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ICT ROAD MAP FOR SUPPORTING ENERGY SYSTEMS IN SMART CITIES

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Abstract *This paper introduces a road map for ICTs (Information and communication technologies) supporting planning, operation and management of energy systems in smart cities. The road map summarises different elements that form energy systems in cities and proposes research and technical development (RTD) and innovation activities for the development and innovation of ICTs for holistic design, planning and operation of energy systems. In addition, synergies with other ICT systems for smart cities are considered.*

There are four main target groups for the road map: 1) citizen; 2) building sector; 3) energy sector; and 4) municipality level. As an example for enabling active participation of citizens, the road map proposes how ICT can enable citizens' involvement among others into building design. The building sector roadmap proposes how ICTs can support the planning of buildings and renovations in the future, as well as how to manage building energy systems. The energy sector road map focuses on city's energy systems and their planning and management, including e.g. demand side management, management of different district level energy systems, energy performance validation and management, energy data models, and smarter use of open energy data. Moreover, the municipality level road map proposes among others ICTs for better integration of city systems and city planning enabling maximised energy efficiency. In addition, one road map section suggests development needs related to open energy data, including among others the use of energy data and the development and harmonisation of energy data models.

The road map has been assembled in the READY4SmartCities project (funded by EU 7th Framework Programme), which focuses on the energy system at the city level, consisting of centralised energy systems and connections to the national level energy grids, as well as interconnections to the neighbourhood and building level energy systems.

1. INTRODUCTION

Recently the focus of research and development for energy efficient and sustainable built environment has been broadening from building level to district and city levels. Currently, one of the hot spots is smart cities, and many cities are racing in their development and modernisation to become such. There exists already many definitions and assessment methods, as presented among others in [1-3]. In general, a smart city is seen as a large connected system consisting of several sub-systems, which are planned and operated in close communication and coordination among a wide range of stakeholders, experts, city officials, service providers, and end users.

We concentrate especially on energy systems of smart cities, taking into account all energy solutions and technologies for energy supply (i.e., production), energy distribution, storage and energy demand/consumption/use in cities. In addition, there are links to other sub-systems of smart cities, such as transportation systems or waste and water management. The improvement of energy efficiency of transportation and transportation fuel supply is excluded from the road map scope.

Our main goal is to suggest development needs for energy systems of smart cities and especially on how ICT is enabling and supporting the connection and integration of all the subsystems, resulting in an overall efficient energy system that is holistically coordinated. The road mapping work supports the realisation of the European Commission's energy and sustainability policy targets for lowering emissions, increasing energy efficiency and improving the overall energy efficiency.

2. BACKGROUND

This road map is a continuation of previous roadmaps proposing ICT solutions and recommendations for energy efficient buildings (REEB [4] and ICT4E2B Forum [5]); energy efficient neighbourhoods (IREEN [6]); and for investigating cross-sector expectations under the common theme of ICT 4 EE (REViSITE [7]). All these activities have been funded by the European Commission. Following the different results and conclusions from these roadmaps, it appears that the scale of the city is an important step in the race towards the energy efficiency goal. The detailed summary of these road map projects is available in [8]. These previous road maps form the base knowledge in the area, which has been broadened and adapted in this work.

The European Commission has set energy and climate policies for its member countries. Currently, effective 20-20-20 policies foster improving energy efficiency, increasing the use of renewable energy and lowering carbon emissions [9]. Moreover, by the time of writing this paper, the European commission is preparing a new integrated policy framework for the period up to 2030, aiming to continue the development towards a low-carbon economy [10]. The European Commission has also adopted the Energy Performance of Buildings directive (EPBD) on 2010 [11] with minimum building energy performance requirements by 2021 by introducing the so-called 'nearly zero energy buildings'. This road mapping work takes into account the European framework, policies and energy targets, and it can offer support in developing further Horizon2020 research framework.

3. METHOD

The methodology for developing this road map is fine-tuned from the experiences from previous ICT road mapping projects, especially from the IREEN road map [6]. The road map has been developed with a top-down approach, starting from setting up its framework and main scope [8], where the structure of the road map was set according to the four main target sectors: citizen, building sector, energy sector, and municipality level. Next, the main vision for each target section is formed, as described in section 4.

