READY4SmartCities - ICT Roadmap and Data Interoperability for Energy Systems in Smart Cities

Deliverable D5.5: Impact assessment

Document Details

Delivery date:	*M21*
Lead Beneficiary:	*AIT Austrian Institute of Technology*
Dissemination Level (*):	*Public*
Version:	*1.0*
Preparation Date:	*03/09/2015*
Prepared by:	*Jan Peters-Anders, Nicolas Pardo Garcia, Florian Judex, Charlotte Marguerite, Julia Schmidmayer AIT* *Kleopatra Zoi Tsagari, Dimitrios Meskos, CERTH/ITI* *Mari Sepponen, Elina Grahn, VTT* *Bruno Fies, CSTB* *Andrea Cavallaro, DAPP* *Anna Osello, POLITO*
Reviewed by:	*Matthias Weise, AEC3* *Simon Robinson, EMP*
Approved by:	*Technical Coordinator (UPM) and Project Coordinator (DAPP)*

Project Contractual Details

Project Title:	ICT Roadmap and Data Interoperability for Energy Systems in Smart Cities
Project Acronym:	READY4SmartCities
Grant Agreement No.:	608711
Project Start Date:	2013-10-01
Project End Date:	2015-09-30
Duration:	24 months
Project Officer:	Svetoslav Mihaylov

Revision History

Date	Author	Partner	Content	Ver.
05.05.2015	Peters-Anders, Pardo Garcia	AIT	Plan of the content and document structure, work plan and schedule for task 5.5	0.1
23.06.2015	Zoi Tsagari	CERTH	Impact of Linked Data in Smart Cities	0.2
24.06.2015	Judex	AIT	District level electricity management	0.3
2.7.2015	Sepponen	VTT	VTT's contributions to introduction and impact assessment chapters.	0.4
6.7.2015	Pardo Garcia	AIT	Planning of district level energy system	0.41
7.7.2015	Judex	AIT	Controlling and managing energy performance of buildings	0.42
08.07.2015	Peters-Anders	AIT	Introduction part and editing tasks	0.43
09.07.2015	Osello	POLITO	Polito's "City's energy performance validation and management" and "Participation to building design" chapters.	0.44
09.07.2015	Meskos	CERTH/ITI	Updates regarding the Impact of Linked Data in Smart Cities and Impact of Energy data roadmap	0.45
16.07.2015	Marguerite	AIT	District level thermal heating and cooling management	0.46
30.07.2015	Andrea Cavallaro as representative of D'Appolonia project team	DAPP	Quality check	0.5
18.08.2015	Peters-Anders	AIT	Concluding remarks	0.6
28.8.2015	Sepponen, Grahn	VTT	Final updates from CSTB and UPM, sent for internal review	0.7
02.09.2015	Weise, Robinson	AEC3	Internal review comments added	0.7
03.09.2015	Judex, Schmidmayer	AIT	Final Version	1.0

Statement of originality:
This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

Statement of financial support:
The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement no. FP7-SMARTCITIES 2013-608711

Executive Summary

This document is the counterpart to D5.3 [Sepponen et al., 2014] of the Ready4SmartCities Project. While D5.3, the "Draft of an innovation and research roadmap" is a guideline how to proceed in the research and innovation needed in ICT toward transforming Europe's cities into Smart Cities, this deliverable describes the results of the actions, and therefore necessary components and processes which make a city "Smart".

For each of the sectors citizens, buildings, energy as well as for the municipalities itself the impacts are estimated for

- Short term: approx. 1-3 years usually,
- Medium term: approx. 2-5 years usually and
- Long term: approx. 4+ years usually

This is accompanied by the impacts of the improvement in the field of open data, smart use of energy data and data models, which are often a prerequisite for the innovations on the sectors to take place.

For citizens, available energy data and an environment allowing for the smart use thereof will result in them being able to change their behaviour towards a more energy aware way of live. From being able to monitor their energy usage to getting interactive advice on how to improve their energy efficiency will become part of everyday live.

In buildings, the harmonization of data towards BIM over the whole live cycle will facilitate efficient planning with the added benefit of citizens, as well as building management and renovation, as reliable data reduces costs of measures and improves the impact assessment as well.

In energy sector, the transition from consumer to prosumers will be facilitated, with ICT and new market models enabled by the ICT allowing for a more flexible and focused use of the available energy. This allows for direct integration of a high share of intermittent renewable sources within the neighbourhood, further lowering the carbon footprint of the city.

Finally the municipalities will get the tools to plan the transition of their energy systems and to monitor and therefore control the implementation of energy efficiency and GHG reducing measures, allowing feedback to stakeholders and decision maker about the impact of their actions.

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Terms and acronyms

API	Application Programming Interface
AR	Augmented Reality
BEM	Building Energy Models
BEMS	Building Energy Management Systems
BIM	Building Information Models
CHP	Combined Heat and Power
DER	Distributed Energy Resources
DH	District Heating
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution System Operator
ESCO	Energy Service Contractor
FM	Facility Management
GHG	Green House Gases
GIS	Geographic Information System
HEMS	Home Energy Management System
ICT	Information and Communication Technologies
KPI	Key Performance Indicator
LOD	Linked Open Data
OWL	Web Ontology Language
RDF	Resource Description Framework
ROI	Return On Investment
TRL9	Technology Readiness Level 9 (of 9 levels)
VPP	Virtual Power Plant
W3C	World Wide Web Consortium

1 Introduction

1.1 Purpose and Methodology

This report describes the mechanisms on how ICT contributes to city level energy efficiency, and it assesses the potential impacts of the proposed ICT roadmap developments. The target is to describe the cause-consequence interdependencies between ICT solutions and the suggested actions by the main stakeholders (citizens, energy and building sector and municipality). The analysis focuses on different activities for improving energy efficiency at a city level and on how the interoperability of different energy and ICT systems and business processes enables the exchange of data and sharing of information.

The impact assessment presented in this deliverable relies on the information and results gained earlier in the project. The base structure of the work was set in D5.1 [Fìes, 2013], including the choice of the main focus groups: citizens, the building and energy sector, and municipality. In addition to these, based on WPs 2 – 4, the data interoperability and open linked data approach was included as a fifth base element.

