Innovation and research roadmap

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

Deliverable 5.6: Innovation and Research Roadmap

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Table of contents

Executive summary

The READY4SmartCities (R4SC) project examines the adaption of Information and Communication Technologies (ICT) in energy systems, in order to improve their sustainability and energy efficiency in smart cities. This deliverable presents an innovation and research roadmap, suggesting the development needs of ICTs in short, medium and long term for the holistic design, planning and operation of energy systems. The focus is on large energy systems at the city level: centralized and distributed energy systems with connections to both national level energy systems and to the neighbourhood and building level energy systems.

The roadmap is divided into five roadmap sections: citizens, the building sector, the energy sector, municipality and energy data. Each roadmap sector introduces drivers, needs and requirements, visions, barriers, expected impacts and key stakeholders. In the following, the goals of the different roadmap sections are specified from the viewpoints of key stakeholders. The role of ICTs and energy data in enabling these goals is also identified.

The involvement of ***citizens*** in decision making related to energy aspects should be increased. Citizens should take an active role in the operation and use of energy to improve their energy behaviour. ICTs could help citizens to improve their energy behaviour by making them aware of the impacts of their actions.

Buildings should become connected objects operating actively with energy networks and are optimized to balance the energy behaviour and thereby maximize the comfort of the inhabitants. Efficient energy use and on-site renewable energy production in the buildings is expected to be of high importance. Buildings could also be able to act as energy providers. This requires the smart use of data from the built environment, energy grids, the weather etc., implying that interoperability is ensured at different levels.

The ***energy*** supply in cities should rely both on distributed and centralised energy production with using many renewable and local energy sources. Cities would become large power plants and virtual storage, reacting flexibly on the availability of renewables. ICT standards are needed for the communication between all the energy systems.

Municipalities should foster the integration of different city systems to maximize their synergy impacts. Efficient energy use and supply could be realized through appropriate decision making, energy planning, development projects and daily operation within cities. Energy supply and use are integrated to other city operations with various ICT solutions.

Access to open ***energy data*** would enable the sharing of cross-domain data between different stakeholders, leading to the consolidation of energy-related knowledge in cities. The use of energy data would also give the stakeholders a holistic view of the energy systems.

The repeating theme throughout the roadmap is a strong need for broad collaboration, communication and interoperability within all the stakeholder networks. This requires the standardisation of both interfaces and systems themselves, to enable cross-organisational operation.

1 Introduction

1.1 Purpose and scope

The READY4SmartCities project focuses on energy systems in smart cities and their interconnections, including centralised and distributed energy systems and connections both to the national level energy grids, as well as interconnections to the neighbourhood and building level energy systems. The proposed technologies are mostly applicable to both urban and rural communities.

This report presents an innovation and research roadmap. It suggests research and technical development (RTD) and innovation activities in short, medium and long term for Information and Communication Technologies (ICT) for holistic design, planning and operation of energy systems in smart cities. The drivers, barriers and enablers of energy systems in smart cities are identified. In addition, synergies with other ICT systems for smart cities are considered.

1.2 Partners' contributions

The partners' contributions to this report is summarised in Table 1.

Table 1. Partners' contributions to this report

Partner	Resources	Contributions to sections
VTT	4.5	Task lead, input collection, main responsibility of the deliverable. Sections: 2. summarising the vision 4.3.3 Controlling energy performance of buildings 4.4.2 Demand side management 4.4.9 Energy trading & brokering 4.5 Municipality 4.5.1 Electrical vehicles integration to city's energy systems 4.5.2 City planning enabling maximised energy efficiency
DAPP	1.5 PM	2. Vision summary based on D5.2 4.2 Citizens involvement
UPM	1.5 PM	4.6.2 Smarter use of energy data 4.6.3 Open energy data, ecosystem and regulations
CSTB	1 PM	2. summarising the vision 4.3 Building sector 4.3.1 Planning of buildings 4.3.2 Planning and implementation of building renovations
CERTH/IT	1.5 PM	4.2.1 Participation to building design 4.2.2 User behaviour & decision support for energy efficient living and working 4.6.1 Development and harmonisation of energy data models
INRIA	0.5 PM	3. Enabling technologies: Linked data for energy data interoperability
AIT	1.5 PM	4.4 Energy sector 4.4.1 Planning of district level energy system 4.4.3 District level electricity management 4.4.4 District level thermal heating and cooling management
EMP	0.5 PM	4.3.4 Building energy performance validation and management 4.4.5 City energy performance validation and management

1.3 Road mapping methodology and relations to other work packages

The methodology for developing this roadmap is fine-tuned from the experiences that were got from previous ICT road mapping projects. Especially know-how from the IREEN project[1] is reflected here. The road mapping methodology in the IREEN project was also built on earlier ICT roadmap projects, such as REEB[2], ICT 4 E2B Forum[3], and REViSITE[4] projects.

The most relevant lessons learnt to be considered from the IREEN project were [Sepponen et al., 2013]:

- The implementation action recommendations included different points of views for different stakeholder groups, which was useful.
- The roadmap template worked well, and it was well structured. However, the different views of stakeholder groups could perhaps be added to the template.
- The length of the roadmap deliverables was too long. The chapters need to be shorter, for each roadmap topic a maximum should be approximately three pages in total with a roadmap picture (0.5 pages) included.
- It is useful to make a global picture of the roadmap that visualises the spear head issues and topics of the proposed roadmap and that summarises the project scope.

In the IREEN project, one of the challenges was to structure the roadmap to support and show all the links and integration needs between different research and technical development and innovation (RTDI) topics of the roadmap. Furthermore, the relationship between the scenarios and the actual roadmap sections could be strengthened. Expert engagement, feedback and inputs are crucial for the roadmap development and thus, there is a strong need for collaboration with the R4SC's work package (WP) 1 called Community Creation and Dissemination.

The steps for developing the roadmap are presented in Table 2, including the planned roles and involvement of stakeholders and experts in the work. In addition to developing the roadmap itself, another crucial target is to make experts validate the proposed roadmap.

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[1] ICT Roadmap for Energy Efficient Neighbourhoods project 2011-2013. http://www.ireenproject.eu/

[2] REEB project, the roadmap book: ICT Supported Energy Efficiency in Construction. Available at: http://ec.europa.eu/information_society/activities/sustainable_growth/docs/sb_publications/reeb_ee_construction.pdf.

[3] Full project title was "European stakeholders' forum crossing value and innovation chains to explore needs, challenges and opportunities in further research and integration of ICT systems for Energy Efficiency in Buildings. Project was implemented in 2010-2012.

[4] REViSITE: Roadmap Enabling Vision and Strategy for ICT-enabled Energy Efficiency. www.revisite.eu/

Table 2. The road mapping methodology step-by-step and related actions for involving stakeholders (WS = Workshop, ON = online discussions, FF = Face-to-face interviews).

Step	Action	Stakeholders' role
1	Identification and defining of different energy systems in smart cities.	Feedback from expert for term definitions, further development and validation
2	Identifying links and integration possibilities between different energy systems in smart cities. This will be presented as a matrix showing linked energy systems, and it will visualise, which energy systems need to be integrated or which systems are interoperable.	FF/ON: identify and validate the links
3	Identify and develop future envisioned scenarios for smart energy systems based on the identified links between the different systems. The scenarios are developed based on a top-down (vision based) approach and they are reported in Deliverable 5.2: Vision of Energy Systems for Smart Cities [Cavallaro et al., 2014].	Develop and validate scenarios: WS (preliminary) and FF (mature)
4	Roadmap to present: how ICT can support and enable future scenarios for linked energy systems. A draft roadmap [D 5.3, Sepponen et al., 2014a] is done for experts' feedback. The roadmap topics visualize the development path towards the vision. The goal is to set the structure and topics of the roadmap, and to make a first version of it.	FF, WS: to give feedback and inputs
5	Finalising the roadmap by taking different viewpoints into account: the impacts of the roadmap content for ICT and energy system experts, end users, etc. The aim is to tell what is important or essential for ICT/buildings/ municipality/energy companies.	VoCamp and FF discussions for feedback and validation of the roadmap
6	Implementation recommendations based on the roadmap [D5.4, Sepponen et al., 2015].	Input and validation
7	Impact assessment [D5.5, Peters-Anders et al., 2015]. Enhance impact assessment from REVISITE. Consider rebound effects and cause-consequence interdependencies.	Input and validation

This report is partially based on the findings in the other project WPs 1- 4, and the tasks 5.1 (framework) and 5.2 (vision). The following IREEN deliverables are used as background material: D3.3.1 Strategy for European-scale innovation and take-up [Sepponen et al., 2013] and D3.3.2 Roadmap for European-scale innovation and take-up [Sepponen et al., 2014b].

The roadmap is developed with a top-down approach, starting from setting up the framework and the main scope in Deliverable 5.1: Conceptual framework & methodology [Fies, 2013], and the main vision of the roadmap in Deliverable 5.2: Vision of Energy Systems for Smart Cities [Cavallaro et al., 2014]. The road mapping work in this report presents the state of the art and RTD and innovation needs for

ICT in short, medium and long term towards achieving the vision. Drivers, requirements, barriers and expected impacts on each roadmap section are also presented.

The relations between this task, task 5.3, and the other WPs in the project are visualised in Figure 1Figure 1. Previous R4SC deliverables from tasks 5.1 and 5.2 set the base for the roadmap development. Experts' collaboration and inclusion to the work is arranged by WP 1. The other work packages, WPs 2 – 4, produce more specific information about linked data for energy systems of smart cities, and the results and findings of these are included in the roadmap.

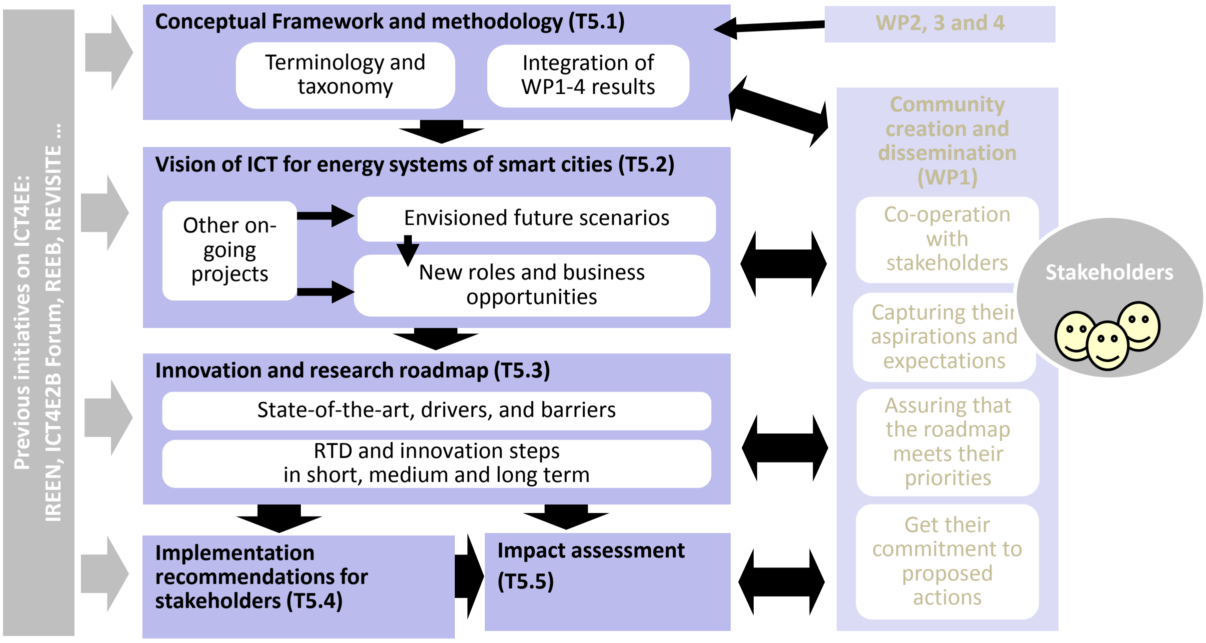

Figure 1. Relation between task 5.3 and the other work packages

1.4 Background: Energy systems in smart cities and their integration possibilities

The first and second road mapping steps are: identification and definition of different energy systems in smart cities, and links and integration possibilities among different city systems. Energy systems in smart cities refer to all energy solutions and technologies for energy supply (in other words: production), energy distribution, storage and energy demand/consumption/ use in cities. In this project, improved energy efficiency of transportation and transportation fuel supply is excluded from the project scope. Figure 2 shows a matrix of different energy systems considered in the project scope. It also shows an identification of links and integration possibilities between different energy systems in smart cities (see Figure 2). This is presented as a matrix showing linked energy systems, and it visualises possible integration opportunities between different energy systems.

