly benefit from such new services.

The governance of the smart services in a federated smart city scenario has to be held by local public bodies (such as the Municipality) because the citizen has to access a set of core features with no costs. Third-party services have to be non-essential, according to a "freemium"-based business model.

The legislation should overcome the "property lot-based" approach and encourage "smart-districts" as the optimal scale for both public and private infrastructural investments.

B. Citizen engagement: from awareness to involvement

As explained in Section III, citizen engagement is essential to achieve important results. First of all, citizen awareness leads to mature decisions from both economic and environmental points of view. Second, active participation assures high-quality feedback, which is vital for any management system. As a result, the energy policy can rely on a proper combination of general public requirements and citizen-specific needs, thus providing a better understanding of the complex trade-offs and choices that should be made to support energy transition decisions. Moreover, local and interactive involvement is probably the most effective approach for the development of sustainable energy strategies, as citizens can cooperate with energy companies and the government while the government can involve citizens in energy budgeting. It is also important to evaluate whether the decisions are socially and politically acceptable and do not violate privacy issues. In this respect, the role of citizens is essential.

From the smart energy perspective, citizen engagement is technologically feasible through Internet and mobile phone technologies. Smart metering, advanced big data analytics and prediction technologies can be used to exploit aggregate citizen data, thus contributing to address local and global societal challenges.

V. Conclusions

Energy efficiency and sustainability are key priorities for smart city development, both at the local and the European levels. However, such goals cannot be addressed with stand-alone solutions but instead through the integration and combination of multiple systems and strategies involving a variety of areas and skills.

On the technological side, existing ICT solutions can already provide adequate answers to the needs of future smart cities. In particular, the city of Trento is planning to develop various pilot projects including smart energy systems and Internet of Things.

On the political side, various actions aimed at promoting energy efficiency and the use of distributed energy resources in both public and private contexts are currently ongoing to increase user awareness and to actively involve the citizens of Trento in the evolution of their city. Indeed, a clear engagement of the end users is considered a key factor to make a city truly smart and to improve the quality of life of its inhabitants.

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