The road mapping has been strongly supported by experts involved in the iterative road mapping process. This paper presents the first road map draft that has been exposed to experts' comments and further development via various interviews and workshops. Experts will also validate the proposed road map. This road mapping work will continue until September 2015.

3.1. Structure of the road map

Each road map section begins by introducing drivers, needs and requirements, vision, barriers, expected impacts, and key stakeholders. Each sector has their own RTD and innovation focus topics, with descriptions of background, state of the art, and suggested RTD and innovation needs identified in short term (pilots and take ups; ~ 1-3 years), medium term (incremental development; ~ 2-5 years) and long term (radical research; 4+ years).

4. VISION FOR ICT SUPPORTING ENERGY SYSTEMS IN SMART CITIES

This section summarises the task of identifying and developing future envisioned scenarios for smart energy systems based on identified links between different energy systems [12]. Scenarios can be developed both based on bottom-up (what are next possible steps) and/or top-down (vision based) approaches.

The road map vision has been collected by stating the development needs for energy systems of smart cities and especially on how ICT is enabling it. The proposed scenarios represent the development needed and foreseen based on the 20-20-20 targets and on the 2030 and 2050 targets agreed in the environment, energy efficiency and sustainability policies by the European Commission. This kind of development is needed to adapt to targets of lowering emissions, increasing energy efficiency, and improving the overall performance of energy systems. The vision is structured into four main categories, which aim towards the same future.

Citizens are taking the active role of a prosumer (energy consumer that also produces energy). In addition, with the increasing use of "connected objects", citizens become the real actors of their own energy demand by making their own control settings for their use of energy appliances according to various indicators such as energy price levels or carbon foot print, being also active participators in demand side management. They have the opportunity to decide how much they are willing to pay for using electricity in different equipment and with what environmental impact during peak hours. Also gamification approaches provide new opportunities for engaging especially young generations e.g. to improve energy efficiency, energy savings, and sustainability of their daily actions and

behaviour.

The building sector has energy efficient, nearly zero, net zero, and energy positive buildings with on-site renewable energy production, connected to the energy networks. Buildings have systems and tools for managing the building as an active consumer and producer in the city's energy system. Building Management Systems enable buildings to be also connected objects that are able to communicate and negotiate with the electricity and heat networks' systems. As the big producer of data the sector has also the opportunity to learn and fine tune (by developing auto adaptive algorithms) its own energy behaviour and usage for better planning of on-site energy production, e.g. is it better to start a peak in power plants to meet the peak load demand, to decrease energy loads via demand side management, or is there energy storage available (and dimensioned accordingly) and feasible to use.

The energy sector is closely interconnected with the building sector at its city-scale systems and is participating to the local energy production and distribution; as such, its systems are able to communicate and negotiate with Building Management Systems that are also considered as distributed energy suppliers interconnected with the rest via energy networks. There are systems and tools for management and optimisation of the use of energy supply, or storage and demand, based on better predicting energy profiles and forecasting based on weather forecasts.

The energy sector operates the heat, cooling, and electricity supply, distribution and storage efficiently with the support of ICTs developed taking into account the intrinsic characteristics of various energy sources and networks. The use of different energy sources is balanced and optimised taking into account their own specificities and predicted energy demand profiles and renewable energy yield forecasts. Heat and cooling networks are operated at the local and city level with the use of low temperature levels more efficiently, and increasing the overall sustainability and efficiency of district heating systems. On the other hand, electricity suppliers do not have clear city level systems or networks, but they work on national and international grids with various electricity distribution companies for different areas and separately centralised large electricity producers. Electricity markets are global, e.g. European level electricity markets are foreseen. It is common to have energy brokers operating between the global electricity grid and a group of consumers. However, electricity and heat networks have also linkages, for example via combined heat and power production (CHP), where operation and optimisation for different situations is easier via the coordinated management of energy systems. New opportunities are rising for new actors in the local energy markets.