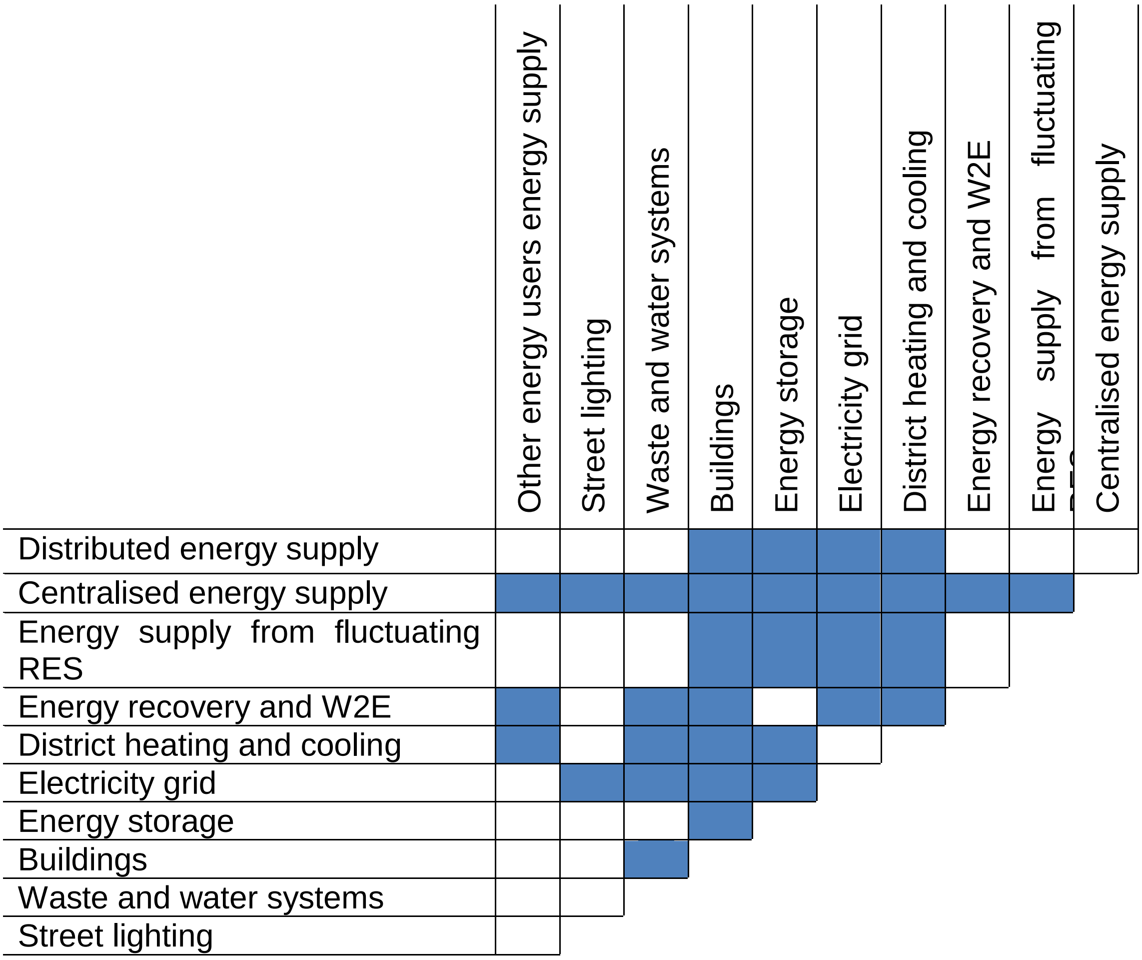

Figure 2. A matrix showing energy systems for smart cities and their possible synergies and beneficial integration (blue colour signals potential for integration or link points between different energy systems).

2 Vision for the ICT supporting energy systems in smart cities

This section summarises the third roadmap development step: identification and development of future envisioned scenarios for smart energy systems based on the identified links between different energy systems. The scenarios are developed in task 5.2 and this work is reported in more detail in deliverable 5.2 Vision of Energy Systems for Smart Cities [Cavallaro et al., 2014].

The READY4SmartCities' vision has been created 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 2030 and 2050 targets agreed in environment, energy efficiency and sustainability policies by European Commission (EC). This kind of development is needed to adapt to the targets of lowering emissions, increasing energy efficiency and improving the overall performance of energy systems. The vision is structured into four main categories, which all are aiming towards the same future.

Citizens are taking an active role of a prosumer (energy consumer that also produces energy by themselves). 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, carbon foot print, being then also active participators in demand side management. They are given an opportunity to decide how much they are willing to pay for using electricity for different equipment and with what kind of environmental impacts during peak hours. A gamification approach provides also new opportunities for engaging especially young generations e.g. to improving energy efficiency, energy savings and improving of sustainability of 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. The buildings have systems and tools for managing the building as an active consumer and producer in the city's energy system. Building Management Systems (BMS) enable buildings to also be connected objects that are able to communicate and negotiate with the electricity and heating systems. As a big producer of data, the sector also has the opportunity to learn and fine tune, by developing auto adaptive algorithms, its own energy behaviour and usage for improved planning of on-site energy production. Such algorithms could decide whether it is better to start peak power plants to meet the peak load demand, or if the energy loads can be decreased via demand side management, or if there are energy storage available (and dimensioned accordingly) and feasible to use.

The ***Energy sector*** is closely interconnected with the building sector since its city scale energy systems are participating in the local energy production and distribution. Thus, the systems are able to communicate and negotiate with BMS that are also considered as distributed energy suppliers interconnected with the rest via the energy networks. There are systems and tools for management and optimisation of the use of energy supply, storage and demand, based on better prediction of energy profiles and forecasting based on weather forecasts.

The energy sector operates the heating and cooling, as well as the electricity supply. The sector also operates distribution and storage of energy more efficiently with the support of ICTs developed taking into account the intrinsic characteristics of various energy sources and networks (heat and cooling, as well as electricity supply). The use of different energy sources is balanced and optimized taking into account their specificities, predicted energy demand profiles and renewable energy yield forecasts.

Heating and cooling networks are operated at the local and city level with the efficient use of low temperature levels, increasing the overall sustainability and efficiency of district heating systems. On the other hand, electricity supply does 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 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), which operation and its better optimisation for different situations is easier via coordinated management of energy systems. New opportunities are raising for new actors in the local energy markets.

The ***Municipality*** plays 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 the use of electrical cars is included in the coordinated and optimised operation of citys' 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 use of energy, to balance such complex/ ramified networks the processing of the huge amount of corresponding data is also of key importance.
- **Communication protocols, data models and standards for all ICT communication between energy system nodes:** This enables the technical realisation of the real and open interoperability.
- **Security:** The data exchanged could be private data (citizen behaviour) or strategic data, especially when smart grids are concerned. Thus the security and privacy of the 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. For a large deployment of these systems, they must be easy to use and to interconnect to each other. Thus, the interoperability issues have to be solved from the hardware level up to the semantic level.

3 Linked data as an enabling technology for energy data interoperability in smart cities

3.1 Linked data

Linked data uses semantic web technologies to publish data on the web in such a way that it can be interpreted and connected together. At its core is the use of the Resource Description Framework (RDF) to express data. RDF simply represents data as a graph of resources linked together. It is thus a very flexible model (it can express more than tables). These resources are identified by Uniform Resource Identifiers (URIs which are well known on the web through URL). URIs have two interesting properties: (a) they are non-ambiguous, so one can confidently refer to them, (b) they can be used for expressing relations across data sets, hence effectively linking data from various data sources. Additionally, the web ontology language OWL may be used in order to define the vocabulary used for expressing data. This can be considered as a formal documentation of published data. In particular, this allows interpreting linked data with some certainty.

When we talk about linked data (and even linked open data) this does not mean that all data should be made available to everyone for free. Certainly some data can be available and some cannot, deciding this is up to the data provider. Issues such as privacy or secrecy may be treated by classical techniques that are put in place for any type of data exploitation. The same holds true when security is at stake. There are now techniques for controlling access to linked data like there is access control in other parts of information systems [Costabello et al., 2013; Rodríguez-Doncel et al., 2013].

In the subsequent chapters, the roadmap will describe, activity for activity, the involvement of linked data for reaching better interoperability. Here we describe the general contribution that linked data and in particular linked open data can have to data interoperability.

3.2 Benefits of linked data for interoperability

The intrinsic benefit of linked data is that it is a model that is (a) internationally recognised (RDF, SPARQL, OWL, are W3C Recommendations), (b) not domain specific, it is used in many different domains and in particular in smart cities applications which exchange data from various sources, (c) scalable: using URIs avoids name clashes globally, (d) well-instrumented, as there are many reliable and open tools for dealing with linked data, and (e) open in the sense that adding information to open data is never forbidden by a schema: it is always possible to extend and merge data sources.

The traditional way to exchange data is the following: when one party needs to obtain data from another party, they sit down around a table, decide the particular format and modalities, and implement data exchange. Such a procedure is reasonably efficient for that purpose. However, in a world where the data exchange is permanent, it becomes costly to constantly have to agree among stakeholders.

The next step is to put all stakeholders around a table and decide which standards to use, or if there is a need to create a standard for exporting such data. This definitely delays applicability and increases costs (and modalities still have to be discussed). This is especially true when data evolves: indeed, data evolve more often than buildings. Then, the standard is not perfectly adapted, the discussion must be reiterated, generating more delays and costs (not preventing to end up with several standards). The capability of ICTs to react quickly to changes in the environment is often seen as a precious feature.

The approach which is promoted by linked open data publication is to replace the a priori exchange agreement or standard approach by a more agile “publish first, think later” (or “thinking does not subsume not publishing“) approach. A data owner exposes its data in RDF, creating or reusing an ontology for documenting it. If other parties are interested in this data, they will take the pain to adopt this ontology or to align it with their own. This is a lightweight process which does not need a present agreement to work.

This process is ideal for public bodies which have to publish data by law (see data.gov, data.gouv.fr). It may be useful for companies as well. This is because they can take advantage of such data published by public bodies, but also because they can contribute to the public welfare (like they do when they sponsor some action for prestige).

Linked data adoption can be achieved progressively by first offering what is needed by others and ready to be exported in RDF. Once the skills for doing this are acquired, further publication of other data is facilitated. These skills can also be put to work in order to exploit data published by others and, in the context of smart cities, there should be many occasions to do so. Moreover, once such techniques are mastered, it is likely that they will be used internally for exchanging data and not only for publishing data to the outside. This should also bring more fluidity internally.

3.3 Linked data in smart cities

Smart cities primarily need fluid data exchange which can ease the life of citizens. Energy data is a part of this smart city data. Currently, energy providers tend to develop their own data formats for collecting and reporting consumption. They do not exchange much data among them. They return it partially (in particular on bills) to consumers in a non-machine processable format. They communicate it, in an aggregated way, to public bodies and agencies. Nothing is done to provide other parties (building managers, urban planners, etc.) with such data. Nothing is done either to take advantage of data that others could offer (extracting RDF from open street map is not a problem for instance, neither technical nor legal).

This is, in fact, true for most data exchanged in smart cites and is not restricted to the given example.

Instead of a pairwise tuned data channels, it should be possible to establish a fair data ecosystem in which all parties could benefit. There could still be bilateral channels for reasons of security or privacy (typically all data directly involving citizens), but they should be intelligible: using an open format provides this once and for all. Moreover, instead of considering that any data opening could be used - in principle - by competitors, it would be worth considering if reciprocated data sharing may not be beneficial to everyone. Again, this would create an open ecosystem.

By asking operators to provide data to citizens, we do not mean that all citizens will become experts in statistics and scrutinizing consumption plots, let alone RDF. Instead, they will be able to use appliances, made by third parties, for taking advantage of this data.

Many of the consideration above are political. On a technical ground, if data should be shared in whatever occasion, it should be easy. Then it should be achieved in RDF.

4 ICT roadmap for energy systems of smart cities

4.1 Target groups and the structure of the roadmap

This section introduces a roadmap on how ICT can support and enable future scenarios for interconnected energy systems. The scope and different layers of this roadmap are set in Deliverable 5.1: Conceptual framework & Methodology [Fiés, 2013], as shown in Figure 3 on the right hand side. It visualises the different layers that are taken into account in the roadmap and the five main target sectors of the roadmap as follows:

- Citizens
- Building sector
- Energy sector
- Municipality
- Energy data

Both the project vision [Cavallaro et al., 2014] and this roadmap are structured according to these four main target sectors and the actual roadmaps are presented in the following five chapters. The first one focuses on citizens (excluding professionals). The second and third sections focus on building and energy sectors, while the fourth roadmap section covers the entire municipality and city level issues. Finally, the energy data roadmap proposes how open linked energy data could be utilised in supporting various different energy systems and solutions.

