MULTI-DISCIPLINARY STRATEGIC RESEARCH AGENDA FOR ICT-ENABLED ENERGY EFFICIENCY

Keith Ellis, Senior Researcher, Keith.A.Ellis@Intel.com
Innovation Open Lab (Intel Labs Europe), Intel Ireland Ltd, Leixlip, Co. Kildare, Ireland
Matti Hannus, Chief Research Scientist, Matti.Hannus@vtt.fi
VTT Technical Research Centre of Finland, Espoo, Finland
Jilin Ye, Research Associate, A.J.Ye@Lboro.ac.uk
Tarek Hassan, Professor, T.Hassan@Lboro.ac.uk
Steven Firth, Lecturer, S.K.Firth@Lboro.ac.uk
Farid Fouchal, Research Associate, F.Fouchal@Lboro.ac.uk
School of Civil and Building Engineering, Loughborough University, Leicestershire, United Kingdom
Bruno Fies, Senior Engineer, bruno.fies@cstb.fr
Centre Scientifique et Technique du Bâtiment, Sophia Antipolis Cedex, France
Nico Vlug, Senior Consultant, Nico.Vlug@dnvkema.com
DNV KEMA Energy & Sustainability, Arnhem, The Netherlands
Kai Lindow, Project Engineer, Kai.Lindow-projekt@ipk.fraunhofer.de
Fraunhofer-Institute for Production Systems and Design Technology, Berlin, Germany

ABSTRACT

Information and Communication Technologies (ICTs) are today pervasive to all industrial sectors which are faced with a sustainability paradox in maintaining economic growth while consuming fewer resources. ICTs have proven central to the performance driven development of modern industry in supporting production systems at all levels. Given this pervasiveness ICTs have a unique opportunity to address the sustainability paradox by enabling energy efficient viable operations. However, often the issue is not a lack of technological options, but rather a problem in understanding what choices will have the greatest impact. This paper introduces a multi-disciplinary strategic research agenda (SRA) for ICT-enabled energy efficiency developed by the REViSITE (Roadmap Enabling Vision and Strategy for ICT-enabled Energy Efficiency) EU funded project covering migration pathways from the state of the art to a common vision of ICT for energy efficiency (ICT4EE). These pathways are based on research and technology development (RTD) topics for short, medium and long term delivery in terms of industrial take-up. The developed SRA suggests ICT4EE research priorities for four targeted sectors: building, grids, manufacturing and lighting, since these four sectors often come together in delivering infrastructures and environments for production, service, business and living. It is anticipated that the identified RTD topics will be relevant to many other sectors in which ICTs can contribute to improving energy efficiency.

Keywords: Strategic research agenda, ICTs, Energy efficiency, ICT-enabled energy efficiency

1. INTRODUCTION

The European Union (EU) has set its energy target for 2020 already: 20% energy saving in EU energy consumption, 20% share of renewable energies in overall EU energy consumption and 20% reduction in emissions (EU Council 2007). In order to achieve this goal by 2020, innovative breakthroughs in research and technology developments (RTDs) are required. The European Commission (EC) has recognised that information and communication technologies (ICTs) as an enabler will play a vital role in reducing energy consumption and increasing energy efficiency across the whole economy (Barroso 2008). It has also identified a clear need for common ways of measuring energy performance and a common understanding of commitments, targets and methodology (EU Commission 2009).