Municipalities play a role in energy efficient and sustainable city planning, smarter controlling of street lighting, and other city infrastructures such as waste and water management. Transportation planning and use of electrical cars is included in the coordinated and optimised operation of city's energy systems.

In order for such futuristic scenarios to emerge, ICTs as a set of pervasive enabling technologies have to play a major role especially in the following areas:

- Linked data/Big Data: In order to optimise the energy use and to balance the

- networks, the processing of huge amounts of interconnected data is a priority issue.
- Communication protocols, data models and standards for ICT communication between energy systems. This enables the technical realisation of interoperability.
 - Security: The data exchanged could be private data (citizen behaviour) or strategic ones, especially when smart grids are concerned. Thus the security and privacy of exchanges is of key importance to prevent from any breach or leak.
 - Internet of Things: All these systems will rely on sensors and actuators coupled to decision making mechanisms. These systems, to be largely deployed, must be easy to use and to interconnect to each other. Interoperability issues have to be solved from the hardware level up to the semantic level.

5. ICT ROAD MAP FOR ENERGY SYSTEMS OF SMART CITIES

The road map is structured according to the four main target sectors: citizens (excluding professionals), building sector, energy sector, and the entire municipality and city level. In addition, an overall energy data road map section has been developed.

5.1. ICT road map for citizens and their involvement

Citizens are increasingly interested in the social and environmental impacts of city evolution. Furthermore, Web 2.0 capabilities and, more in general, emerging technologies like open data are opening more possibilities for citizens to influence and participate into cities decision making processes. Finally, new ways of communication enabled by ICT (e.g., gamification) can allow providing more effective messages to people.

There is a need to improve information sharing, not only by opening available information, but also by adapting to the different levels of technical literacy of citizens, allowing them to understand impacts as well as the potential of different actions and solutions to be taken directly by them or by the city as a whole.

The vision is that citizens are fully involved in the decision making process through online collaborative platforms, which are able to explain at different levels of detail the social and environmental impacts of proposed city evolutions, as well as to collect contributions and feedback from citizens in a structured way. Applications and ICT infrastructures are able to help citizens to improve their energy behaviours on their daily lives by involving them and making them aware of the impacts of their actions.

There can be difficulties for many citizens to access ICT solutions, both for economical accessibility and technical preparation. Also difficulties can arise to communicate technical data in a meaningful way without losing their relevance.

Impacts are expected on increasing energy efficiency by new infrastructures that are planned and designed in a participative way, and by improving the citizens' behaviour to be more energy efficient.

5.2. ICT ROAD map for the building sector

Climate change is one of the main reasons for setting European and national regulation and

policies and has a large role for buildings and their energy efficiency, municipalities, transport and energy. Also the increase of energy prices drives to an increase of energy efficiency.

From the point of view of the road map, the needs are on data, which means data acquisition, data storage, and data processing from the building environment but also from other domains (energy grids, transportation systems, weather and urban activities at large). This implies that interoperability is ensured at different levels (from the physical level, where sensors, actuators, and acquisition systems are connected together, to communication protocols, data structures and semantics).

The vision is that the energy positive building is another connected object optimised to balance its energy behaviour to maximise the comfort of its inhabitants and to act as a power provider when required by external actors.

Barriers are mainly technical barriers related to the lack of interoperability standards, restricting the access to operational/dynamic data and the exploitation of data at higher/bigger levels. But there are also unsolved issues about the privacy of citizens that hamper the “opening” of private data on energy behaviours.

The expected impact is the generalisation of building energy management systems (BEMS) (and of course of buildings equipped with them) designed to “connect” these buildings to the energy and information grids, publishing open energy related information to internal and external requests compliant with local regulations (especially with respect to privacy aspects). These BEMS will be able to learn from their occupants and from their surrounding environment in order to refine/adapt their own energy scenarios (when to store energy, when to sell back to the grid, etc.) in order to develop self-adapting capabilities. But these abilities/functionalities rely on the public availability of comprehensive and accurate information on energy production and consumption and on enhanced energy management at the building and city level. Reaching such a “big picture” about the energy situation at the city level will require an appropriate interoperability approach, based on standards including those for ontology and open linked data. The standards will emerge to guarantee a full interoperability over the various systems and applications.