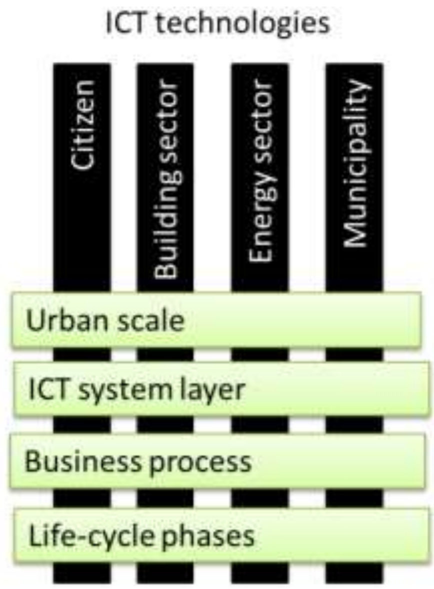

Figure 3. Layers and main sectors of the roadmap

Each roadmap section begins by introducing drivers, needs and requirements, vision, barriers, expected impacts and key stakeholders. Each sector has its own RTD and innovation focus topics, with descriptions of the general background, state of the art, and suggested RTD and innovation needs identified in short, medium and long term as follows:

- State of the art: what is available and in use currently.
- Short term: innovation actions, piloting, take-ups ~ 1-3 years usually.
- Medium term: incremental research and development needed ~ 2-5 years usually.
- Long term: research and more radical development needed ~ 4+ years usually.

The RTD and innovation topics of the roadmap are summarized in Figure 4.

RTD and innovation focus topics		Target sectors: Citizens	Building sector	Energy sector	Municipality
	Participation to building design	Ch. 4.1			
	User behavior and decision support for energy efficient living and working				
	Planning of buildings		Ch. 4.2		
	Planning and implementation of building renovation				
	Controlling energy performance of buildings				
	Building energy performance validation and management				
	Planning of district energy system			Ch. 4.3	
	Demand side management				
	District electricity management				
	District heating and cooling management				
	Cities' energy performance validation and management				
	Energy trading and brokering				
	Electrical vehicles integration to cities' energy systems				Ch. 4.4
	City planning enabling maximized energy efficiency				
	Development and harmonization of energy data models	Ch. 4.5			
	Open energy data, ecosystems and regulations				
	Smarter use of energy data				

Figure 4. A summary of RTD and innovation topics of the roadmap.

4.2 ICT roadmap for citizens and their involvement

Drivers

Citizens are increasingly interested in the social and environmental impacts of city evolutions. Furthermore web 2.0 capabilities and, more in general, emerging technologies like open data and Internet of Things (IoT) are opening more possibilities for citizens to influence and participate in cities' decision making processes. Finally, new ways of communicating enabled by ICT (e.g. gamification) can allow providing more effective messages for people. It is to be kept in mind that ICT solutions from different sectors (not only those presented in this report) can be integrated resulting in better and more complete solutions for the society. Data acquired through ICT would help in the coordination of these kinds of "ecosystems" to ensure benefits for the parties involved. Citizens, on the other hand, will be more likely to become investors of different solutions or services. This means also that local citizens will have a greater role in the procurements of services and solutions affecting themselves and the area that they live in.

Needs and requirements

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 the impacts as well as the potential of different actions and solutions to be taken directly by them or by the city as a whole. In order for people to get involved they have first to understand the issue that they are taking part of. The involvement processes are therefore to be made simple enough in order to achieve greater numbers of participants. However, not all people might be interested in being involved and there will be a risk that a smaller group of people, with certain characteristics, might generate outcomes affecting a larger population. Relevant decisions and approval processes are to be made smoother so that citizens involved might gain from the results in time.

Citizens one of the main data producers and at the same time data consumers. There is a need to rely on distributed and multi-scale solutions for sharing specific information from the building scale up to the city scale in the different local social networks, e.g. among the people living in the same building. Such solutions could be enabled by in the IoT paradigm. This will also facilitate inter-connections with other sectors.

Vision

Citizens are fully involved in the decision making process by 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 in their daily lives by involving them and making them aware of the impacts of their actions. New attractive services need to be developed guaranteeing citizens' commitment and participation over the time.

Barriers

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. The motivation (especially for the citizens) is low and difficult to maintain over the time. In a similar way, there are low incentives for business actors.

Expected impacts	People, in general, will have better understanding for decision making, or further communicate their interests to decision makers. Expected impacts on increasing energy efficiency by new infrastructures that are planned and designed in a participative way, and by improving the citizens' behaviours to be more energy efficient.
Key stakeholders	Citizens, decision makers, software providers, and planners of city, energy and infrastructure systems.

4.2.1 Participation to building design

There is a need to create high quality buildings (from utilities to households) that support the dynamic needs for suitable working and living environments. This requires building occupants' participation. Buildings are more than ever considered as facilities for dynamic processes rather than passive physical constructions. ICT technologies need to evolve in order to better capture knowledge towards more efficient building design. ICT can also enable users to see the effects of different design solutions to the energy efficiency of buildings.

State of the art

The **Building Information Model** (BIM) methodology captures construction performance and constitutes the basic component of creating **Virtual Buildings** (VB). However, CAD tools do not emphasize end users' involvement in order to ensure building functionality and services. Integrated ICT tools for decision support according to users' preferences, at early design phase, are still at an initial development stage. Moreover, current technologies in gaming world and virtual environments that would be more user friendly set further barriers as they do not offer interoperability that would support the import of building models created in external software programs. ICT technologies need to further develop in order to involve occupants together with building designers and finally accomplish their revealed or even unrealized needs. The extended adoption of open linked data standards by creators of buildings models, e.g. in the publication of CAD tool output, promises to accelerate progress beyond this state of the art.

Key research and innovation needs are:

Short term	ICT solutions could be developed in order to support and store **energy performance-based design** with broad competences collaboration. ICT solutions for building occupants for comparing different building design choices and their effects to energy demand and energy costs. Buildings' end users could build their own building models through **web interfaces in collaboration with architects through an iterative design process**, which can be very flexible and easy to learn and use, while building designers could extract this knowledge and formulate it into a consistent design. Provision of web-based tools can be accelerated by adoption of web standards for data publication. **Game console based solutions** could contribute in motivating end-users to provide valuable information to designers in the early design phase (but also during the management phase). In addition to this, the opportunity for adding in-built building design tools in these platforms

will offer the interoperability needed for the actual collaboration between designers and end-users and evaluation of services. An alternative to building the functionality in is to provide application programming interface (API) access and open service provision enabling software collaboration in providing services to users.

Medium term	**ICT systems** supporting users to see and **compare different design choices** on how building's energy performance could be adapted in different situations, such as varying energy prices and peak load times, and availability of local renewable energy supply. ICT systems enabling easy comparison of different choices via key performance indicators (KPIs). Dynamic properties will be added in **ICT platforms** (containing virtual rooms, utilities etc.) and they will be able to change status and user demand over time and spaces making real time annotations through the whole life cycle process. Reuse of these properties will be made much easier by presenting the entire model in open data structures. **ICT systems** along with physical component systems will be continuously evaluated and performance usability will be tested via context sensitivity and built-in memories. Licensed information from these memories will be made available to third party system designers, enabling them to rapidly deploy new ways of supporting the different user groups. **Online communication**, through networking and media environments, could enable users at distributed sites to participate in real-time in a shared simulation environment as if they were into the same physical environment.
Long term	ICT systems will evolve and interoperate and as a result, different types of buildings and infrastructures will interact in a **virtual environment and its energy performance**. Interoperation will be supported by references to agreed, shared ontologies and consistent use of web standards. Citizens' needs, wishes and ideas together with societal requirements could then be evaluated. The vast amount of collected data needs to be analysed for optimizing the development of buildings, districts and their urban environment.

Participation to building design

Vision: Opportunities for citizens to be involved in the decision making process in cities. ICT infrastructures and applications help the citizens to improve their energy behaviour.

State of the art:

- CAD tools do not allow user involvement.
- Integrated ICT tools for decision support at the initial development stage.
- Available, user friendly tools can not handle models from external software programs.

Key research and innovation needs:

Short term

ICT solutions for:

- Supporting energy performance-based building design.
- Comparing different building design choices and their effects to energy demand and costs.

Web standards for data publication.

Web interfaces where users can make their own building models.

Gamification solutions enabling end-users to provide information to designers.

Medium term

ICT systems:

- Easy comparison of design choices and their energy performance.
- Continuous evaluation of building systems.
- **Dynamic status updates** in design platforms.

Information about design from data bases available to **third party system designers.**

Real time communication among the design team in a shared building design environment.

Long term

Interoperable ICT systems supporting evaluation of citizens' needs:

- Interaction between different types of buildings and infrastructures in a virtual environment.
- Agreed and shared **ontologies and standards.**

Citizens
Energy companies
Architects, engineers, construction companies
Facility managers
City planners
Standardization bodies
Researchers
Decision makers
Software providers

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

The basic aim here is the optimization of comfort living and working provided by ICT solutions through **users' engagement**. ICT technologies should support people in their **behaviour and decision making, motivating** them to a more energy efficient way of living through a user-oriented environment.

State of the art
There is currently generic information in terms of collaboration between the energy efficiency issues and city inhabitants. It is remarkable that research progress has been made as there are concepts that **enhance user's behavioural change** through energy monitoring and advisory (e.g. ME'GAS[5], BEAWARE[6]). However, the existing CleanWeb solutions (e.g Opower[7]) target to energy consumption monitoring and saving **focused** on **domestic buildings** rather than utilities, public organisations, transportation system etc. Thus, basic components that comprise a city are still ignored. Fragmentation and lack of interoperability between different ICT functions delay the creation of a common network where city inhabitants will interchange energy information, motivating each other for a greener behaviour. Open data is not yet used much in integrating ICT-based services and functions.

Key research and innovation needs are:

Short term	ICT tools will provide a **user-oriented, visualized environment** in order to collect energy information. Energy information will be made accessible while respecting data privacy requirements and shared in an intelligible way with end-users. The exploitation of open linked data, web services and innovating ICT applications could provide well-established targets in order to **motivate users** to participate in energy efficiency decisions based on the predicted available energy supply and energy prizing in the near future. Different means are needed for motivating and rewarding citizens for increasing their energy efficiency. **Open web platforms** based on common standards could be able to access information shared from individuals in order to foster noble competition among them and enhance energy friendly decisions.
Medium term	Use of enhanced internet addressing, the internet of things, will **correlate users with physical objects and devices,** extracting and storing real-time information for inhabitants' energy performance and making this accessible to authorised users using open data. Integration technology development should allow interconnections and interoperability between user profiling data and devices. In addition to this, **ICT tools,** drawing directly on the open data, will develop consumption patterns **giving** useful **advice** to inhabitants for decision support, according to their preferences and daily routine, and predicted energy prices based on open weather forecasts. Consumers will be able to have a more precise overview of their energy performance, realizing that comfort living could be combined with energy efficiency and

[5] ME^3GAS project 2010-2013 http://www.me3gas.eu/
[6] BeAware project 2011-2013 http://www.energyawareness.eu/beaware/
[7] http://opower.com/

actual cost savings. Different means are needed for motivating and rewarding citizens for reducing their energy consumption during peak loads. However, this is possible only after the ICT system is in place for real time energy pricing.

Long term The adoption of ICT technologies and open linked data will help city inhabitants to make conscious choices on energy resources, improving energy efficient living and working. The collection of citizens' real time energy data would lead to **concrete analysis of the historical data through integrated learning mechanisms** and **smart equipment**. This could also support energy performance benchmarking in increasing citizens' motivation and engagement. To allow further improvements, the performance will be depicted in **comparison** to other cities with similar user profiling.

User behaviour and decision support for energy efficient living and working

Vision: Opportunities for citizens to be involved in the decision making process in cities. ICT infrastructures and applications help the citizens to improve their energy behaviour.

State of the art:

- Solutions for monitoring of energy consumption and energy savings are available for buildings but not on a city level.
- Lack of interoperability between different ICT solutions.
- Open data not usually integrated to ICT-based services and solutions.