A widespread data gathering and analysis exercise has revealed that, while the ICT industry accounts for about 2% of global CO_2 emissions, ICTs can have a significant enabling capacity of reducing the remaining 98% of carbon emissions which come from the other sectors of the economy and of society (Gartner 2007). The focus of this research is on the development of a multi-disciplinary strategic research agenda (SRA) for ICT-enabled energy efficiency in four target sectors, namely buildings, manufacturing, grids and lighting, since these four sectors often come together in delivering infrastructures and environments for production, service, business and living, and together they produce and consume a significant proportion of Europe's energy (Ye et al 2010, 2011). Although versatile statistical information is available on energy saving in different sectors, there is still limited knowledge/understanding of the potential of ICTs to improve energy efficiency in the identified four sectors. Furthermore, while the enabling role of ICTs is inherently apparent, understanding which ICTs are best positioned to deliver meaningful impact and where future research should focus on is still less evident. Within this context, the need for a multi-disciplinary SRA for ICT-enabled energy efficiency is apparent. Such an SRA will provide a holistic cross-sectorial view on synergised research topics and their priorities in the domain of ICTs for energy efficiency (ICT4EE).

This paper begins with an introduction to the REViSITE (Roadmap Enabling Vision and Strategy for ICT-enabled Energy Efficiency) project, followed by a brief description of the REViSITE approach which employs the common assessment model – the developed REViSITE framework based on 'life cycle thinking' and an adapted 'capability maturity framework', and the SMARTT (Specification and design, Materialisation, Automation and operational support, Resource and process management, Technical and semantic interoperability and Trading management) taxonomy. Using the developed REViSITE methodology, a multi-disciplinary SRA for ICT-enabled energy efficiency which includes six 'roadmap' tables based on the six main categories and 21 sub-categories of the REViSITE SMARTT taxonomy has been shaped with a holistic cross-sectorial view. Finally, conclusions are summarised and follow-up research recommendations are provided.

2. THE REVISITE PROJECT

REViSITE is a coordinated action project co-funded by the EC under the 7th Framework Programme to promote cross-sectoral synergies in understanding which ICTs are best positioned to positively impact on sustainability goals and to identify cross-sectoral research priorities, covering the domains of grids, manufacturing, buildings and lighting (REViSITE 2011). The aims/objectives of REViSITE are listed below in order to capitalise on its potential benefits in the domain of ICT4EE:

- A multidisciplinary community to promote cross-sectorial ICT4EE i.e. the project looked to leverage the heuristic and domain expertise of different stakeholders.
- A common means of assessing the impact of ICTs on energy efficiency i.e. a generic means of identifying and assessing across the four target sectors.
- A cross-sectorial ICT4EE Roadmap including - the Vision, the Strategic Research Agenda (SRA) and its associated Implementation Action Plan (IAP) i.e. where should ICT4EE research focus and who should do what in supporting that research effort.
- A set of recommendations for standards to address interoperability barriers to ICT4EE.

The collective heuristics of the 'multidisciplinary community' coupled with a 'common means of assessment' are horizontals to all other project objectives and outputs. The envisaged 'real-world' value of the project is essentially based on the premise that many ICTs and ICT4EE tools and systems are generic and can serve different industry sectors with no or reasonable adaptation. This offers opportunities for larger markets to the ICT providers and better services to ICT users. Additionally, synchronised development of energy management systems for different sectors offers opportunities for energy trading via energy information exchange.

3. THE REVISITE APPROACH

3.1 The REViSITE Framework

Previous work on assessment of best practice suggested that the capacity to quantitatively assess ICT impact, while desirable, was in practice an arduous task (Kuhn et al 2011). Situations where an

existing system and a replacement ICT-enabled system can be directly measured are not overly common. Where feasible, the task is often complex by the fact that the replacement system rarely differs from the old with respect to just the ICT element. As such it can be difficult to apportion energy savings as being ICT enabled or otherwise, while abstraction to the sector level becomes an even more onerous process. In other words, determining whether an energy impact [effect] is solely attributable to an ICT [cause] can be difficult.

Typically, in scenarios where opportunity for direct quantitative comparison is limited, one must make some form of estimate based on heuristics whereby part-measurement, secondary data, specialist knowledge etcetera all play a part. In that vein, REViSITE developed a qualitative based framework for identifying those RTDs/ICTs most likely to positively impact on energy efficiency. The framework (as shown in Figure 1) was based on 'life cycle thinking' and an adapted 'capability maturity framework', and utilised a triangulation of approach in leveraging the heuristics of domain experts, together with available quantitative and qualitative sources.