5.3. ICT roadmap for the energy sector

The energy sector is driven by an increasing share of volatile renewables in the energy market with an increasing amount of renewable energy production within the city. There is a need for local regulation of energy saving which, e.g., leads more and more to the introduction of smart metering techniques. Furthermore, there exists a drive to put off long term investments in energy infrastructure as long as possible by resorting to ICT based technologies.

Key needs here are ICT standards for communication for all systems in the energy market and regulations enforcing those standards taking into account flexible energy markets.

The vision is that a city is acting as a large power plant and virtual storage, being able to produce most of the energy needed by distributed renewable sources within the city itself, while being able to react flexibly on the availability of volatile renewables to enable their large-scale generation also outside the city. Optimized and flexible thermal distribution,

production and the increasing of energy efficiency of systems and interacting with the electrical grid bring mutual benefits.

Barriers include inflexible regulations for the energy market. Also stakeholders have conflicting interests, of which some examples are building owners versus building tenants, and grid operators versus energy producers.

Expected impacts are an increase in distributed energy production from renewables within cities, and the ability to react to varying energy supply by volatile renewables.

5.4. ICT road map for the municipality level

Cities are increasing their focus on improving sustainability among others by political pressure, cities' own targets, and action plans. Also the image of the city as a forerunner and a smart city supports the business environment and attracts companies to the city. Opportunities are seen for improving energy efficiency via integration and linking of different energy systems. ICT literacy of people and emerging technologies such as open data and Internet of Things offer new opportunities for wide engagement of citizens and system integration.

There is a strong need for broad collaboration, communication and interoperability within the municipality and with other stakeholder networks. Standardisation (both for interfaces and systems themselves) is needed for cross-organisational operation.

The vision is that efficient energy use and sustainable energy supply are included in the cities targets and realised in their planning, decision making, daily operation and development projects. Efficient energy use and supply are strongly linked and integrated to other operations and actions by municipalities through various ICT solutions. Municipalities foster the integration of different city systems to maximise their synergy impacts.

As barriers, municipalities have difficulties to estimate the profitability and other benefits of investments, and they also have difficulties to make long-term budget commitments in order to achieve life cycle optimum.

Impacts can be expected to improve energy efficiency and to reduce environmental impacts. Also increased synergy benefits rise from collaboration among different stakeholders on planning, development and operation.

5.5. Energy data road map

Advanced decision making in smart cities cannot be performed using data from a single or a limited set of sources; instead, smart city data are interconnected and new value will be obtained when understanding and processing these connections. This is also the case with energy data, which are decentralized and distributed across organizations, sectors, borders, and languages. Furthermore, a huge amount of data in the energy domain, or related to such domain, are nowadays online; regardless of whether such data are public or private, the Web is the platform currently used to share energy-related data and to deploy applications to manage them. Besides, the use of ontologies to facilitate energy data integration by representing data with rich semantics in a machine-processable way leads to a scenario where interoperability can be incrementally achieved.

A new generation of producers and consumers of energy data is appearing. One significant example for this are citizens who, apart from beginning to produce data related to their energy consumption or production, start demanding ways of processing energy data themselves or at least having them available to increase transparency.

One of the main requirements for energy data in smart cities is to reconcile heterogeneity in data across different domains, perspectives, and scales, while ensuring their consistency and reusability. Furthermore, such data need to be able to answer complex questions which usually require, on the one hand, unveiling and managing complex relationships between data from different sources and, on the other hand, having contextual information available. The number of ontologies related to the energy domain steadily increases; however, there is a lack of support for non-experts in ontology usage tasks such as ontology discovery and evaluation.

There is also the necessity of encompassing the different actors in the energy data value chain and of supporting them through guiding principles aimed at different profiles. Apart from this, new energy data management systems will have to be able to live along legacy ICT and to satisfy business-level and real-world requirements.