Key research and innovation needs:

Short term	Medium term	Long term
ICT tools providing a user-oriented, visualized environment for collecting energy information. Exploitation of **open and linked data, web services** and **ICT applications based on common standards.** • Accessible energy information. Different means for motivating and rewarding citizens to increase their energy efficiency.	**ICT tools** giving energy efficiency advices to users by utilizing open data and real time energy pricing. Real-time information about inhabitants' energy performance accessible to authorised users. Different means for motivating and rewarding citizens to cut their energy consumption during peak loads.	Adaption of **ICT** and open linked data to support citizens to make conscious energy decisions. Energy performance benchmarking and decision support: • Storage of **real time energy data** from citizens. • **Integrated learning mechanisms** and ICT for analysis of historical data. • Comparison of the performance among cities.

Citizens
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Facility managers
City planners
Standardization bodies
Researchers
Decision makers
Software providers

4.3 ICT roadmap for the building sector

Drivers Climate change is one of the main reasons why European and national regulations and policies are important for buildings and their energy efficiency, municipalities, transport and energy. Rising energy prices are also a driver for increasing the energy efficiency. Target is also to have affordable housing where sufficient service and comfort levels are met.

Needs and requirements From the R4SC project's point of view, there are needs for data, which means data acquisition, data storage, and data processing, from the building environment but also from other domains (e.g. energy grids, transportation systems, weather and urban activities at large). This implies that interoperability is ensured at different levels. For example, at the physical level the sensors, actuators, and acquisition systems are connected together, and communication protocols, data structures and semantics are shared.

Vision Buildings are connected objects, optimised to balance their energy behaviour, to maximise the comfort of their inhabitants and to act as power providers when required by external actors. Buildings become more flexible in terms of purpose of use. For example different types of spaces can be combined depending on the needs of the local people and environment. ICT and open data could provide for information on what is the optimal composition of living, office and commercial spaces in a building in terms of economic and environmental efficiency. Moreover, buildings can be treated as resources for the generation and storage of renewable or waste energy.

Barriers The 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. There are also unsolved issues with the privacy of citizens that hamper the "opening" of private data on energy behaviours.

Expected impacts The expected impact is the development and take-off of building energy management systems (BEMS), which are designed to connect buildings to the energy and information grid, by publishing open energy related information to internal and external requests compliant with local regulations (especially with respect to privacy aspects). The 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.) and in order to develop self-adapting capabilities. These abilities/functionalities rely on the public availability of comprehensive and accurate information on energy production and consumption, and 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.

Key stakeholders Building designers, urban planners, facility managers, inhabitants, utilities, energy suppliers and energy services companies (ESCOs), urban infrastructure manufacturers, local authorities, construction companies, and ICT tool development companies.

4.3.1 Planning of buildings

In the past decades, the activities related to the planning of buildings were mainly focused on the design of the buildings. Because of the increased use of Computer Aided Software, the design of buildings has considerably evolved over the years. Firstly, this has helped the different stakeholders to perform their own tasks in a more efficient way. Secondly, with the emergence of the BIM and the corresponding facilities, collaboration aspects have become important in the design phase. However, the planning of buildings is still focused on the buildings themselves. With the ever-growing number of tools able to perform simulations based on information retrieved from the BIM, and especially with the notion of positive energy buildings, the planning of buildings is taking a holistic approach that takes into account the building and its environment. From an energy point of view, buildings are considered as active nodes in the energy grid and this has led to the evaluation of the impacts of such nodes in their environment (and the impact of the environment on the buildings themselves).

State of the art
The great majority of buildings only benefit from energy related tools acting at their own level (the buildings themselves or considering the different flats independently). From a design point of view, there are different integrated tools that allow calculation/simulation of the energy behaviour of the considered building in its environment and use. Some studies have been carried out where the differences between forecasted energy profiles made during the design stage are compared with the energy profile during the operational stage. There is very little use of open linked data in the design of buildings.

Key research and innovation needs are:

Short term	Generalisation of studies to learn more about the gap between design figures and exploitation figures (including the development of an assessment method and the supporting tool). Analysis of these gaps and elaboration of rules / knowledge to minimise the gaps and thus produce more accurate figures during the design phase.
Medium term	Replication of previous experiments and proposals for building models, including published real use characteristics and self-learning capabilities together with the integration of other external dimensions (e.g. transportation / energy grid) to open the scope of the energy efficiency not only to the building and its energy systems (such as heating, ventilating, and air conditioning (HVAC)) itself but in its environment. Enrichment of open linked data sets and traditional databases with energy related data (incl. measurements, user's behaviours, external constraints, etc.). Development of new functionalities in relevant ICT standards to ensure the interoperability throughout the whole value chain.
Long term	Provide rich building models (and the corresponding tools) aligned to comprehensive and accepted ontologies taking into account all dimensions (material, usage, local grid characteristics, etc.). Thus, being able to support accurate and realistic simulations and to share these results with other domains. Modularized building design concepts could provide better flexibility for the needs of the urban environment. For example, building are composed of modules, which can be spaces

(living, office, commercial etc.) or appliances (heating, cooling or other technologies), that can be changed according to the local needs. ICT tools could support data acquisition and analysis of what kind of modules could be installed in order to maximize the utilization of spaces and minimize the negative environmental and economic effects.

Planning of buildings

Vision: Energy efficient and positive buildings that are optimised to balance their energy behaviour, to maximise the comfort of inhabitants and to interact actively with the city's energy system.

State of the art:

- ICT tools integrating buildings with district systems are under research but not widely available.
- Integrated tools for buildings' energy performance simulation are widely used.
- Open and linked data is rarely used in the planning of buildings.

Key research and innovation needs:

Short term	Medium term	Long term
Tools for reducing the gap between planned and actual energy profiles. An assessment method for forecasting buildings' energy profiles.	Develop common building model elements connected to the district. Adding of energy related data to open linked data sets and traditional databases. ICT standards ensuring the interoperability along the value chain.	**Extensive building models** take into account all the building dimensions and enable accurate simulations.

Citizens
Energy companies
Architects, engineers, construction companies
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City planners
Standardization bodies
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Software providers

4.3.1 Planning and implementation of building renovations

From the perspective of R4SC, mainly two aspects have to be considered:

1) ICT solutions supporting the renovation and increasing energy efficiency of old buildings (with specific attention to historic buildings).
2) Better integration of ICT systems (BEMS, sensors, actuators etc.) and energy related equipment (HVAC, heat pumps, storage systems, etc.) in existing buildings.

The aim is to turn as many buildings as possible into positive energy buildings and by publishing their profiles and performance as “connected objects”, enabling optimisation at neighbourhood and city level.

State of the art

The European building stock is old; the new constructions built within the last year represent only 1% of the overall stock. Thus, to meet the European targets, there is a strong need to focus on the renovation of buildings, especially from an energy efficiency point of view.

Key research and innovation needs are:

Short term	Databases containing the best practices and pilots’ initiatives should be established. Specific energy equipment should be defined, offering enough flexibility to be adapted to existing structures at the best price and effort. The availability of open data and accessible databases of energy performance of retrofitted buildings should be greatly increased. In addition, there is a strong need to develop new materials but also new manufactured products and components specifically designed for the energy efficient retrofitting of existing and occupied buildings. These new components should be adjusted according to the new rules and building techniques that can be taken into account in the design phase of the retrofitting.
Medium term	Adaptation of building models and BEMS functionalities that takes into account retrofitted specificities, making use of the new open data resource. Development of refurbishment packages with affordable prices in order to boost the renovation market.
Long term	Similarly as for new buildings, the long term target for old buildings is to issue a rich building model that takes into account the renovation aspects as well as the other already defined dimensions. Retrofitted buildings being considered as normal connected buildings like the new erected ones.

Planning and implementation of building renovations

Vision: Energy efficient and positive buildings that are optimised to balance their energy behaviour, to maximise the comfort of inhabitants and to interact actively with the city's energy system.

State of the art:

- The building stock in Europe is old and the renovation need is huge.
- Solutions to model existing buildings are under development, some are already available on the market.

Key research and innovation needs:

Short term	Medium term	Long term
Databases containing the best practices for retrofitting. Tools for choosing the specific energy equipment, which can be flexibly adapted to existing building structures at the best price and effort. Increasing of open data about energy performance in retrofitted buildings.	Adaptation of **building models** and **BEMS functionalities** that takes into account retrofitted specialities. Development of **refurbishment service packages.**	**Extensive building model** that takes into account renovation aspects.

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4.3.2 Controlling energy performance of buildings

Building automation and control systems (BACS) and building energy management systems (BEMS) are used for monitoring and controlling the energy performance of HVAC and lighting systems in buildings. BEMS are usually included in the BACS, but in single family houses, unit controllers can also be used for controlling building's HVAC systems. These systems can be connected remotely and some BEMS can be operated online.
Nowadays BACS can include the following functions: the control of lighting (day light switching, automatic lighting, and constant light control), air condition functions (night cooling, air heating/cooling related temperature control, humidity control, air quality control, etc.), load balancing, solar shading, and occupancy and time controls.

State of the art
BEMS are very rarely connected to building information models (BIM). The main data sources of BEMS are real time information from building automation substation related sensors, actuators, controllers and additional energy meters. In Finland, official energy metering data used in the energy billing goes directly from the meter to the energy company, and this data cannot usually be directly used by BEMS. However, some energy companies have enabled the possibility for BEMS to get the measured energy data with the appropriate privacy level according to the legalisation about data privacy. Nowadays BEMS can be connected to additional energy measurements to monitor buildings' energy consumption. Often this is done in more detailed level with several energy measurement points, and hence a more comprehensive view can be formed from building's energy demand, its profile and the share among different types of energy uses. In large building complexes this can mean the use of several hundreds or even thousands of different type of measurement points, possibly including a web service or related application protocol interface (API).

Key research and innovation needs are:

Short term BEMS are able to manage the energy consumption of a building based on the energy price level, for example by temporarily shutting down the heating of a hot water tank, room heating, or outdoor lighting. This is enabled by creating a connection between smart energy network, BEMS and energy equipment (and/or the switch of energy supply to the equipment) to enable balancing buildings' energy demand and e.g. the need for cutting of demand during peak load times. Development of "**open BEMS**" following two mains axes:

1) **Standardisation of inputs and outputs and access to open data** in order to ease the integration of the data consumed and produced in the frame of an approach with "BIG DATA" capabilities.
2) Development of **"standard" simulation functionalities/algorithms** highly replicable to other buildings but also at different levels, e.g. from building to city.

Medium term BACS is remotely connected to more advanced supervisory control and smart grid supported BEMS that is based on big data and simulation algorithms, and is maintained by a service provider.
BEMS could help to reduce the energy costs of a building by optimising the time of energy use to lower electricity price tariff times when possible. E.g. the running of geothermal heat pumps or floor heating could be coordinated based on real time electricity prices retrieved from electricity market operator.

BEMS could also take an active role the electricity load balancing of a building, group of buildings or even in a district scale. For example, if buildings are using on-site (or close) produced solar electricity, and then the solar electricity yield drops quickly (e.g. due to clouds), then BEMS could react immediately to the reduced supply by reducing the electricity demand of a building for a short period of time. This kind of load reduction could be done e.g. by reducing air ventilation and HVAC systems in office buildings, or electrical hot water heaters in an apartment building. Safety and back-up procedures would be needed in case of system malfunction or security breaches.

Long term BEMS are able to manage buildings' energy performance in an optimised way, including their energy demand, on-site renewable energy production (building acting as a "prosumer"), and optimal use of available energy storage. Users can set limit values for controlling the use of equipment that utilize energy, e.g. based on the energy price level. This is enabled by CEM (consumer energy management) standard and related ICT solutions. New BEMS that are able to act locally, taking also various external criteria into account and following energy strategies that can evolve over the time due to learning capabilities.

Controlling energy performance of buildings

Vision: Energy efficient and positive buildings that are optimised to balance their energy behaviour, to maximise the comfort of inhabitants and to interact actively with the city's energy system.

State of the art:

- BEMS are rarely connected to BIM.
- Main data sources of BEMS: real time measurements from devices, instruments and sensors.
- Energy companies use energy metering data in the energy billing. This data can not usually be used by BEMS.