3.2 SMARTT taxonomy

Before the identified four target sectors could begin to compare across their respective domains it was essential to first speak a common technical language and therefore the first stage of framework development focused on developing a common taxonomy. The output was the SMARTT taxonomy comprising of six high level categories with 21 sub-categories nested within them. The high level categories were aligned to a generic bounded life cycle as identified in Figure 2. The REViSITE taxonomy utilises six high level categories and is a variation on the SMARTT acronym.

The categories 'Specification & design', 'Materialisation' and 'Automation & operation support' all vertically align to the bounded life cycle phases. 'Resource & process management' together with 'Technical & semantic interoperability' are themes that align horizontally. 'Trading management' aligns primarily to the 'usage' life cycle phase, as shown in Figure 2.

4. MULTI-DISCIPLINARY STRATEGIC RESEARCH AGENDA

The SMARTT taxonomy discussed in Section 3.2 above provided an integrative classification system and a means of structuring content to REViSITE deliverables. The multi-disciplinary SRA was generally built on the outputs from the REViSITE work package 2 deliverables D2.1 'ICT4EE – Data Taxonomy' (Ellis and Hannus 2011), D2.2 'ICT4EE - Knowledge and Current Practices' (Kuhn et al 2011), D2.3 'ICT4EE - Impact Assessment Model' (Ellis and Sheridan 2011) and the work package 3 deliverable D3.1 'Vision for Multi-disciplinary ICT-enabled Energy Efficiency' (Fouchal et al 2011), as illustrated in Figure 3. The proposed SRA suggests RTD topics in short, medium and long term, bridging the gap between the state of the art and envisioned future.
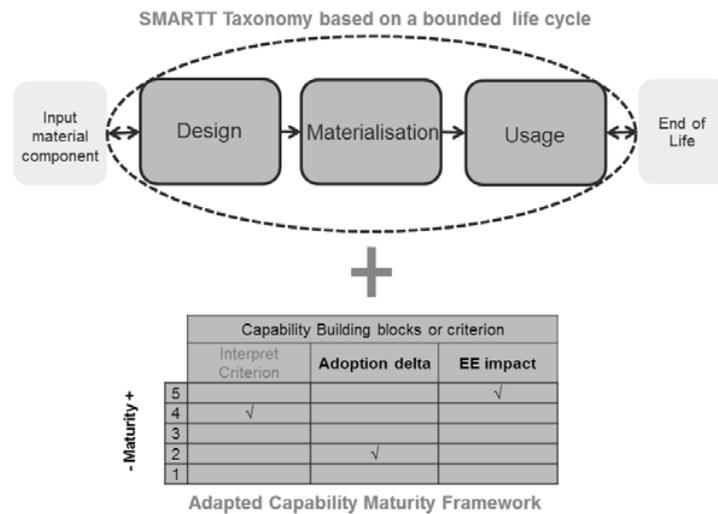