After that, the READY4SmartCities vision, as presented in D5.2 [Cavallaro et al, 2014], was created. The vision is that cities' energy systems are planned and operated with a holistic and sustainable approach. The optimal use of energy in a sustainable manner requires smart energy management, close collaboration as well as interconnections among various systems and stakeholders (citizen, building and energy managers, municipalities) in a complex operation (smart city) environment.

Next, a first version of the roadmap [D5.3: Sepponen et al, 2014], was created in collaboration with experts from different related energy fields and based on workshops. Then, a set of more practical level ideas for how to realise the roadmap suggestions was presented in D5.4 [Sepponen et al, 2015].

The potential impacts of the proposed ICT roadmap developments are assessed in qualitative terms. The assessment is based on available information ranging from the analysis of available research results to qualified expert opinions. In addition, an assessment is done about rebound effects that may reduce or delay the potential positive impacts.

1.2 Document Structure

The report is structured as follows. First, a summary of how ICT solutions enable the development of energy systems in smart cities is given. After that, the potential impact of the proposed developments for ICT supported energy systems is assessed. The impacts of Linked Data are estimated in Chapter 5 while the potential impacts of the READY4SmartCities roadmap are evaluated in Chapter 6. After that, a summary of the barriers and rebound effects for the potential impacts are determined. Finally, conclusions are drawn.

1.3 Contribution of Partners

AIT has had the main responsibility to prepare this document. The contributions from the partners are listed in Table 1.

Table 1. Contributions of partners

Partner	Resources planned	Contributions to sections
AIT	1,5 PM	Leading of work, collection of inputs, and main responsibility of the deliverable. Contributions to chapters 3, 6.2.3, 6.2.4, 6.3.1, 6.3.3, 6.3.4
DAPP	0,5 PM	Contributions to Chapters 3, 4 Overall check as PC.
CSTB	0,25 PM	Sections 6.2.1, 6.2.2, 7
CERTH/ITI	0,5 PM	Chapters 5, Section 6.7, Contributions to Chapter 7
VTT	0,5 PM	Sections 6.1.2; 6.3.2; 6.3.6; and 6.4.

		Contributions to Chapters 3 and 7.
POLITO	0,5 PM	Sections 6.1.1, 6.3.5

2 How ICT solutions enable the development of energy systems in smart cities

Integrated (City) infrastructure, including buildings and districts as well as eGovernment services, all linked via ICT, are key fundamental elements for bringing a city to be Smart. The vision developed in the context of deliverable D5.2 [Cavallaro et al, 2014] takes into consideration such elements with the aim of leveraging ICT solutions for increasing the sustainability - at energy, economic, and social level - in a Smart City.

Integration of ICT solutions for effective energy management and supporting decision making at building, neighbourhoods, district and city level as well as the adoption of ICT solutions applied for simplifying the relation between citizens, building and energy sectors and municipalities are not the only thing to consider.

Citizens for example are nowadays increasingly taking an active role as a prosumer (an energy consumer that also produces energy by themselves) and become the real actors of their own energy consumption by making their own control settings for their use of energy appliances.

The building sector is developing and implementing energy efficient, nearly zero, zero, and energy positive buildings with on-site renewable energy production, connected to the energy networks. Buildings have systems and tools (such as BEMS) for being managed as an active consumer and producer in the city's energy system.

Furthermore, the energy sector is closely interconnected with the building sector as the city scale systems are participating to the local energy production and distribution. The city scale systems are able to communicate and negotiate with BEMS that are also considered as distributed energy suppliers interconnected with the rest via the energy networks.

Within this scenario the role of local authorities, municipalities and government is fundamental in a Smart City for facilitating the adoption of standardized ICT processes and solutions. It is evident that without their support and cross-cooperation the "concept" of Smart City is inapplicable, because governments at national level and local authorities at city level have the power for leading the change for a more energy efficient and sustainable city planning.

3 Impact of Linked Data in Smart Cities

This chapter presents the impacts of Linked Data in smart cities. Section 5.1 focuses on the impacts of Linked Data as an enabling technology for interoperable energy systems in smart cities. The impacts of the Linked Data implementations themselves are then described in Section 5.2.

3.1 Impact of Linked Data as an enabling technology for interoperability in Smart Cities

Linked data, as the core constituent of the Web of Data, is one of the key factors for energy data interoperability in the context of smart cities which aims towards the creation of a global information space with links among the separate data resources. The Web of Data connects several information hubs that allow browsing, while data linking enables intuitive information discovery. This kind of interoperability does not intend to create an innovative querying technique for database silos or a common data format but desires to enable knowledge access and sharing without barriers.

The process of making data available for re-use and linking it with other resources under a unified knowledge framework reveals a new era of developments that improve collaborations among companies, organisations, institutions and simple users of different domains and regions. The Linked Data concept, with special emphasis on the energy data management, has been analysed in D5.3 [Sepponen, et al, 2014]. In addition to this, and from a technical point of view, a set of data requirements and best practises have been provided in WP4 (the public deliverables D4.1 [Radulovic et al., 2014] and D4.2 [Radulovic et al., 2015]) to the stakeholders' community towards maximizing the publication and the utilisation of such data as well.

The Web 2.0 fostered the current city policies to consider Internet, including mobiles, as a more participatory tool for citizens' participation and engagement. Currently, the quantity of published Linked Data increases day by day. Linked Data include open government data and semantically integrated data from sensor networks. Such networks have been deployed within the cities for the efficient management of heterogeneous processes and data sources (transportation, energy, planning, administrative tasks etc.) as well as the development of innovative key services. Furthermore, until 2017 the smart phone penetration per capita, which can be exploited for users interaction with available information via apps, is projected to reach 64.7 % in Western [The Statistics Portal, 2015a] and 58.2 % in Central & Eastern Europe [The Statistics Portal, 2015b], respectively.

The above mentioned technologies enable the seamless extraction and exchange of Linked Data realising the World Wide Web, while they integrate the physical world information into digital information for interoperability in a variety of short and long term city processes, namely:

- The creation of sustainable services on top of the data in order to efficiently react to city events and citizens' requests;
- Data-driven decision support allowing advanced and proactive planning based on historical data from multiple resources of information;
- Impact analysis based on measurable effects and comparison to benchmarking values (key performance indicators);

  Forecasting and predictive analytics for the identification of patterns, leading to advanced knowledge and interpretation of different city incidents.