The vision is the consolidation of energy-related knowledge in cities through stable and accessible open energy data and through mechanisms that enable seamless sharing of cross-domain data between different stakeholders. This knowledge will be interpreted using a set of ontologies developed by standardization processes, thus ensuring their consensus and long-term maintenance. Energy-related data will be managed by public and/or private software infrastructures that support the distributed storage, sharing and processing of such data.

A barrier to this vision is that different types of stakeholders have different interests and viewpoints. Therefore, there are some non-trivial tasks such as reaching agreement on common ontological approaches between different domains or producing ICT that is easily usable across stakeholders. Furthermore, one main driver for the vision is the availability of a critical mass of open energy data. Currently, the publication of energy data is mainly hindered by privacy and security concerns; in order to change this, regulations and legal frameworks need to be adapted to the new energy data landscape.

The expected impact is to strengthen the energy data value chain through new business models that make value of open energy data. Furthermore, stakeholders will have a holistic view of the energy data ecosystem and be more efficient and effective in decision-making.

6. CONCLUSIONS AND DISCUSSION

The presented road map envisages future scenarios and development for smart energy systems based on identified links between different energy systems and interconnection needs and possibilities to broader smart energy networks. In addition, synergies with other ICT systems for smart cities are considered. This kind of development is needed to adapt to the European Commission's political targets for lowering emissions, increasing energy efficiency and improving the overall performance of energy systems. This version is the preliminary draft road map for experts' feedback. The road mapping work will continue until September 2015.

This road map suggests research and technical development and innovation activities in short, medium and long term development and innovation of ICTs for holistic design, planning and operation of energy systems in smart cities. The road map is structured into four main domain area roadmaps for citizens, building sector, energy sector and municipality level, as well as one integrating section related to energy data and its usage.

The repeating theme throughout the road map is a strong need for broad collaboration, communication and interoperability within various stakeholder networks. This requires standardisation (both for interfaces and systems themselves) to enable cross-organisational operation. Also the role of open energy data and its utilisation is included here.

The road map envisages increasing citizens' involvement and their active role in the daily life and decision making related to energy aspects. Buildings are becoming (nearly) zero energy buildings that are active prosumers that both use energy efficiently and also produce renewable energy on-site, and they are connected objects that are optimised to balance their energy behaviour to maximise the comfort of inhabitants and to act as energy providers when required by external actors of the energy systems.

It is foreseen that both in cities and in energy markets there are increasing amounts of fluctuating renewable energy supply. Additional ICT solutions are needed for cities that are developing and starting to act as a large multi-source power plant and virtual storage, being able to produce most of the energy needed by distributed renewable sources within the city itself, while being able to react flexibly also on the availability of volatile renewables to enable their large scale generation also outside the city. As a consequence, optimised and flexible thermal distribution, production and the increasing of energy efficiency of systems and interacting with the electrical grid will bring mutual benefits.

All this requires ICT standards for communication for all systems in the energy market and regulations enforcing those standards taking into account flexible energy markets. Another requirement is the smart use of data, which means data acquisition, data storage, and data processing from the building environment but also from other domains (buildings, energy grids, transportation systems, weather, urban activities, etc.). This implies that interoperability is ensured at all levels (from the physical level, where sensors, actuators, and acquisition systems are connected together, to communication protocols, data structures and semantics). At the same time, there is a need for local regulation of energy saving which, e.g., leads more and more to the introduction of smart metering techniques.

European countries and cities are increasingly adding to their agendas targets to improve sustainability. Also the image of the city as a forerunner and a smart city supports the business environment and attracts companies to the city. Opportunities are seen for improving energy efficiency via integration and linking of different energy systems. ICT literacy of people and emerging technologies such as open data and Internet of Things offer new opportunities for wide engagement of citizens and system integration. The project vision is that efficient energy use and sustainable energy supply are included in the cities targets and realised in their planning, decision making, daily operation and development projects. Efficient energy use and supply are strongly linked and integrated to other operations and actions by municipalities by various ICT solutions. Municipalities foster the integration of

different city systems to maximise their synergy impacts. Even with these future goals, the current reality is that often municipalities have difficulties to estimate the profitability and other benefits of investments and also have difficulties to make long-term budget commitments to achieve life cycle optimum. This challenge can also be supported by ICTs.

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