Figure 1: The REViSITE Framework
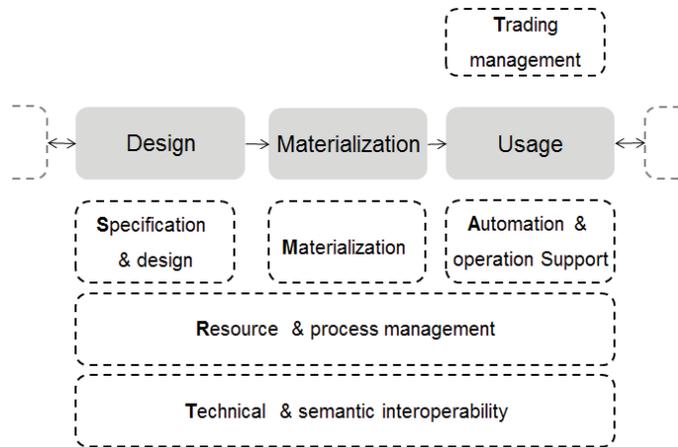
Figure 2: The SMARTT Taxonomy categories mapped to Life Cycle phases
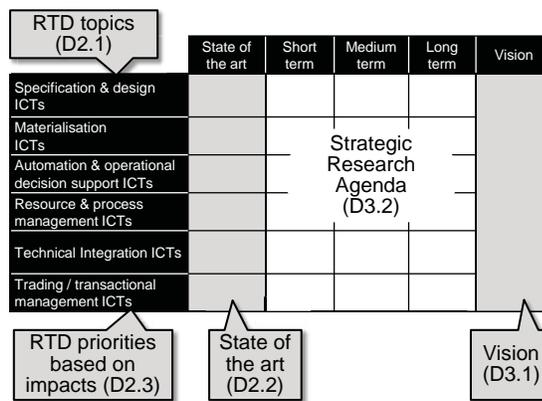
Figure 3: Combining deliverables in informing SRA development

The SRA essentially consisted of six 'roadmap' tables aligned to the SMARTT categories and sub-categories. Each table briefly described:

Current state of the art for ICTs relating to each sub-category

Short-term research priorities (~3 years to industrial usage; adaptation, testing & take up of new technologies, etc.)

Medium-term research priorities (~6 years to industrial usage; development of new applications and incremental technologies, etc.)

Long-term research priorities (~9 years to industrial usage; radical technical developments, etc.)

Vision (~desirable future situation based on currently foreseen developments)

4.1 SRA for specification and design ICTs

Design is central given estimation that a major share (indicatively ~80%) of a product life time environmental impact is determined in the design phase. This is especially the case when new products/systems are designed. However, design for retrofitting of existing systems is also crucial as many products/systems are renewed several times throughout their life time. The degree to which the designed energy efficiency potential will be actually materialised, depends on the downstream life cycle stages (materialisation, operation). Therefore, integration between different stakeholders and stages is of fundamental importance for design.

The main trend in this area is 'integrated design' implying interoperability of various ICT applications and sharing of information at high semantic level between stakeholders over all life cycle stages. Impact beyond current state of the art will stem mainly from the integration of standalone ICTs in terms of holistic energy efficiency design, see Tab
le 1 for more details.

Table 1: Specifications and design ICTs

RTD topic	State of the art	Short term ~3yrs	Medium term ~6yrs	Long term ~9yrs	Vision
Design conceptualisation	Limited tools for requirements capture and engineering, energy analysis and concept visualisation.	Methods for early stage decision support. Templates for requirements and user profiles.	Tools for concept development. Reference models for LC requirements and usage scenarios. Simulation based systems for refining requirements for highly interdependent complex systems.	Generation of requirements from related system models. Context aware visualisation based EE criteria, with context specific content suggestion, all rendered based on device capability & user preferences.	Integrated ICTs for holistic design, modelling and assessment covering energy interaction between the different subsystems, technical, commercial, sustainability and regulatory factors.
Detailed design	Scanning of existing facilities for retrofitting design. General purpose tools like CAD, PDM, PLM and visualisation. Proprietary and domain specific applications. Web based product catalogues.	CAD tools with design templates and interoperable component libraries. Support for designing service oriented systems.	Parametric design using templates and design rules. Parametric product libraries.	Configuration design based on reference solutions, adaptation rules and intelligent component objects.	Interoperability of design ICTs in model based information sharing.
Modelling	Evolving model based tools for mostly isolated design & analysis applications, file based data exchange, reverse engineering, digital/hybrid prototyping, rapid manufacturing, visualisation etc.	Domain specific application tools enhanced with energy related attributes. Tools for modelling existing products/systems.	Model based tools (design, performance estimation, state prediction, optimization, simulation, etc.) and object libraries.	Functional (beyond data) product/system objects enabling new object oriented applications.	Libraries of re-usable design solutions with rich search capabilities. Standardised data models covering energy related aspects.
Performance estimation	Tools (LCA) for assessing costs, environmental impacts, comfort etc. (e.g. CFD).	Metrics and validation methods for holistic static performance: technical, economic and environmental. Quality of Service and Service Level Agreements.	Metrics for dynamic performance. Simulation based validation methods.	Metrics and validation methods for real time performance.	Standardised energy performance indicators. Models of stakeholder profiles, requirements, energy consumption, market dynamics etc.
Simulation	Tools for simulating energy consumption, generation, markets. CFD. Some interfaces from CAD/design tools to simulation. 2D/3D/4D visualisations.	Simulation methods for design & validation. Dynamic/4D visualisation.	What-if analysis using simulation, interfaced with models. Integrated cross-domain simulation of interactions within complex systems such as major infrastructures.	Live virtual models enabled by simulators and models. Live virtual models capturing each system parameter & user experience / perception.	Certified software for compliance assessment. Evidence-based knowledge about the impacts of ICTs on energy efficiency.
Specification & product/ component selection	Limited sector specific specification methods and tools, e-procurement.	Specification templates. Catalogues of materials, products & suppliers. E-market tools.	Specification models. Model based product libraries. Selection tools.	Optimally automated component selection & procurement.	