3.2 Impact of Linked Data applications in Smart Cities

The combination of Linked Open Data and common vocabularies bridge the gap for the essential energy data transformation under a unified framework and offer unique collaboration opportunities among different domain stakeholders. The exploitation of Linked Open Data for the development of services, web applications, software tools, etc. directly impacts the Smart Cities' multi-disciplinary domains, which can be highly supported by semantic interoperability in terms of transforming their diverse resources into Linked Data. To this end, cities manage a huge amount of heterogeneous data (related to context, quality, security, access, etc.) and thus the Linked Data initiative, as a reference practice for sharing and publishing structured data on the Web ([Berners-Lee, et al., 2006], [Bizer, et al., 2009]), reveals the hidden interrelation and correlation among the distributed knowledge resources. Under this common Linked Data layer, the design and development of a variety of smart city applications is enhanced and the direct impact of designing such applications is addressed. Moreover, the availability of Linked Open Data resources enables the implementation of a variety of scenarios and use cases with the respective social-economic, environmental and technological impact. For instance, several application use cases, such as reegle[1], OpenEI[2] and data.gov.uk[3], demonstrate how Linked Open Data can have great impact on the respective target groups in a global layer [Bauer, et al., 2012].

The impact assessment of smart cities applications and services using Linked Open Data as the key enabling technology is a major challenge, as comprehensive and quantitative measurements have not been carried out due to the enormous amount of data collections and processing. In addition to this, a well-structured modelling of the urban system would be required [Komninos, et al, 2014]. On the other hand, web analytics (e.g., Alexa and Google page rankings indicate positive diffusion regarding new data technologies) can provide an overview regarding the usage of such smart cities applications and services but they cannot describe the impact of the actual interoperability performance at a city level. Furthermore, the Linked Open Data field suffers from a mismatch between the availability of data and its actual use (supply and demand gap), hence putting additional barriers on their final impact and its ability for socio-economic and environmental change [Loutas, 2014].

It is certain that Linked Data technologies have impact realised in various sub-systems of the city and, more specifically, these impacts reach beyond the city level and influence global major challenges. As a matter of fact, the contribution of Linked Open Data is vital to address the future world and urban commitment towards *preventing and reducing the impacts of climate change following the commitment to reduce the greenhouse gas emissions by 80% from 1990 to 2050* [European Commission, 2015]. To this end, Linked Open environmental, energy and building Data will impact the smart energy technologies (e.g., the optimal allocation of distributed energy resources, smart energy and grid technologies and efficient energy transmission) as well as consumers' awareness to make informed decisions. Towards this direction, the development of new products and services delivered to the citizens will help community groups and individuals to choose the best suited solutions in a cost effective way (energy efficiency improvements, the reduction of carbon emissions as well as fuel and energy bills).

In addition, many data related issues, such as availability, formatting, quality, APIs' development, exploitation, license, and provenance of information should be examined. This is relevant among others for the following future challenges towards maximizing the positive impacts:

- Fast growing and large-scale utilisation of sustainable energy sources in cooperation with citizens and other energy system users without compromising their tangible (e.g., cost savings due to efficient operation) and intangible (e.g., personalized comfort levels) needs.
- Motivation for reducing the energy consumption and higher penetration of renewable energy resources leading to a reduction of (1) CO_2 emissions and (2) environmental pollution.
- Improved access to secure and trustworthy data enables better data services and decision support, which will raise transparency and social awareness.
- Sustainable energy investments leading to market growth for clean energy solutions that are also providing a return on social, economic and environmental impacts.

[1] reegle application available at: http://www.reegle.info/
[2] OpenEI application available at: http://en.openei.org/
[3] data.gov.uk available at: http://data.gov.uk/

4 Impact of the ICT roadmap for energy systems of smart cities

This chapter presents the potential impacts of the READY4SmartCities' ICT roadmap for energy systems in smart cities. The impacts are divided into five different target sectors, the same ones as in the roadmap: citizens, the building and energy sector, municipality and energy data. The sectors have several sub categories with different approaches. The impacts are represented for each of these sub categories (in total 16), in the short, medium and long term. As defined in D5.3 [Sepponen, et al, 2014], the following

- Short term: approx. 1-3 years usually
- Medium term: approx. 2-5 years usually
- Long term: approx. 4+ years usually

applies for these three categories.

4.1 Impact of ICT roadmap for citizens and their involvement

4.1.1 Participation to building design

A well-developed community involvement program allows people to share ideas and concepts in order to arrive at a consensus on what is the best for the community [Green Communities, 2015]. This should be true particularly for building design (for both new buildings and renovation of existing ones) because people spend the most time of their life in buildings.

The ICT roadmap can help this activity thanks to **3D visualization based on interoperability** among:

- Building Information Models (BIM), used for the project at building level comparing different solutions;
- Building Energy Models (BEM), used to verify the "quality" of the project at building level starting from the different solutions developed using BIM;
- Facility Management (FM), used for the management at building level paying attention to energy saving;
- Geographic Information Systems (GIS), used for data querying at district/city level comparing buildings, different construction periods, use, etc.;
- Augmented Reality (AR), used for data visualization (by tablet, smartphone etc. using QRCode, markers, real objects/buildings, etc.) at building and district/city level.

The **short term** citizens' involvement process should begin immediately in order to:

- Enable participants to feel they are part of the process.
- Develop a spirit of cooperation among participants.
- Encourage the flow of accurate and unbiased information.

Effective community involvement in **medium term** can:

- Provide a way for community members to share information.
- Provide dialogue between the community and designer/decision makers.
- Generate creative alternatives and solutions integrating technical (from designer) and non-technical (from citizen) requirements.

As the process of community building does take time and needs to be followed up in the **long term**, effective citizen involvement goes beyond a time frame of four years. As it does not just happen, this process requires careful planning. This means that the roadmap has to: (i) identify the scope of the citizens (issues, needs and concerns); (ii) identify stakeholders involved in the design process (make a list, organize meetings, etc.); (iii) develop goals (inform/involve and educate citizen about the issues); (iv) select tools and techniques (as shortly described above in this chapter and in next chapter, chapter 6.1.2).