Key research and innovation needs:

Short term	Medium term	Long term
BEMS being able to manage the energy performance of a building based on the real time energy price. **Connections** between the smart energy network, BEMS and energy equipment enabling energy balancing. **BEMS** with an open data approach: • Standardisation of inputs and outputs and access to open data. • Faster simulations based on standard simulation algorithms.	Remote connections between BACS and advanced supervisory control and a smart grid supported by BEMS.	**BEMS** manage the energy performance of buildings in an optimised way and act in connection to the district energy system. Users can set limit values for controlling energy equipment. **CEM standard.**

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Software providers

4.3.3 Building energy performance validation and management

The quality of buildings in terms of their energy performance has to be verifiable and accurately measurable, a prerequisite relevant for many of the stakeholders involved in energy-related activities in smart cities. For energy contractors, particularly ESCO contracting, this is the basis for apportioning rights to revenue and agreeing metrics (key performance indicators (KPIs) and other metrics). For policy makers, it helps to manage and regulate public resources to achieve political targets.

State of the art

Currently the building energy performance requires a process that follows the steps described below:

1) Targets for the energy performance are set, usually referring to a decrease in the building's energy consumption.
2) Monitoring services measuring the energy performance and record results. Performance indicators are calculated to allow for meaningful interpretation of the measured performance.
3) The outcomes of the measurement are compared to the targets (validation process) and used to prompt actions (decision support).

Target setting is used to compare actual consumption with expected one. Generally targets can be very subjective, as there aren't any widely accepted standards or guidelines for this. Monitoring of energy performance is facilitated by BEMS, which have already been introduced in detail in previous section 4.3.3. The outcomes of the process should be verifiable and accurate. The predictive models applied for consumption analysis use the consumption data as well as exogenous variables to correct for energy requirement variation (e.g. heating degree days).

Key research and innovation needs are:

Short term Performance metrics deal with building energy consumption and on-site energy production. To be useful, industry must agree on standard **definitions** for these metrics and share **consistent procedures** for collecting and reporting data as well as ensuring data quality.

Medium term **Interoperability and data exchange** for planning and design tools that support energy management tools and systems (see section 4.3.3), and validation of building energy performance are key points to be addressed in the mid-term. Based on the best practices, the different solutions need to be **harmonised** in terms of expected inputs, outputs, and operation. Distributed energy production and local storage will lead to an increasing complexity of the energy grid. To utilise the benefits and to reduce potential risks (the instability of the grid, and hence the power failures to building and city levels), exchange of data will become more important, for which ontologies, protocols and standards are needed for "interconnecting" buildings and energy grids. In addition, it is crucial to assure that data is interpretable and comparable for the general population in order to engage them in necessary processes.

Long term Solutions supporting **collaboration** with the different stakeholders (utilities, building occupants and end users, etc.). **Standardisation** (both for interfaces and systems) is needed for cross-organisational operation.

Building energy performance validation and management

Vision: Energy efficient and positive buildings that are optimised to balance their energy behaviour, to maximise the comfort of inhabitants and to interact actively with the city's energy system.

State of the art:

- The current building energy performance validation process:
    1) Target setting for the energy performance.
    2) Measuring of the energy performance. Calculation of performance indicators.
    3) Comparison of the measurements and the targets.
- The predictive models are used for energy demand analysis.

Key research and innovation needs:

Short term	Medium term	Long term
Performance metrics for measuring buildings' energy consumption and on-site energy production. **Standard definitions** for the performance metrics. **Consistent procedures** for collecting and reporting data.	**Interoperability and data exchange** for design tools that support energy management systems. Validation of building energy performance. **Ontologies, protocols and standards** are needed for "interconnecting" buildings and energy grids, and for harmonization of data.	Solutions supporting **collaboration** between different stakeholders. Standardisation of both interfaces and systems for cross-organisational operation.

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4.4 ICT roadmap for the energy sector

Drivers	The Energy Sector is driven by an increasing share of volatile renewables, and by an increasing amount of renewable energy production within cities. There is a need for local regulation of energy savings which e.g., leads more and more to the introduction of smart metering technologies. Furthermore, there exists a drive to put off long term investments in energy infrastructure as long as possible by resorting to ICT based technologies – the so called smart grid. New innovations are needed in order to make renewable energy more attractive from a financing perspective and additionally open up financing opportunities for a larger group. For example selling and buying energy between prosumers can be made easier with the help of ICT technologies.
Needs and requirements	ICT standards are needed for communication between all systems in the energy market and regulations enforcing those standards taking into account flexible energy markets. Regulations are needed for the use of ICT to secure customer privacy, and enable open data that can be made available to different stakeholder groups. However, ICT and the possibilities that it provides might be still unknown for many players, which suggest the need for capacity building.
Vision	Cities that act as their own power plants and virtual storage, being able to produce most of the energy needed by distributed renewable sources within the cities themselves, while being able to react flexibly on the availability of volatile renewables to enable their large scale generation also outside the cities. Optimized and flexible energy distribution, production, increased energy efficiency of all systems and interaction with the power system beyond the city brings mutual benefits. ICT solutions of different service sectors could also be coupled to provide for more holistic solutions for the end users and the entire community.
Barriers	The main barriers are inflexible regulations of the energy market and missing standards. Stakeholders have also conflicting interests, for instance building owners versus building tenants, and grid operators versus energy producers. Lack of complete solutions that require less effort and (technical) knowledge from the end customers and prosumer.
Expected impacts	Increase in distributed energy production by renewables within cities and the ability to react to varying energy supply by volatile renewables.
Key stakeholders	Municipalities, distribution system operators (DSOs), energy service companies (ESCOs), energy retailers, energy consumers, building operators, and regulatory bodies.

4.4.1 Planning of district energy system

Today's challenge is to design complex, interconnected energy supply solutions and dynamic considerations, in order to integrate fluctuating, distributed heat and electricity generation with a relatively inflexible load as well as to distribute renewable energy across long distances (e.g. electricity from costal to inland regions or thermal energy from remote industrial areas to a city's residential areas).

ICT solutions with a high level of interoperability and shared databases are needed to plan and operate new smart city networks and to identify energy demand and supply structure and potential energy storage options.

State of the art

The planning of electricity grid and district heating and cooling networks is based on existing tools supporting the dimensioning based on the energy demand density and worst case scenarios (with static considerations). Although energy systems are more and more integrated into urban energy planning and smart city projects, most energy networks are still usually planned and operated in an isolated, centralized way and the optimizations are considered at a district scale.

Key research and innovation needs are:

Short term In the short term, electricity and district heating and cooling systems need to be integrated in a holistic way, including the interoperability of physical components. Each network should be modelled taking into account the evolution of the energy demand, which is likely to change because of new buildings usage and building renovations, new districts' development, and the evolution of standards. Implementation of demand side management measures are also expected to affect the energy demand in a near future and should be considered[8]. Tools that allow designing energy networks based on dynamic considerations and temperature requirements for heating and cooling are needed for the integration of decentralized and fluctuating energy sources such as renewables and energy prosumers (prosumers are energy consumers that also produce energy by themselves). Multidisciplinary planning where the energy systems and energy infrastructure are designed in combination with other systems to increase benefits. The opportunities for ICT to enhance business communication between stakeholders (producers, deliverers, operators and consumers) related to the energy system are to be taken into consideration during the planning phase.

Medium term In the medium term, ICT solutions for planning and operating electricity, district heating and cooling networks should consider the evolution of the global energy context, for instance energy markets and regulations. In the planning phase, tools are also needed to take into account the life cycle and different scales of networks (e.g. micro-grids) with a sustainability approach, to build up integrated networks that are viable from energy, economic and environmental points of views. Optimization tools require standardization of data exchange flows at city scale between different stakeholders to improve the usability and provide relevant information throughout the life cycle of integrated district energy grids.

Long term In the long term, ICT solutions for sharing information at city scale are needed to optimize the planning and management of hybrid grids, as well as to increase the energy awareness of customers. Generation of coordinated holistic solutions is necessary and should be done through an optimal operation of hybrid grids, where each interconnected single grid is optimally designed. This will support decision making and allow an efficient use of multi-energy sources at the city level.

[8] See chapter 4.4.2 Demand side management for more information.

Planning of district energy system

Vision: Cities' energy systems are efficient, optimized and flexible. Energy supply is sustainable, using local distributed and renewable energy sources.

State of the art:

- The planning of energy networks is based on energy demand density and worst case scenarios.
- Most energy networks are planned and operated in an isolated, centralized way.
- Optimizations of energy networks are considered at a district scale.

Key research and innovation needs:

Short term	Medium term	Long term
Holistic integration of electricity and district heating and cooling systems through interoperability of physical components.	**ICT solutions** for planning and operating energy networks that consider the evolution of the global energy context.	**ICT solutions** for sharing information at city scale. The solutions need to be holistically coordinated.
Modelling of each network, taking into account the evolution of the energy demand.	**Planning tools** taking into account the different energy networks, the life cycle and sustainability.	
Tools for designing of energy networks based on dynamic considerations and temperature requirements.	Standardization of data exchange flows between different stakeholders at city scale.	

Citizens
Energy companies
Architects, engineers, construction companies
Facility managers
City planners
Standardization bodies
Researchers
Decision makers
Software providers

4.4.2 Demand side management

Demand side management (DSM) is an important part of holistically coordinated energy systems in cities. Increasing volatile renewable energy supply causes more and more fluctuations in the power generation and the electricity grids. Thus, there is also an increase in the varying imbalance between energy supply and demand. In addition, local and on-site renewable energy generation in buildings are becoming more common. Both of these create a need for ICT supported DSM in balancing energy grids, especially from the point of view of peak load smoothing and minimisation. Peak power supply should first be reduced from those generation units with 1) highly polluting sources, or 2) high production costs of electricity. If there is lack of available and suitable production capacity, peak load management can also eases the situation. Optionally demand side management can aim at increased use of RES.

State of the art
DSM is already being deployed in the industry sectors with high energy intensity, and in areas with less-then-stable energy grids (e.g. California) but it is not typically used in cities, buildings, or organisations in Europe. Smart meters allowing for bi-directional communication are currently rolled out in Europe and should be prevalent until 2019.

Key research and innovation needs are:

Short term In a simple form, DSM could already be realised in the consumer side via multi-tariff supporting smart meters with the capability for bi-directional information flows. These smart meters would be the connection between buildings and smart grid, and they would communicate the DSM request from the smart grid to BEMS or BACS, or as a lighter solution directly to smart circuit-breakers, which possibly adapt energy use based on the request if the limit setting values are met.

Medium term Development of standards, methods and tools as well as devices for interaction between different energy nodes (supply, storage, and demand) and how the entire energy system and its flows could be managed, resulting in an optimal energy balance and control of peak load times. This is supported by energy profile estimates for energy demand, supply and optimal use of storage, based on weather forecasts and historical data of energy profiles.

Long term In the long term the electrical equipment in buildings could react itself to up-coming DSM requests, enabling more specific control of equipment' energy use. DSM can enable the negotiation between energy supply and demand to balance them.

Demand side management

Vision: Cities' energy systems are efficient, optimized and flexible. Energy supply is sustainable, using local distributed and renewable energy sources.

State of the art:

- Demand side management (DSM) is deployed in energy intensive industries but not yet in buildings and cities.
- Buildings' energy meters are remotely readable.
- Smart meters are increasingly used.

Key research and innovation needs:

Short term	Medium term	Long term
Realisation of DSM **by multi-tariffs**, supporting smart meters with the capability for **bi-directional information flows**.	Development of standards, methods, tools and devices for interaction between different energy nodes. Optimal energy balance and control of peak loads through predicting energy demand, supply and optimal use of storage.	DSM enables the **negotiation between energy supply and demand** to balance them. Automatic reaction by electrical equipment in buildings to up-coming DSM requests.

- Citizens
- Energy companies
- Architects, engineers, construction companies
- Facility managers
- City planners
- Standardization bodies
- Researchers
- Decision makers
- Software providers

4.4.3 District electricity management

Achieving zero- and plus-energy buildings, neighbourhoods and districts requires local distributed energy generation (DER), using renewable energy sources in large scale with high density. Electricity management on district scale can be reduced to managing the low voltage grid with respect to frequency and voltage to mitigate the effect of the DER, mostly by demand response measures.

State of the art

Electricity management on district level is currently most done by traditional voltage and frequency control on the grid level to assure electric energy supply, with the only active element beyond the substation represented by inverters able to produce both active and reactive power, based on the local grid conditions. RES integration is realized only as optimized on-site use. Automated demand response solutions are used for large customers, while smaller customers only can use open loop systems, e.g. broadcasting of emergency signals or request for the reduction of energy consumption are implemented, due to financial reasons.