Holistic design of the interactions between different subsystems. Interoperability between CAD tools, applications for design, performance analysis, simulation, visualisation, libraries etc.

4.2 SRA for Materialisation ICTs

Materialisation follows the design phase and is a non-sector specific term understood within REViSITE to encompass construction, grid infrastructure & production-system development i.e. realisation of the physical. ICTs in this space are similar, identical in most cases to decision support ICTs in the operational phase. What is different is the context, which undoubtedly has greater significance for, but is not limited to, the construction sector. In short, benefits for energy efficiency stem from the optimisation of in-the-field work and coordination of different stakeholders, enabling abatements in terms of overruns and unnecessary logistical runs etc. The REViSITE vision sees the SRA for materialisation to include ICTs for usage of control mechanisms at various scales to optimise financial results as well as environmental parameters and stability, ICTs to support optimal materialisation/procurement decisions (e.g. onsite v off-site production), ICTs to rationalise materialisation processes in terms of planning and control (e.g. logistics, sequence etc.), easily deployable mobile communications and tracking and visualisation of materialisation processes. Table 2 gives details about the SRA for materialisation ICTs.

Table 2: Materialisation ICTs

RTD topic	State of the art	Short term ~3yrs	Medium term ~6yrs	Long term ~9yrs	Vision
Decision support & visualisation	Manufacturing / process simulation tools. 4D visualisation / animation of processes e.g. in construction. Life Cycle Assessment of different construction / manufacturing options.	Tools to visualise real time progress to plan for energy sourcing options regarding cost & CO2 Impact (including CO2 certificates). Energy related aspects included into decision support to select production strategies e.g. offsite / onsite production and materials. Tools and e-commerce platforms for waste re-use.	Tools & interfaces using data from multiple ICT systems (e.g. BIM/PLM/ERP) to analyse and visualize (e.g. in 3D/4D/VR) current state, energy related information, environmental impacts etc. Location based services to decide on optimum materials suppliers. Visualisation of trade-offs between environmental and economic concerns.	Automated alerts to persons in charge on deviations in the production process. ICT for proactive decision making (instead of support only). Decision recommendation to solve trade-offs between environmental and economic concerns.	ICTs to optimise / select production / materialisation / procurement methods based on optimum energy consumption. ICTs to rationalise materialisation processes (in terms of planning and control) for energy efficiency (e.g. logistics, sequence, etc.).
Management & control	Generic project planning tools (Gant charts, cost estimation etc.). ERP, BIM & PLM systems.	Energy related aspects integrated into planning tools (finance, logistic, scheduling) to define energy targets for production.	Whole life cycle costing. Automated tools for testing energy performance & validation of compliance to energy related requirements. Automatic calculation of energy consumed during production.	Simulation based real-time production management. Real time target/actual performance comparison.	Real-time communication in materialisation phase. Tracking and visualisation of materialisation process in virtual planning models.
Real-time communication	Syndication tools (e.g. RSS). Collaboration tools from video conferences to CAD collaboration used in project management.	Using RFID/ NFC tags or similar to track transport & status of components, enabling near real time manufacturing.	Pervasive Context related multi-media content provided to workers on portable devices & back office.	Direct feedback of changes into planning models / simulations.	