4.1.2 User behaviour and decision support for energy efficient living and working

Energy monitoring and its visualisation offer citizens a way to increase their awareness about their energy use and how it could be improved, but without compromising with the living and working comfort. In the longer term, ICT enables new ways to support this e.g. by integrated (self) learning mechanisms and advice about energy saving possibilities.

Short term ICT developments include providing a **user-oriented, *visualised way to show the real time energy demand information from smart meters*.** For this, the main impacts expected are to increase citizens' awareness about their own energy use, and as a consequence, to support them in reducing their energy use, and hence, their energy bills. E.g. Neenan and Hemphill [2010] reviewed energy savings achieved from smart meters in 24 different studies, showing the huge variation of achieved energy savings with smart meters ranging from 2.5 % to 18 %, with an average saving of 8 %. The way data is represented has a significant impact on the user behaviour. For example, Jain, Taylor and Culligan [2013] state that users contributed to higher energy demand savings, when they saw the information represented as CO_2 emissions than if the energy usage data was provided in kWh.

A step further could be taken by ICT tools providing consumption patterns and advice to citizens on how to improve energy efficiency according to their preferences and daily routines in the **medium term**. This is expected to increase potential energy savings for citizens. ***Real time energy data and integrated learning mechanisms*** enable improved decision support for users for increasing energy efficiency, and enable better ***energy performance benchmarking***. This also enables energy demand data to be integrated e.g. with community based social marketing, which will enable peak demand reductions (up to 20 %) in the participating households, as well as load shifting for moving e.g. 10 % of the peaks away from the peak load times, and the total average energy use reductions (approximately 10 %) [Martin and Temmen, 2014].

In the **long run** these measures and actions are implemented in the residential area at large scale and an interactive and effective interaction between ICT systems and residents is enabled. Impacts are linked to the planning of district level energy system (see Section 4.3.1 of this Deliverable) and Demand Side Management (see Section 4.3.2)

4.2 Impact of ICT roadmap for the building sector

4.2.1 Planning of buildings

The crucial role of ICT in the design of buildings was identified long time ago. Several roadmaps have been issued, focusing on various targets and scales (e.g. building / efficient building / smart building / building and the neighbourhood).

Interoperability of data models is the key enabler for ICT. The leading and structuring role of the BIM approach, playing the role of a unique reservoir of information for a given building project federating the various actors (and especially in this case of "planning of buildings", the actors involved before the construction phase), has already been mentioned. Nowadays the approach is more holistic, considering not only the building itself but also its environment. Beside the construction sector, the other sectors (i.e. Energy, Health, Road, Transportation, etc.) have developed their own models (ontologies, support languages and tools). The focus on the harmonisation of these various models will help in developing integrated design tools and solutions, able to manage the complexity of such holistic systems.

The **short term** impact of the roadmap in the planning of buildings will be new ICT tools that are able to facilitate the building design and take into account the multiple facets of their future environment, e.g. Sustainable & Social footprints, Health, Safety and Comfort.

The **medium** impacts will be in the continuity of the short term impact. The holistic simulations will be able to interest a larger audience that then will be committed to react and participate to the design (see the other chapters of this section).

In the **long term**, the data and tools used at the planning process will be seamlessly integrated in the overall building lifecycle. Panning, construction, building management, refurbishments and in the end the decommissioning and pulling down of the building will be a continuous process, with real data using the developed ontologies.

4.2.2 Planning and implementation of building renovations

The building renovation, from an energy efficiency point of view, is a key point. The policy directives at the European level, including the Energy Performance in Buildings Directive, its recast in 2010 (2010/31/EU), and various communications from the commission related to sustainability targets, have mentioned the requirement that public building retrofits should result in net zero energy buildings by 2021.

The building stock in Europe, that already exists, was built at a time when energy efficiency was not a design parameter. The stock is aging and the European Insulation Manufacturing Association (EURIMA) estimates that buildings waste €270 billion each year in energy costs and that if this was addressed, 530,000 full time jobs would be created and 460 million tons of CO_2 would be saved annually. A similar message is provided by the Energy Action Task Force, which identifies retrofitting as the most immediate, pressing, and cost effective mechanism to reduce energy consumption and carbon emissions in buildings and carbon emissions in the building and construction sector.

However, building retrofitting is challenging – not only because of the economic constraints and the diversity in usage, age and size of buildings, but also because of their cultural significance and listed/protected or monument status, which often makes it difficult to obtain necessary approval for work that may have an impact on the appearance or the structure of the building.

Occupant behaviour is an important issue that affects energy consumption patterns. A comprehensive understanding of the human dimension is, therefore, essential. Energy retrofits in buildings are thus highly complex and characterised by multidimensional constraints such as physical (space), economic, social and technical limitations.

When it comes to designing retrofit solutions, conventional thinking is dominated by (low) cost, aesthetics and occupant comfort satisfaction, often at the expense of energy use. Given new policy and focus on sustainability, there is a requirement to invent new concepts that satisfy occupant requirements and comfort needs, while also achieving substantial reductions in energy use. This requires new ways of evaluating systems, informing design teams to make optimal design decisions, and adopting appropriate retrofitting techniques. The retrofitting process requires a global perspective to be effective, such as:

- Strategies have to be devised, to convince the building owners of the possibility to couple energy optimization with planned maintenance or regular refurbishment activities;
- Knowledge-based decision-making tools and guidance frameworks must be provided to designers, contractors, building owners, and other stakeholders for them to be supported in making the right choices;
- Business models must account for all retrofit value prospects;
- Return on investment must be optimised by leveraging renewables, reducing solution manufacturing and deployment costs, attaining low-maintenance solutions, and through the implementation of a global, effective, focused, and optimised retrofitting strategy.

The main impact of the present ICT roadmap will be:

Short term: Facilitating the creation of knowledge repositories of practices that can be linked and compared together, thanks to the development of semantic based tools.

Medium term: As a consequence, decision support tools will be extended in order to take into account these new knowledge sources.

Long term: Validated holistic renovation methodologies will become available, along with simulation tools well suited for the various situations and typology of buildings and districts.