Key research and innovation needs are:

Short term	Medium and **large scale experiments/demonstrations on district energy management** are needed **to assess the actual potential** in European cities. The focus should be on usage types and urban morphology, (building types, building energy systems and climate zones), as a supplement to the theoretical studies about the potential of district energy management already available. This holds for the **use of existing buildings and energy systems**, using the building thermal mass or suitable industry processes as storage or flexibility and adding only ICT components, as well as for including DER into **retrofitting** approaches, e.g. by **adding dedicate storage equipment**.
Medium term	**Standards for communication** between the different entities (grid, building, ESCO) have to be decided on to foster the creation of **open systems**, allowing for **flexible relations between stakeholders**. This goes along with **safety, security and privacy protection** of the end users.
Long term	**Cost reduction** to enable wide spread roll out of energy management solutions have to be archived, as the margins for most of the stakeholders involved will always be quite low. Management of **electricity** has to be **coupled to existing thermal grids**.

District electricity management

Vision: Cities' energy systems are efficient, optimized and flexible. Energy supply is sustainable, using local distributed and renewable energy sources.

State of the art:

- Electricity grid management is performed by voltage and frequency control.
- Integration of RES is realized only as optimized on-site use.
- Automated demand response solutions are used only by large customers.

Key research and innovation needs:

Short term	Medium term	Long term
Medium and large scale demonstrations on district energy management, with the focus on usage types and urban morphology. The including of DER into building renovation.	**Standards for communication** between the electricity grid, buildings, and ESCOs. **Open systems,** allowing flexible relations between stakeholders.	Cost reduction of energy management solutions. Coupling of electricity management and existing thermal grids.

Citizens
Energy companies
Architects, engineers, construction companies
Facility managers
City planners
Standardization bodies
Researchers
Decision makers
Software providers

4.4.4 District heating and cooling management

The vision for the future of smart cities is in hybrid energy grids, which integrate different district energy networks (electric grid, heating and cooling networks), with decentralized energy production and fluctuating energy sources with various temperature levels and that are able to solve technical limitations (such as hydraulic limitations). Energy management of such integrated networks in a cost efficient way requires new ICT solutions that can handle a large amount of data for real-time monitoring and supervisory control of interconnected systems. New energy regulations offer market opportunities, for which efficient planning and operation can be achieved through intensive collaboration between stakeholders and ICT solutions.

State of the art
Existing ICT solutions for monitoring heating/cooling at district level do not provide many functions that deal with interconnecting producers and consumers to the energy systems. Optimizations are implemented at local level while the global scale is not considered. Currently, centralized energy production is very common and there is no coordinated management of hybrid grids, but specific isolated management of each single grid. Regarding business issues, such as integration of prosumers into the economic chain, flexible energy pricing and temperature dependent tariff systems, there is a lack of relevant business models, which could allow expanding access to energy market.

Key research and innovation needs are:

Short term In the short term, the amount of data to be shared between the different stakeholders at city scale is expected to grow radically. Thus, there is a need for more reliable and complete datasets (considering cost-benefit ratio) for decision making and efficient energy management. From this perspective, it is important to be able to collect and share large amount of information regarding consumers stocks (type of energy generation/distribution system, building usage, user behaviour, etc.). Development of ICT tools for large scale identification and efficient implementation of demand side measures (e.g. load profile and temperature adaptation, hydraulic balancing, etc.) and supply side measures (e.g. supply temperature adaptation) are necessary. Services for increasing energy efficiency and share of renewables also require business models, which should allow overcoming the regulations and policy barriers. Compensation methods for prosumers that feed-in heat at different temperatures (and hence, at different exergy levels) into the network. Moreover, the primary energy source of the heat has to be accounted for and how this would affect the emission values of the district heating network.

Medium term In the medium term, to manage complex grids at city level with decentralized energy producers, it will be necessary to use and develop new appropriate ICT tools to evaluate in advance new control strategies and to integrate new components in the overall hybrid city grid. Elements of a smart city should be interconnected on various scales to communicate and cooperate in balancing energy supply and demand. Moreover, clarifying the interactions between stakeholders will allow creating new business models to promote flexible energy markets.

Long term In the long term at city scale, it is important that hybrid grids are operated, monitored and controlled in a coordinated way. To improve energy and cost efficiency, as well as to allow a better integration of renewable energy sources a deep collaboration between stakeholders is needed. This can be done through the development of planning tools at city scale enabling simulation and optimization of complex interactions between electric, thermal and gas networks. Energy monitoring of structural (consumer stock) and operational indicators (energetic performances of systems) is becoming necessary to deal with the complex issues of interconnected networks (from an energetic, economic and legislative point of view). In the same way, real-time control tools that can share and handle a large amount of data are needed for systematic control and optimization.

District heating and cooling management

Vision: Cities' energy systems are efficient, optimized and flexible. Energy supply is sustainable, using local distributed and renewable energy sources.

State of the art:

- Most ICT solutions do not interconnect energy producers and consumers.
- Energy optimization is implemented at local level.
- Centralized energy production is common.
- No coordinated management of hybrid grids.

Key research and innovation needs:

Short term	Medium term	Long term
Datasets about energy production, building energy demand and user behavior.	**Management tools** for complex grids and decentralized energy production at city level.	**Hybrid grids are operated, monitored and controlled in a coordinated way in real-time.**
ICT tools for large scale identification and implementation of demand side and supply side measures.	**Interconnected smart city elements** on various scales to balance energy supply and demand.	Planning tools for **simulation and optimization of complex interactions** between electric, thermal and gas networks at city scale.
	New business models.	

Citizens
Energy companies
Architects, engineers, construction companies
Facility managers
City planners
Standardization bodies
Researchers
Decision makers
Software providers

4.4.5 Cities' energy performance validation and management

In the energy domain, cities can validate and manage their energy performance using indicators. If these indicators are harmonised across Europe, cities could benchmark with other cities and gain insights into how to improve their systems and processes. Such key performance indicators (KPIs) need to be developed using a framework that allows for comparability and common data collection processes to be applied. For example, a new call by the EC urges organisations to develop a framework for collecting data and performance measurement that builds upon projects with different methodologies that haven't achieved that goal, such as CONCERTO[9], CIVITAS[10] and the Green Digital Charter[11]. CITYkeys[12] project aims to develop and validate KPIs and data collection procedures for the common and transparent monitoring and comparability of smart city solutions.

State of the art

Cities' energy performance can be seen to include both managing and assessing its energy efficiency, not only in public and private buildings, but also in neighbourhoods, public spaces and related to mobility. Currently, the management takes place with the help of ICT, and for all these activities the active participation of citizens is required or recommended. The larger scope of cities compared to building level analysis and management calls for a strategic approach and clear prioritisation.

The Strategic Implementation Plan of the European Innovation partnership on Smart Cities and Communities [2013] concentrates on three areas – sustainable mobility, sustainable districts and built environment, and integrated infrastructure. Eleven key actions are proposed to speed up the transformation of European cities into smart cities, including:

- Agree on a common Smart City indicator framework to help cities self-evaluate, monitor, progress and more reliably compare themselves with other cities – providing certainty for long term industrial investments in innovation.
- Make relevant data widely available in the urban domain through culture change towards "open data by default" with public and private actors.

Key research and innovation needs are:

Short term	The relevant stakeholders need to better **understand** the importance of city energy performance validating and management activities. They need to be **motivated** to provide results for analysis, and in an open format. The take up of such activities proves very successful when using **pilots**. The metrics, such as KPIs, needed to monitor and evaluate cities have to be clearly **defined**. **Guidelines,** as results of EU projects, clearly stating the value proposition for each stakeholder group together with detailed description of steps to take in order to replicate the project success are also very beneficial for their wider uptake.

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[9] http://concerto.eu/

[10] http://www.civitas.eu/

[11] http://www.greendigitalcharter.eu/

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

Medium term	Activities towards **inter-city exchange** should be fostered. For that, the developed metrics and indicators need to be **harmonised** to allow for benchmarking and comparison. **Interoperability and data exchange** for tools that support energy management and validation in cities are key points to address in the mid-term.
Long term	Solutions supporting **collaboration** with the different stakeholders (utilities, tenants, etc.). **Standardisation** of data exchange (both for interfaces and systems) is needed for cross-organisational operation.

Cities' energy performance validation and management

Vision: Cities' energy systems are efficient, optimized and flexible. Energy supply is sustainable, using local distributed and renewable energy sources.

State of the art:

- Cities can validate and manage their energy performance using indicators.

Key research and innovation needs:

Short term	Medium term	Long term
Pilots for motivating stakeholders to **provide energy performance data** for analysis.	**Interoperability and data exchange** for tools that support energy management and validation in cities.	Solutions supporting **collaboration** between stakeholders.
Clearly defined metrics for monitoring and evaluating cities.	Activities towards exchange between cities.	Standardisation of data exchange for interfaces and systems.
Guidelines for stating the value proposition for stakeholders and replicating of pilots.	**Harmonization** of developed metrics and indicators.	

Citizens
Energy companies
Architects, engineers, construction companies
Facility managers
City planners
Standardization bodies
Researchers
Decision makers
Software providers

4.4.6 Energy trading and brokering

The foreseen changes in the operation environment of energy systems of smart cities (e.g. energy positive buildings as prosumers, DSM and CEM) are setting a promising starting point for enabling more active energy trading. It is foreseen that new business opportunities will rise in energy trading and brokering, 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 still open who could take the energy brokering role, whether it is for traditional energy companies, or new operators joining in to emerging energy trading business. Energy brokering supports also the Europe competitiveness e.g. via maintaining the reasonable energy price levels even with an increasing share of renewable energy.

There are two base conditions enabling energy brokering business on the wider scale. The first requirement for the emerging of wide scale energy brokering opportunities is an increasing number of prosumers and local/on-site renewable energy supply, which creates the need for active energy trading. This development has already been fostered by EC's Energy Performance of Buildings directive, which guides the development of buildings towards (nearly) zero energy buildings and even beyond towards energy positive buildings. The second requirement is to set up the needed ICT systems and protocols, which are suggested in this section.

State of the art

Currently, simple energy brokering is possible by buying energy at the right time and then selling it further, and a certain quite high volume is needed by a stakeholder to be able to operate on this. There are a few energy brokering operators in Europe, and some aspects of such business can be found from current energy companies. In the large scale their roll-out is still yet to come. Some energy brokering companies exists, such as TheEnergyBrokers[13], who use a variety of in-house developed IT solutions, such as websites and reporting tools for fixed price and volume usage, in addition to systems tailored to specific clients. Currently these kind of companies focus on selling energy, and not to buying of distributed energy from prosumers. As another example, Finnish people can buy electricity that is priced according to Nordpool[14] prices via electricity companies. In addition, there are some companies providing ICT solutions for better energy management (e.g. for following current energy demands and the actual energy price levels), but often these systems are still separate and they offer only a minor level of support for following and deciding how and when it would be most profitable to use electricity. Some smart meters can already take into account the real time energy pricing tariffs (e.g. in Germany).

Key research and innovation needs are:

Short term	User and building level ICT systems and protocols are needed for the communication between buildings and the energy network. The operation of these needs to be monitored. At first energy brokering could trade energy based on known historical data about buildings' typical energy demand. Other basic ICT solutions enabling energy brokering are buildings' smart metering and their protocols. The real time energy tariffs (e.g. 24 hours) needs to be communicated to smart meters. Then BEMS and/or BACS can adjust the energy

[13] http://www.tebl.com/FAQs.aspx
[14] http://www.nordpoolspot.com/

performance of the building according to the energy tariff in real time.

Medium term

Energy brokering can be enabled among others via multi-level energy tariffs (e.g. energy price tariffs from levels 1 to 10) and by supporting demand side management platforms. The following forecasts and estimates bring further benefits for energy brokering:

- Prediction of upcoming energy supply profiles (next 24-48 hours) and forecasting of near future energy pricing.
- The forecasting of near future energy demand in building nodes based on weather forecasts and from measured historical data of buildings' energy demand profiles.
- Predicted unbalance between energy supply and demand, and how much of unbalance can be taken care of with available energy storage.

This enables energy brokers 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. Energy brokers can optimise the buying of energy from local energy suppliers or prosumers, and from national grid, and how to use direct local suppliers versus national electricity supply. Main input data needed for this is buildings' energy demand (history data & forecasts), and right pricing, but also communication protocols, data models and tools must be in place.

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.
In the long term, buildings reacting to energy brokering related pricing can also be supported by electrical equipment, if they would have their own tariff based power on/off switch. Then user could set the limit tariff value when the equipment gets power or not.

Energy trading and brokering

Vision: Cities' energy systems are efficient, optimized and flexible. Energy supply is sustainable, using local distributed and renewable energy sources.

State of the art:

- Energy brokering is possible by buying energy at the right time and then selling it further.
- A few energy brokering companies in Europe.
- A few companies providing ICT solutions for improved energy management.
- Smart meters are able to take into account real time energy pricing tariffs.

Key research and innovation needs:

Short term	Medium term	Long term
Systems and protocols for communication between buildings and the energy network. Monitoring network operation.	**Multi-level energy tariffs**.	Negotiations on the energy price tariffs between the smart meter/building and the energy grid via related protocols.
Energy brokering for energy balancing based on historical data about buildings' energy demand.	Supporting of demand side management platforms.	Buildings react to energy brokering related pricing with electrical equipment.
ICT solutions for buildings' smart metering and their protocols, enabling energy brokering.	**Forecasts and estimates** for: • Upcoming energy supply profiles (next 24-48 hours) and near future energy pricing. • Near future energy demand in buildings. • Balancing between energy supply and demand, with energy storage.	
Communication of real time energy tariffs to smart meters.		

Citizens
Energy companies
Architects, engineers, construction companies
Facility managers
City planners
Standardization bodies
Researchers
Decision makers
Software providers

4.5 ICT roadmap for the municipality level

Drivers	Cities have increased their focus on improving the sustainability as a consequence of political pressure, cities' own targets and action plans. The image of the city as a forerunner and the smart city concept supports also the business environment and attracts companies to the city. There are opportunities for improving the 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 with the corresponding framework (oneM2M standard) offer new opportunities for the wide engagement of citizens and cross-sectoral system integration, for instance the electrical vehicles connection to the electricity network (in 4.5.1).
Needs and requirements	There is a strong need for broad collaboration, communication and interoperability within the municipality and with other stakeholder networks. Standardisation (of both interfaces and systems themselves) is needed for cross-organisational operation.
Vision	Efficient energy use and sustainable energy supply are included in cities' targets and realised in their planning, decision making, daily operation and in the development projects. Efficient energy use and supply are strongly linked and integrated to other operations and actions by municipalities via various ICT solutions. Municipalities foster the integration of different city systems to maximise their synergy impacts.
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 a life cycle optimum. Moreover, municipalities and cities have different amount of resources (people, solution providers, economic etc.), which causes them to have different levels of readiness for the adaptation of ICT solutions.
Expected impacts	Expected impacts are an improvement of energy efficiency and a reduction of environmental impacts, as well as increased synergy benefits through collaboration between different stakeholders in the planning, development and operation of cities. Municipalities and cities are quicker to spot and react to changes in their level of sustainability since they are kept updated through ICT solutions and metering. This might even concern a wider area of interest (population, services, housing etc.) than only sustainability.
Key stakeholders	Key stakeholders are decision makers, and city/transport/energy system planners.

4.5.1 Electrical vehicles integration to cities' energy systems

It is possible to use electrical vehicles as energy storage (in extreme situations). One barrier to this can be the amount of people that are ready for potentially restricting the immediate availability of their cars and with what battery charging levels.

State of the art

Usually the charging of an electrical vehicle starts immediately when it is plugged into the charging station.

Key research and innovation needs are:

Short term	The timing of the charging of electrical vehicles could be more actively controlled as a node in the energy system. Thus, electrical vehicles can be used for energy balancing, and in demand side management for cutting of peak loads (e.g. based on historical data about timing of peak loads). Also, if possible, charging times would be focused on low energy tariff times. In both cases, the user should be able to set the (default) car usage times: when the car is needed and what the minimum operation radius is needed to the next charging point.
Medium and long term	A further development step could be 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. ICT would have a crucial role also in the development of self-driving vehicles or the coordination of co-owned vehicles in the future.

Electrical vehicles integration to cities' energy systems

Vision: Efficient energy use and sustainable energy supply in cities. Municipalities foster the integration of different city systems to maximise their synergy impacts.

State of the art:

- Electrical vehicles start to charge their batteries immediately when plugged into the charging station.

Key research and innovation needs:

Short term	Medium term / Long term
Active charging control of vehicles. Possibility for the user to set default car usage times.	**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. Possibility for the user to set default times when car would be available to be used as energy storage.

Citizens	Facility managers	Researchers
Energy companies	City planners	Decision makers
Architects, engineers, construction companies	Standardization bodies	Software providers

4.5.2 City planning enabling maximised energy efficiency

In the city planning there is a need for planning and design tools with energy efficiency evaluation/suggestions, and solutions for easy and quick evaluation and visualisation of energy and emission performance of potential city plans and scenario tests.

State of the art
Currently city planners use map applications and CAD tools for drawing city plans. The needed base data exists in various data bases in distributed locations and in different formats (existing city and regional plans, targets for the area, city's action plans etc.). This base information often needs to be checked manually by the city planner, which can require a lot of time. City planning and design tools rarely have possibilities to assess energy and environmental impacts inherent to the plan, and comparing different scenarios is time consuming. There exist some check lists and separate tools (e.g. based on spreadsheet calculation) for assessing the environmental impacts of city plans, but typically city plan options need to be manually inserted to these assessment tools. Often these tools are also complex and interpretation of results needs special expertise.

Key research and innovation needs are:

Short term City planners need planning and design tools, which allow for quick and easy **evaluation and performance estimation** to assess energy and environmental impacts. Tools need to enable the comparison of different scenarios against each other, of regulations, city plans and key performance indicators. Clear visualisations of the expected impacts are also required, because this enables the presentation of plans and their impacts to decision makers and other stakeholders. Tools need to support the engagement of citizens and other stakeholders and handling of feedback from them (see also roadmap topic 4.2.1 Participation to planning).

Medium term **Interoperability and data exchange** for planning and design tools for city planners and databases. Tools also need to have an easy access and transfer to the various data sources, such as areal and city plans, GIS files, demographics, ground water area maps, renewable energy potential maps and data bases, city system and network information (e.g. existing district heating and cooling networks), etc.

Long term Solutions supporting **collaboration** within the different municipality departments as well as with other external stakeholders, such as construction and energy companies. **Standardisation** (both for interfaces and systems themselves) is needed for cross-organisational operation. Simulation could help urban planners to assess different scenarios. This would be some type of gamification involving real measured data.

City planning enabling maximised energy efficiency

Vision: Efficient energy use and sustainable energy supply in cities. Municipalities foster the integration of different city systems to maximise their synergy impacts.

State of the art:

- Map applications and CAD tools for drawing city plans.
- Data is got from different data bases in different formats.
- Tools used for assessing energy and environmental impacts of city plans are complex and interpreting of the results needs special expertise. Comparing different scenarios is time consuming.

Key research and innovation needs:

Short term

Planning and design tools for quick and easy evaluation and performance estimation of energy and environmental impacts.

Desirable **tool functions:**

- Comparison of different scenarios, regulations, city plans and key performance indicators.
- Clear visualisations of the expected impacts.
- Support citizen engagement.
- Handling of user feedback.

Medium term

Planning and design tools for city planners and databases allowing interoperability and data exchange.

Easy access and transfer to various data sources (e.g. city plans, GIS files and city system and network information).

Long term

Solutions supporting collaboration within the different municipality departments and with external stakeholders.

Standardisation of interfaces and systems.

Citizens
Energy companies
Architects, engineers, construction companies
Facility managers
City planners
Standardization bodies
Researchers
Decision makers
Software providers

4.6 Energy data roadmap

Drivers

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 information 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. These data could be aggregated information coming from various sources and sectors, which would support decision making at different levels.

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.

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, being significant example 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. The progress made in the big data domain will be investigated closely towards this objective.

Needs and requirements

One main requirement 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 is steadily increasing. However, there is still 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.

New energy data management systems will have to be able to live along legacy ICT and to satisfy business-level and real-world requirements.

Data management and analysis will be needed since there will be large amounts of data available that needs to be compiled into useful information that also require less storage capacity.

Vision

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 through 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.
Barriers	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.
Expected impacts	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.
Key stakeholders	Key stakeholders are citizens, decision makers, urban planners, distribution system operators, energy service companies, authorities, regulatory bodies, and ICT developers.

4.6.1 Development and harmonisation of energy data models

Conceptual barriers set both **syntactic** and **semantic** differences of information to be shared. Based on the findings of the READY4SmartCities project WPs 2 and 3 and the related deliverables D2.2 [Weise et al., 2014] and 3.2 [Birov et al., 2014], multilingualism, license policies as well as optimization of content negotiation mechanisms require the selection of a unified strategy in order to represent cross-domain energy data. The exchange of heterogeneous information and the interoperability between ICT systems requires the development of a **common vocabulary and metrics**. The Linked Data initiative[15] requires formal models that will ensure interoperability and exploitation of the structured data.

State of the art

There has been remarkable progress in the development of **ontologies** (e.g. W3C[16] developments in Web Ontology Language) across different domains that allow the **incremental interoperability** between ICT systems offering a starting point for **Linked Data** generation. However, a new ontological formalism is still considered to be far easier than developing the content to populate it in a satisfactory depth and make it applicable. Hence, the reliability of already existing models in terms of consistency and reusability is still restricted. Although some first attempts of ontological models are published via web, supporting the exchange of energy information between remote and heterogeneous ICT systems, there is still inadequacy of mechanisms that promote **ontologies searching**. The different domain-

[15] Linked Data-Connect Distributed Data across the Web http://linkeddata.org
[16] http://www.w3.org/standards/semanticweb/ontology

oriented rules influence the generic character of knowledge setting further constraints in the agreement of a common ontological approach that will lead to the exploitation of Linked Data.
Some prominent representatives of currently used standards/data models related to energy systems in smart cities are the Common Information Model (CIM)[17], developed by the electric power industry, aiming to allow application software seamlessly exchange electrical network information, the ASHRAE/NEMA Standard 201/Facility Smart Grid Information Model[18], and the IEC 62056 (DLMS/ COSEM specifications)[19] targeting at data exchange for electricity meter reading, tariff and load control etc. These data models either follow different data formats or follow a specific-aided design, rendering difficulty the capability of making them extensible. In this area, there is also relevant initiatives managed by ETSI and DG Connect around smart appliances composed of the oneM2M framework[20] and the SAREF ontology[21].

Key research and innovation needs are:

Short term The collection of all the existent energy related ontologies in an **open online informed platform** accessible to all stakeholders from different domains will create the opportunity to structure their data collected from different case studies and experiments (e.g. energy consumption/production/storage). **ICT tools** will be used for this scope in order to motivate education and training of the experts from the different smart city aspects. Furthermore, ICT expertise tools will be developed in order to identify new ontologies as well as to evaluate their performance in data modelling and harmonisation through several criteria and metrics.
Moreover, ICT technologies will not only contribute to the **assessment** of these ontology representation formats by reassuring their applicability and reliability in real life scenarios but also will **create data repositories** for further exploitation.

Medium term The collaboration among different stakeholders will further improve the **knowledge consolidation** on energy efficient cities. ICT applications could further improve their interoperability by having access to **structured cross-domain energy data** in **repositories** as well as developing **know-how services**.
The ICT tools could further evolve in order to achieve **concurrent processing** of data models, through graphical interfaces (descriptive languages are much more complex) and across the different domains, a matter of crucial importance in a city level scale.

Long term The vision of **high quality sharable and reusable expressive languages** will be accomplished. Data models will be formalized according to standardized city ontologies under a **common linguistic frame**. Consequently, ICT tools will interact and exchange information between stakeholders and citizens, in a seamless way, covering multi-disciplinary aspects of the smart city domains.

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[17] http://en.wikipedia.org/wiki/Common_Information_Model_(electricity)
[18] http://spc201.ashraepcs.org/
[19] http://en.wikipedia.org/wiki/IEC_62056
[20] The purpose and goal of oneM2M is to propose a standardised service that can be embedded within various hardware and software, and as such constitute the first foundation for the Internet of Things. [oneM2M, 2015]
[21] SAREF stands for "Smart Appliance REFerence ontology". It is the result of a consensus created to cover the needs of all appliances relevant for energy efficiency. It intends to play the role of a semantic layer above the M2M Application Layer already standardised by ETSI [TNO/Smart Appliances project, 2014]

Development and harmonisation of energy data models

Vision: The consolidation of energy-related data in cities through stable and accessible open energy data and sharing of cross-domain data between different stakeholders. Managing of energy-related data that support the distributed storage, sharing and processing of it.

State of the art:

- Remarkable progress in the development of ontologies across different domains.
- Attempts of ontological models published via web.
- The reliability of existing ontological models is restricted.
- Inadequacy of mechanisms that promote searching of ontologies.