4.2.3 Controlling and managing energy performance of buildings

Solutions for building energy management and control, e.g. in the form of already commercially available building energy management systems (BEMS), are already well established, especially for large scale buildings. However, the cost for sensors and metering equipment is prohibitive compared with the energy saving mobilized by the equipment. Also, the split between investors, planners and tenants does not create much incentive for technologies with a long return on investment (ROI).

Short term: Static data about building energy performance is gathered in data platforms hosted by cities to get an overview on the overall quality and approximate energy performance of the whole building stock. The usually large numbers of buildings owned and run by cities are looked at in detail, and integrated monitoring solutions for large amounts of buildings are deployed, at first for cost controlling through energy demand controlling. Integrated solutions are the state of the art for larger objects, and their deployment becomes part of legal frameworks for energy monitoring of medium- to large consumers.

Medium term: With the standardization of data, the interoperability of components is largely improved, and providing ICT for measurement and controlling of building energy performance is an established part of construction and refurbishment projects down to multi-family homes. Passive systems which only allow to read and to evaluate building data are replaced by fully functional BEMS. Furthermore, solutions for integrating buildings and their energy systems within the smart grid, or advanced district heating and/or cooling solutions will be realized, using this enhanced building management capability. Systems are fully deployed by municipalities and other public bodies as part of their efforts to act as role models, and also the usually large amount of infrastructure owned by cities makes them prime customers for advanced energy control solutions, e.g. the virtual power plant (VPP) where the combined behaviour of a pool of installations is used to emulate a power plant using demand-response (DR) approach. Standardization of protocols allows for greater interoperability between vendors' products, lowering prices, therefore the profitability, steadily decreasing the size of buildings where BEMS are implemented.

Long term: Building energy performance assessment gets compulsory for buildings from multi-family homes upwards. ICT integration of building energy system data, metering data and external sources (the weather etc.) leads to a reasonable conclusion about the actual energy performance and allows for the readjustment or replacement of building energy systems according to energy efficiency standards over time. BEMS for DR are widespread, allowing full integration of buildings into the grid. City wide management and monitoring can be done on this basis, allowing for strategic planning of energy transport infrastructure on a very fine grained level.

4.3 Impact of ICT roadmap for the energy sector

4.3.1 Planning of district level energy system

The challenges to designing the future energy networks are focused on the integration of several types of distributed energy supply systems, mainly based on renewables. This implies joining together, in the same energy network, several technologies with different dynamics, regulations and usually high fluctuations to cover a relative inflexible demand. Such new networks should be able to manage and integrate distributed sources and supply energy also across a long distance.

Short term: New tools, able to give a holistic approach of the energy networks and systems based on dynamic models, will support energy planers to get a clear and better understanding about the interaction within the new distributed systems. Thus, integrated solutions can be created for updating the current energy networks and developing new ones. These new networks will have a high capacity to integrate distributed energy generation systems, mainly based on renewable energy sources, in an efficient way producing a better use of the resources with a lower environmental impact.

Medium term: The possibility to have solutions to planning and operating the energy networks considering the energy market, regulations and life cycle from an optimal point of view will have a positive impact on the energy planners in the design and on the energy operators in the operation of these energy systems from a better economic and environmental perspective. Furthermore, these new solutions will allow detecting the non-technical barriers into the regulations giving support to the policy makers to elaborate an energy policy with higher economic impact, including additional aspects such as energy security, environmental issues, and better use of the energy resources.

Long term: The possibility of sharing information at the city level will allow better management of the energy networks and an increase in customers' energy awareness. This will allow creating a smart energy community among the different stakeholders including the municipality, companies and citizens to improve the overall efficiency and management of the energy network in a collaborative way.

4.3.2 Demand side management

Demand side management (DSM) supports balancing of the energy grids by reducing the difference between energy demand and supply in real time, among others by reducing and shifting of peak loads. Demand side management is one way to support the increasing use of fluctuating renewable energy sources, such as solar and wind energy. As energy is traditionally supplied during peak load times from highly polluting fossil energy sources, the demand side management supports reducing of carbon emissions and other environmental impacts.

Short term: Energy is typically highly expensive during the high peak load times. Demand side management will offer energy users a new option for reducing their energy costs, as electricity sellers are increasingly starting to offer electricity contracts with using real time electricity price tariffs. This kind of electricity contracts are already available e.g. in Finland and France, whereas e.g. in Austria they are not offered, yet. As a consequence, if energy users can cut their energy demand during the expensive high peak load times or shift it to cheaper low energy load times, they can reduce their energy costs and possibly also their total energy demand.

Medium term: To allow interoperability of Home Energy Management Systems (HEMS) and smart devices (e.g. washing machines, dish washers) as well as heating facilities (e.g. micro-CHP units, heat pumps) the interaction of these technologies is crucial. This means that the activities in the development of standards are much more progressed than it is currently.

Long term: Manufacturer of HEMS and other technologies enable residents to participate in Demand Response programmes and DSM is used to actively support the balancing of energy supply and demand.

4.3.3 District level electricity management

On top of demand side management, district level energy management integrates also the production side. It includes on the one hand monitoring and controlling measures on a district level, to be able to verify the transition of a district toward being part of a smart city. On the other hand, the integration of a high share of Distributed Energy Resources (DER) after a certain point has to be augmented by more advanced control application, especially to cope with solar and wind production which can only be predicted up to a certain point.

Short term: Common legal conditions, market mechanisms and technology standards allow securities for companies developing services and products, by assuring a common market across the whole EU. This leads to services and solutions already tested but not realized yet due to the current obstacles being implemented quickly. Early adopter cities start to implement solutions for monitoring on large scale.

Medium term: Management solutions for districts including control reach TRL9 and that are implemented by Distribution System Operators (DSOs) and energy providers. Intermediaries like virtual power plant (VPP) providers enter the market as well. Improved controls lead to a much improved integration of intermittent and unpredictable energy production, e.g. reducing the need for wind power curtailment, as energy control on district level leads to a much higher total load being able to be controlled.

Long term: Advanced management of energy on district level allow for a high penetration of DER also within the district itself. Production and consumption can be matched on a local level, resulting in the use of the full potential of DER becoming economically and technically feasible on a large scale. Control of the electric energy is fully integrated into an overall city energy management, including heat and gas.