Key research and innovation needs:

Short term	Medium term	Long term
An **open online platform** where all the energy related ontologies are collected. **ICT tools** for identification of new ontologies and evaluation of their performance in data modeling and harmonization.	Collaboration among different stakeholders to improve the **knowledge consolidation.** ICT applications having access to **structured cross-domain energy data** and developing know-how services. ICT tools that achieve **concurrent processing of data models**, through graphical interfaces and across different domains.	High quality, sharable and reusable expressive languages. **Data models** that are formalized according to standardized city ontologies under a common linguistic frame. **ICT tools** that interact and exchange information between stakeholders and citizens.

Citizens
Energy companies
Architects, engineers, construction companies
Facility managers
City planners
Standardization bodies
Researchers
Decision makers
Software providers

4.6.1 Open energy data, ecosystem and regulations

There is a need for a critical mass of open energy data, which is stable and accessible on the web. Such open energy data will require improving current regulations and legal frameworks and will open the path to new business models based on them.

State of the art

Open data is data that is generally accessible online, machine-readable using a common format, and practically and legally reusable. Initiatives towards open data have flourished mainly in the government and science fields. Analysing the case of energy data, such data is currently stored in isolated silos and the existing cases of open energy data are mainly related to the publication of energy data by public authorities. Open energy data, as well as open data in general, is still in its infancy and making it a reality goes beyond merely publishing data on the web. For example, one motivation for organizations to publish their data openly is to be compliant with transparency and accountability regulations. However, organizations are afraid of being legally liable in cases of privacy violation or misuse of the data they have published.

Key research and innovation needs are:

Short term — In order for open energy data to be a valuable asset, the first step is to have more **open energy data** available on the web. Care must be taken on the particular characteristics of energy data, such as the need for **ensuring privacy** through methods and principles to support anonymization and/or pseudonymization and to avoid the re-identification of individuals via the published data. Besides, generating open energy data is a complex and misunderstood activity and there is a need for **guiding principles** derived from practical case studies, educational material, training, and support for opening data.

Medium term — The current trend is to make data available on the web; therefore, there is a need for ensuring **stability and accessibility** of energy data to people and to machines by using the web standards. There is also a need to improve **regulations and legal frameworks** for the management and processing of open energy data (rights of ownership, access and aggregation) as well as to harmonise such regulations and legal frameworks across countries. The availability of open energy data will also lead to the definition of new **business models** that make value from such data.

Long term — Our scenario of cross-organisational energy data management goes beyond the need of having some datasets. It requires reaching a **critical mass** of open and accessible energy data published in common interchange formats. For it to be successful it requires to encompass the whole range of actors involved in the **data value chain**: data producers, who generate and publish their energy data, data intermediaries, able to take such data and turn them into products with social and economic value and data users, who will access and work with data in different ways. To this end, we need to understand the **energy data ecosystem**, the flow of data from consumers to producers (through a number of intermediaries and according to legal and contractual frameworks), the lifecycle of energy data and their governance, as well as how this ecosystem is influenced by external factors.

Open energy data, ecosystem and regulations

Vision: The consolidation of energy-related data in cities through stable and accessible open energy data and sharing of cross-domain data between different stakeholders. The managing of energy-related data that support the distributed storage, sharing and processing of it.

State of the art:

- Open energy data is still in its infancy. Existing cases of open energy data are mainly related to the publication of energy data by public authorities.

Key research and innovation needs:

Short term	Medium term	Long term
Increasing the amount of **open energy data available** on the web. The privacy of published data must be ensured. **Guiding principles** for open energy data generation derived from practical case studies, educational material, training, and support for opening data.	Web standards for ensured stability and accessibility of energy data. Improving **regulations and legal frameworks** for the management and processing of open energy data. Harmonization of the regulations and legal frameworks. New **business models,** making value of open energy data.	A **critical mass of open and accessible energy data** published in common interchangeable formats. **Encompassing all the actors** involved in the data value chain from data producers to publishers and users.

Citizens
Energy companies
Architects, engineers, construction companies
Facility managers
City planners
Standardization bodies
Researchers
Decision makers
Software providers

4.6.2 Smarter use of energy data

There is a need for a smarter use of energy data, which are distributed across sectors, by enhancing such data with explicit semantics and by supporting their processing with ICT that is able of satisfying business-level and real-world requirements.

State of the art
The common scenario in cross-organisational energy data management is that different stakeholders need to share their energy data using the web as a platform. Requirements for data sharing will be different depending on the type of stakeholder (e.g. public authorities, companies, citizens) and its individual interests (e.g. housing provider, energy provider, and tax payer). Furthermore, this heterogeneity will also appear in the ICT, required to manage energy data in the different stages of their lifecycle (generation, combination, publication, discovery, and exploitation). Processing of energy data must be performed across organizations, sectors, borders, and languages. To this end, work has started to develop semantic models (i.e. ontologies), which allow developers to reuse and share domain information using a common vocabulary across heterogeneous systems or environments, to define new architectures, models, and middleware for the integration of distributed energy data across ICT systems (e.g. modelling, simulation, planning, Building Energy Management Systems). Nevertheless, the adoption of distributed energy data will depend on the facilities provided to data producers and consumers to manage such data and their underlying technologies and on the maturity of such technologies.

Key research and innovation needs are:

Short term Energy data need to be represented according to **shared ontological models** that support the exchange of energy information and the interoperability of ICT systems. These ontologies need to cover the complex interactions between different domains and to model information at different scales and viewpoints. The ICT systems that manage and process energy data need to satisfy **business-level requirements** taking into account **real-world data** (such as large sizes, real-time processing, dynamics, consistency, security, or accounting). Furthermore, there is a need for affordable mechanisms to assess the **quality of data** (e.g. consistency, completeness, accuracy) from different viewpoints and tools for **visualizing and analysing data** across domains that take into account the specific characteristics of such data (e.g. spatial, temporal) and allow extracting knowledge patterns and energy KPIs.

Medium term In order to support a meaningful processing of energy data, energy data need to be accompanied by **contextual information** (quality, licensing, provenance, trust) that nowadays is not attached to the data and in most cases not even specified. Apart from this, it is difficult for the consumers of distributed energy data, to find select, access or combine such data. There is a need for usable tools for **consuming distributed energy data**, including not only interfaces adapted to end users (web, mobile, social networks) but also APIs for developers. Work still has to be done to analyse **new business models** based on the use of energy data and to show the value of such data to the different stakeholders.
Open energy data could also be used for demand side management and smoothing of peak loads in the energy system, and balancing energy supply and demand.

Long term In the long term, there is a need for public and/or private **software infrastructures** that support the distributed storage, sharing and processing of energy data as well as the preservation and update of such data in the long term. Furthermore, energy data must be modelled according to international **standards** that ensure consensus and the long-term maintenance of the ontologies defined in them.

Smarter use of energy data

Vision: The consolidation of energy-related data in cities through stable and accessible open energy data and sharing of cross-domain data between different stakeholders. The managing of energy-related data that support the distributed storage, sharing and processing of it.

State of the art:

- Semantic models, i.e. ontologies are being developed.
- New architectures, models and middleware are being defined for the integration of distributed energy data across ICT systems.

Key research and innovation needs:

Short term

Representation of energy data according to shared ontological models. Ontologies that cover the **complex interactions** between different domains and model information from different viewpoints.

Mechanisms to assess the quality of data.

Tools for visualizing and analysing data across domains.

Medium term

Energy data need to contain contextual information.

Tools for using distributed energy data, including interfaces adapted to end users and APIs for developers.

New business models based on the use of energy data.

Use of open energy data for demand side management, smoothing of peak loads and energy balancing.

Long term

Software infrastructures supporting **distributed storage, sharing and processing of energy data** and long term preservation and updating of energy data.

Modelling of energy data according to international standards.

Citizens
Energy companies
Architects, engineers, construction companies
Facility managers
City planners
Standardization bodies
Researchers
Decision makers
Software providers

5 Conclusions

This roadmap suggests research and technical development and innovation activities in short, medium and long term as well as development and innovation of ICTs for holistic design, planning and operation of energy systems in smart cities. In addition, synergies with other ICT systems for smart cities are considered.

The READY4SmartCities' vision suggests development needs for energy systems of smart cities and especially on how ICT is enabling and supporting it. The vision envisages future scenarios and development for smart energy systems based on identified links between different energy systems, interconnection needs and possibilities to broaden smart energy networks. This kind of development is needed to adapt to the EC's political targets for lowering emissions, increasing energy efficiency and improving the overall performance of energy systems.

The roadmap is structured into four main domain area roadmaps and one integrating section related to energy data and its usage. The domain areas are: citizens, building sector, energy sector and municipality level. Each roadmap section introduces relevant drivers, needs and requirements, a vision, barriers, expected impacts and key stakeholders. Each sector has its own RTD and innovation focus topics, with descriptions of the general background, state of the art and suggested RTD and innovation needs identified in short, medium and long term. The sector topics are summarized in Figure 5.

Figure 5. A summary of the roadmap sector topics.

Roadmap section	RTD and innovation focus topics
Citizen	• Participation to building design • User behaviour and decision support for energy efficient living and working
Building sector	• Planning of buildings • Planning and implementation of building renovation • Controlling energy performance of buildings • Building energy performance validation and management
Energy sector	• Planning of district energy system • Demand side management • District electricity management • District heating and cooling management • Cities' energy performance validation and management • Energy trading and brokering
Municipalities	• Electrical vehicles integration to cities' energy systems • City planning enabling maximized energy efficiency
Energy data	• Development and harmonization of energy data models • Open energy data, ecosystems and regulations • Smarter use of energy data

The repeating theme throughout the roadmap 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.

This roadmap has multiple goals. Among others, it aims to increase citizens' involvement and their active role in the daily operation, use and decision making related to energy aspects. On the building side, among others, the energy performance of the Buildings Directive adopted by EC drives buildings to become (nearly) zero energy buildings that are actually active prosumers, which both use energy efficiently and also produce renewable energy on-site. The vision is that buildings are connected objects 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. This again requires among others the smart use of data, which means data acquisition, data storage, and data profiling from the building environment but also from other domains (energy grids, transportation systems, weather and urban activities at large). This profiling activity will take advantage from the research done in the big data area. This implies that interoperability is ensured at different levels (physical level: the sensors, actuators, and acquisition systems are connected to each other, and communication protocols, data structures and semantics are shared). This is fully in line with the activities carried out by ETSI and DG Connect for the smart appliances with oneM2M and IoT standards.

The energy sector roadmap has been developed based on the expectations for an increasing share of volatile renewables in the energy market, and with an increasing amount of renewable energy production within the city. At the same time, there is a need for local regulation of energy savings which e.g., leads more and more to the introduction of smart metering technologies. Furthermore, there exists a drive to put off long term investments in energy infrastructure as long as possible by resorting to ICT based technologies. 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. 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 increase of energy efficiency of systems and interaction with the electrical grid will bring mutual benefits.

European countries and cities are increasingly adding to their agendas targets to improve sustainability. Also the image of the city as a forerunner and 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 municipalities have often 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. This challenge can also be supported by ICTs.

6 Terms and acronyms

API	Application Programming Interface
BACS	Building automation and control systems
BEMS	Building energy management systems
BIM	Building Information Model
BMS	Building Management Systems
CEM	Consumer Energy Management
CHP	Combined Heat and Power production
DER	Distributed Energy Generation
DSM	Demand Side Management
DSO	Distribution System Operators
EC	European Commission
EE	Energy efficient
Energy systems in smart cities	Refer to all energy solutions and technologies for energy supply (in other words: production), energy distribution, storage and energy demand/consumption/ use in cities. In this project the improving of energy efficiency of transportation and transportation fuel supply is excluded from the project scope.
ESCO	Energy Services Companies
GIS	Geographic Information System
HVAC	Heating, Ventilating, and Air Conditioning
ICT	Information and Communication Technologies
IoT	Internet of Things
KPI	Key Performance Indicator
Linked data	Linked data is the publication of (structured) data using semantic web technologies and, in particular RDF which represents data as graphs. In addition, data be made accessible by identifying resources with HTTP URIs (dereferencability), intelligible by describing it through ontologies and interoperable by linking its resources to other data sources. However, linked data may be offered by other means such as SPARQL endpoints. [Heath and Bizer, 2011]
Linked open data	Refers to the opening of linked data, i.e., making it accessible to anyone.
OWL	web ontology language
Prosumer	Energy consumer that also produces energy, e.g. (nearly) zero energy building
R4SC	READY4SmartCities
RDF	Resource Description Framework
RES	Renewable energy source
RTD	Research and Technical Development
RTDI	Research and Technical Development and Innovation
URI	Uniform Resource Identifier
VB	Virtual Buildings

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