4.3.4 Thermal heating and cooling management at the district level

On the same lines as the electric energy management, thermal networks also will have to adapt to the switch from consumers to prosumers. Unlike electrical networks, the physical constraints are much stronger in this case, so management will include much more planning aspects in this case.

Short term: In the short term, the energy measures will lead to significant efficiency gains of the District Heating (DH) network with regards to the reduction of the heat distribution losses and pumping costs due to the adaptation of DH network temperatures. Peak load reductions directly lead to the reduction of the primary energy consumption. Renewable energy carriers and waste heat sources can be more easily integrated into the DH network (e.g. into the return line). The effects of those measures are overall lower primary energy consumption from fossil fuels and thus, the decrease in the total CO_2 emissions in a city are noticeable. New business models are starting to be introduced, including new tariff systems and thus, the involvement of related stakeholders is stimulated and the motivations for efficiency gains are triggered.

Medium term: Medium impacts will include an increasing share of decentralized energy sources that are managed in an optimal way. Multiple interconnections between the different networks will be realized on various levels (e.g. establishing hybrid control strategies for small and large scale heat pumps and CHPs), optimizing the performance in flexible energy markets. This will decrease the primary energy consumption and CO_2 emissions of cities' energy systems significantly. All relevant stakeholders are activated and new business models established leading to a segregation of market players.

Long term: In the long term, the complete transformation of the cities' energy networks into a fully integrated system will be achieved. The optimized operation of hybrid networks will enable the maximum utilization of all available renewable energy carriers, both for heat such as ambient heat, solar thermal and geothermal energy and for electricity --such as PV and wind energy-- and waste heat sources (e.g. from industrial processes). This is attended by a minimization of the overall primary energy demand and CO_2 emissions and therefore the maximization of the security of supply. At the same time, the operational costs are minimized by having a transparent marked and fair competition, ensuring the customers' rights.

4.3.5 City's energy performance validation and management

In order to measure results about the city's energy performance (for both validation and management) at medium/long term, some Key Performance Indicators (**KPIs**) have to be developed (see e.g. the City Keys Project[4]). Table 2 below presents an example of the elements that could be used:

[4] http://www.citykeys-project.eu/

Table 2. Possible KPIs for measuring cities' energy performance

KPIs about
Total annual consumption of electricity from the grid
Total annual consumption of electricity directly purchased from renewable sources
Total annual consumption of district heating
Total CO_2 emissions from electricity consumption
Total CO_2 emissions from heating and cooling consumption

In **short term,** those KPIs are used on a high level for a critical view at the current state of the city, leading into insight in which field the transition to a smart city is already ongoing and where it is lacking.

In **medium term**, the necessary ICT infrastructure to collect and maintain the data used to calculate the KPIs is established. Together with LOD an eco-system of application built on this data can evolve.

In the **long term**, it is essential to underline that significant results can be achieved starting from the use of energy simulation of the building working with interaction between building/energy network/policies at city level, as shown in Fig. 6-1 below (example from District Information Modelling and Management for Energy Reduction - DIMMER, FP7).

Figure 1: Energy performance validation and management

4.3.6 Energy trading and brokering

Energy brokering and trading plays a significant role in enabling holistically operated optimal energy systems in cities. Together with the demand side management (see Section 6.3.2), and energy systems' management (Sections 6.3.3 and 6.3.4), it supports increasing the share of renewable energy sources, and especially the use of fluctuating solar and wind energy.

Various new business opportunities are expected from energy trading, including energy selling, buying and pricing: where to buy energy and when, and how to better utilise the flexibility in energy demand and supply. It is yet unclear, who of the current actors will take this new business opportunity, or whether it brings new actors to the energy service business.

In **short term**, energy brokers could be able to e.g. forecast near future unbalances, find appropriate pricing levels for (distributed) energy supply, peak energy pricing, and support energy utilities in adjusting their energy supply for balancing it with the demand. To enable this two-way energy brokering between buildings, prosumers, producers and the energy networks and storage, firstly there is a need to develop user and building level ICT systems and protocols for the communication among them. Also, their operation needs to be monitored.

In **medium term**, more mature energy brokering could be managed with multi-level energy tariffs and by supporting demand side management platforms. This could be optimised with using forecasts about upcoming energy supply and demand profiles, available energy storage potentials. Then energy brokers would be able to forecast near future unbalances, and to take care of the energy pricing between energy users and suppliers of peak power and/or adjusting energy utilities for balancing energy supply and demand. With appropriate prising, energy brokers could support lowering the energy costs for their clients, and potentially finding better profitable business for small scale local distributed energy suppliers and prosumers, such as (nearly) zero energy buildings.

In the **long term**, an energy brokering system can be further improved by negotiating the energy price tariffs between the smart meter/building and the energy grid via related protocols. This would support increasing the use of fluctuating RES and reducing the unbalance between energy supply and demand, while keeping energy price levels on acceptable level.

4.4 Impact of ICT roadmap for the municipality level

4.4.1 Electrical vehicles integration to a city's energy systems

The overall target for smarter integration of electrical vehicles to the city's energy system is to (1) choose the best suitable time for charging the vehicles, and (2) enable a possibility to use electrical vehicles as energy storage in extreme situations.

In the **short term**, the timing of the charging of electrical vehicles could be more actively controlled as a node in the energy system. This would enable using them for energy balancing and cutting of peak loads. This could also support minimising of charging costs, when scheduling the charging for low energy tariff times. However, this shouldn't limit the user's possibility to use the vehicle, so user should be able to set (default) times when the car is needed and what is the minimum operation radius.

In the **medium**, the goal is to provide more flexibility for the city's energy system by balancing the energy supply and demand. This can be done with ICT systems and related standards supporting the usage of electrical vehicles as storage in the energy system in collaboration with demand side management and energy balancing. Then the user would need to be able to set (default) times when car would be available to be used as storage.

In the **long term**, using electrical vehicles as transport as well as a storage unit will become a business model for utilities, ESCOs and similar entities, selling either mobility or energy, depending on which is more profitable at a given time.

4.4.2 City planning enabling maximised energy efficiency

City planning can be supported by providing planning and design tools, visualisations of plans and their impacts and evaluation and scenario comparisons for different planning and design choices. In general, the expected impacts are two-fold: (1) reducing the time and efforts needed in the planning process and (2) improving the energy efficiency and sustainability of the final city plans though better understanding of the impacts of the choices.

The **short term** focus is on tools for the evaluation and performance estimation of the alternative city plans and their impact. Clear visualisations of the evaluation results will support urban planners to better understand the impacts of different planning choices, and make it easier to communicate them to both, decision makers and public audience(s).

The **medium term** target is to improve the interoperability among different data bases and the needed data exchange and access to as well as data acquisition from them. This will reduce urban planners working time for getting relevant information in the most useful format.

The **long term** target is to improve and support collaboration among different municipality departments as well as with external stakeholders, such as construction and energy companies and the public audience. The main impact here is to improve the overall efficiency of the planning process, and to reduce the overlapping work efforts as well as the amount of complaints to the plans.

4.5 Impact of Energy data roadmap

4.5.1 Development and harmonisation of energy data models

In order to facilitate applications to understand Linked Data, the data providers use terms from widely deployed or standardised vocabularies to represent data wherever possible.

Figure 6-2 demonstrates the distribution of the most widely used vocabularies. The majority of data sources in the Linked Open Data cloud use terms from the World Wide Web Consortium (W3C) base-vocabularies Resource Description Framework (RDF), RDF Schema, and web ontology language (OWL).

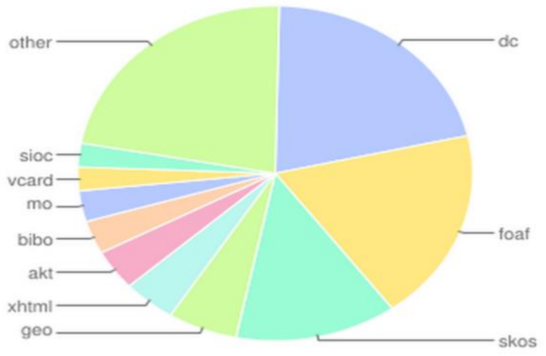

Figure 2: Distribution of vocabularies. [Adapted from Jentzsch et al., 2011]

The roadmap and proposed implementation actions for the development and harmonisation of energy data models are expected to have the following impacts.

Short term: Ontologies will provide semantic meaning to energy data and they will be developed to be utilised as reference models for representing different energy-domain concepts independently of the language and the initial application models. Since data usability is the key factor to make an impact, ontologies and metadata information will serve as the cornerstone towards maximizing data interoperability and exploitation potential. Among others, ontologies are one of the key enablers for technological change to provide formalized energy data models that will help experts to understand various energy systems' behaviour and take measures to improve their performance.

Medium term: Different methods will actively involve users and stakeholders (e.g. User Centred Design, User Created Content and User Co-Creation) in a more proactive role, highly affecting service innovation (e.g. feedback about users' needs) and product development. The semantic tools will improve both the precision and the energy information retrieval systems.

Long term: The adoption of a common ground for energy data models will finally bridge both linguistic and semantic gaps and will further enhance problem solving capabilities. Last but not least, the representation of structured, controlled and defined knowledge will create a common understanding for the rapid development of services and products, applications, and tools (with special focus on the energy domain). These tools will have impact on the increased user engagement, the improved balancing of energy supply and demand, and energy systems optimization leading to cost savings.

4.5.2 Open energy data, ecosystem and regulations

This section concentrates on Open Governmental Data and its impacts in countries with weaker or early stage open data initiatives compared with those that have strong initiatives, thus demonstrating the clear trend of the latter towards greater perceived impact. Figure 6-3 depicts the impact of open data on six major indicators with and without strong open data initiatives as backing support.

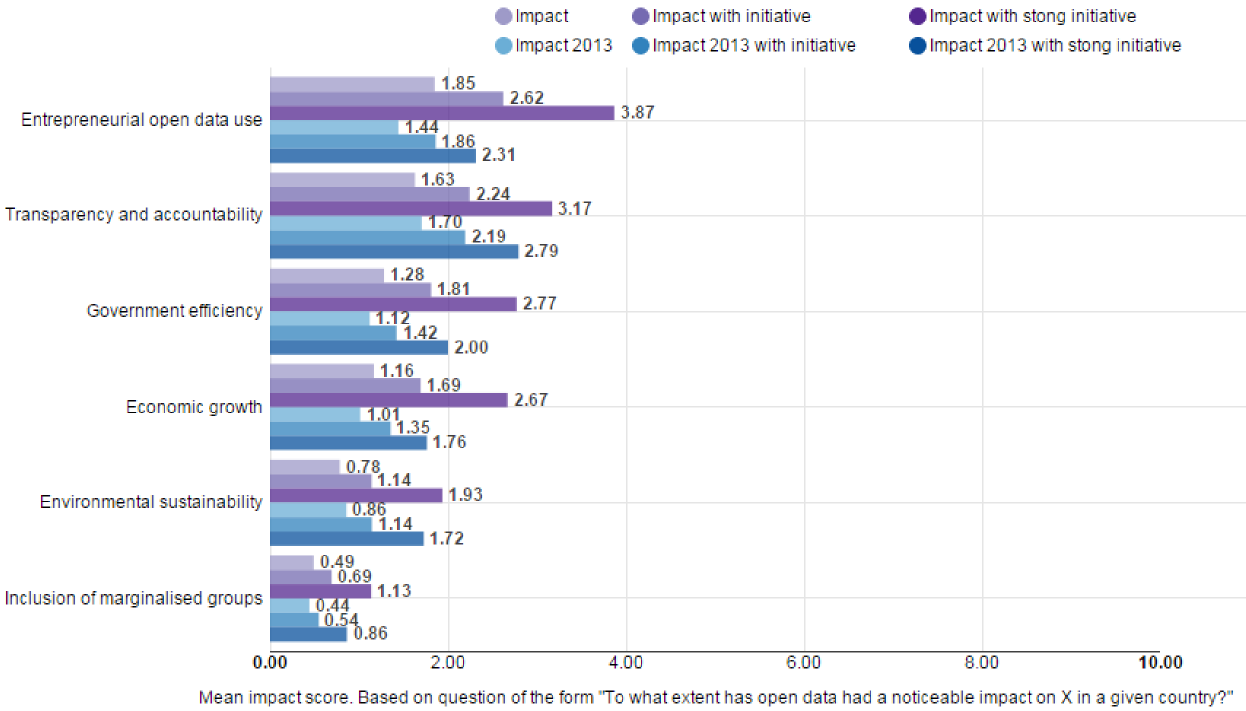

Figure 3: Representation of the 2014 mean score on impact questions [Adapted from World Wide Web Foundation, 2015]

So far, a relatively minor change has been observed in the perceived use of data for environmental issues. The energy sector ecosystem, including data producers and consumers, legislation, urban mechanisms and ICT infrastructures, needs to evolve towards exploiting the open energy data (both legally and technically open). Accessibility, discoverability and usability of energy data are the indicators for the maximising of impacts in terms of efficiency, scientific discovery and research, cost savings, business development, services, policy planning, transparency and public engagement.

Short term: The creation of open energy data strategies for supporting the data availability on the Web, along with the development of high level policies and guidelines, will ensure privacy and foster stakeholders to open their energy data. The impact of these strategies is not only directly depicted on digital services (maps, data-driven recommendations for energy usage etc.) but also contributes to the growth of economical scheme as more and more stakeholders can exploit open data easier for using and sharing.

Medium term: The opening of energy data will contribute to the identification of high value datasets to be prioritized for analysis and will lead to the development of solutions towards augmenting data accuracy, completeness and usability. In addition to this, the common effort for open energy data will connect data providers, users and policy makers for collaboration and solutions will be developed.

Long term: The Open Energy Data Ecosystem will be the catalyst for both national and global goals on energy efficiency exposing data to measure as well as predict energy consumption and production and related savings. The impact is not only limited for the public sector area and research, but can be expanded to the energy markets characterized by system inefficiency and different incentives.

4.5.3 Smarter use of energy data

The smart use of energy data for cross-organisational data management is currently based on the adoption of different models as well as the development ICT based innovations. These innovations are the most cost-effective means to achieve the required interoperability among distributed systems and applications.

Short term: The smarter use of energy data encompasses a variety of processes, such as the development of common ontological models offering interoperability and ICT developments according to the underlying technologies for the management of energy data assessed for their quality. The optimization of all these various processes is expected to have an enormous impact on the execution times for the realization of energy projects by avoiding data heterogeneities and inaccuracies for informed decision making. The consecutive financial benefits will further act as the main driver for the evolution of existing energy optimization systems.

Medium term: Energy data accompanied with contextual information (quality, licensing, provenance and trust) will contribute to the efficient exploitation of previous knowledge that was generated in relative projects based on actual facts offering new prognosis capabilities. Massive volumes of energy data will enable useful insights and in-depth analysis and modelling. The subsequent optimization of energy processes through accurate forecasts will further lead to the reduction of energy costs and to the achievement of carbon emission targets.

Long term: The global trend for international established data standards will impact the demand of solutions in the energy sector because of their added value raised by the interoperability among them. The increased adoption rate of ICT networks, along with the digital services supporting and consuming distributed energy data, will create new business opportunities for a wide variety of solutions regarding energy optimization.

5 Barriers and Rebound effects

Smart (City) infrastructure, smart buildings and districts, smart energy system as well as smart eGov services are key fundamental elements for bringing a city to be Smart. Thus, leveraging on ICT solutions could increase the sustainability in a Smart City. This section gives an overview of the barriers and assesses the rebound effects that may reduce or delay the potential positive impacts of ICT solutions.

The roadmap related barriers identified for the different stakeholders are the following ones [Sepponen et al, 2014]:

- **Citizens:** There can be difficulties for many citizens to access to 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.
- **Building sector:** 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. However, there are also unsolved issues with the privacy of citizens that hamper the "opening" of private data on energy behaviours.
- **Energy sector:** Barriers include inflexible regulations for the energy market. Also stakeholders have conflicting interests, for example building owners versus building tenants, and grid operators versus energy producers.
- **Municipality:** Municipalities have difficulties in estimating the profitability and other benefits of investments, and they also have difficulties in making long term budget commitments in order to achieve life cycle optimum.

The current barriers for the uptake of Energy Data are the following ones:

General barriers/challenges to be addressed:

- Lack of public understanding regarding the potential and added value provided by open data (advice, managed services, public events people to create products and services etc.);
- Community building difficulties in order to understand the needs of various actors in terms of datasets or specific visualizations;
- Lack of Legislation when implementing open data policies (not sure about what data to publish). Urgent need for the establishment of the proper legal instruments;
- Lack of support from the authorities. The role of the Government, municipalities and local authorities is fundamental in Smart City. Without their support the "concept" of Smart City is inapplicable, cause Government and local authorities have the power for leading the change;
- Technical and human resource capacity. Lack of the necessary IT infrastructure, difficulties in data extraction or lack of human skills to work with such data;
- No balance between the supply and demand of Linked (Open) Data. No mechanisms developed to support external requests for open data;

In terms of data context:

- Lack of inventories, slow identification and formatting of datasets that could be made available;
- Data quality;
- Privacy and confidentiality: Data requiring extensive anonymization or removal of sensitive information;
- Licensing terms;
- Accuracy;
- Timeliness, provenance and accessibility.

6 Conclusions

As we have seen in this document, the impact that ICTs have and will have (in some cases could have) on city level energy efficiency in the medium and long term is immense. The big questions will be if e.g. Linked (Open) Data initiatives will be adopted by the different stakeholders and communities they are developed for, and how this process can be triggered, fostered and seen through in the future. During its execution, the READY4SmartCities project encountered many stakeholders who were very interested in Linked (Open) Data techniques, but were reluctant to apply/deploy them due to lack of training and weak knowledge about the technologies and their benefits besides overall privacy concerns and the question on how to overcome those first. The impact of ICT in the field of energy efficiency within cities will therefore be a question of an extensive and comprehensive information and dissemination strategy in the near future to convince involved parties to adopt those technologies in order to improve energy efficiency measures and CO_2 emission reductions.

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