4.3 SRA for automation and operational support ICTs

This category, given its direct relationship to the operational phase of the respective sector life cycles, is probably the most obvious in considering impact on energy efficiency, especially in the context of existing buildings, production systems and grid infrastructure (as shown in Table 3).

Table 3 : Automation and operational support ICTs

RTD topic	State of the art	Short term ~3yrs	Medium term ~6yrs	Long term ~9yrs	Vision
Automated monitoring & control	Existing software, algorithms / embedded microcontrollers, sensor / actuation hardware, variable speed drives, remote lighting, heating & appliance control etc. Standalone component technology relatively sophisticated, issue is integration & interoperability of same.	Integration of heterogeneous sensors i.e. sensor fusion. Interconnected systems through internet of things / IPV6. Advancement primarily aligns to the Technical Integration space. Combined local v Cloud based control services for automated control & monitoring.	Virtual sensors, inference technology & non-intrusive load monitoring. Increased levels of autonomous diagnostics & machine-learning. Advancement again aligns to Technical Integration space. Dynamic dependable combination of local v Cloud based control services for automated control & monitoring.	Autonomous machine level diagnostics, prediction & optimization, real time monitoring of streamed data, full integration & interoperability of sensor & actuation devices with optimised use of ambient resources [ambient light, passive cooling] + increased use of renewable energy & water thru integration with Smart Grid/Water networks.	Embedded ICTs permeate sectors providing the "intelligence" to monitor & control energy resources in sustainable ways. ICT systems facilitate user control through integrative data visualizations that sustain user interest.
Operational decision support & visualisation	Existing Information Systems, HEMs type devices, decision support dashboards. Visualisation technologies / methodologies.	Energy dashboards & real-time communications regarding usage. Based on HFE, Data Visualization & cognitive work analysis principles. Ability to cope with Big Data volumes & diverse data source via semantic ontologies, cloud based data services, & real time streaming data processing. Streamlining the design process by simplifying data acquisition, manipulation & assignment to graphical components.	Intuitive, easily deployable, easily-usable, dynamically adaptable visualisations incorporating streamed & asynchronous data & platforms e.g. What if - simulations to support operational EE optimisation in manufacturing lines, micro-power generation, heat systems or spatial representations integrating real time data to a BIM platform. Contextual rendering of data visualisations based on end-user device capabilities & information consumption preferences.	Visual programming of performance indicators. Full integration and optimized data visualization of diverse systems e.g. weather, security, energy, price information etc. Moving towards autonomous & automated 'context aware' decision support.	ICT act as learning systems providing reliable, secure & affective decision support to prosumers. Building operating systems & district energy Mgmt. systems automatically install software & services in buildings / districts similarly to PCs now. Predictive control algorithms perform real time optimization.
Secure Wired / Wireless sensor networks & Quality of service	High speed wired / wireless networks, sensor hardware /software essential for sub-metering strategies & linking to HAN type technologies such as 6LoWPAN, ZigBee, PLC etc.	Secure communications with defined QoS, QoE & privacy in terms of grid infrastructure & at the edge devices Self-configuring, scalable secure & adaptable WSN. NFC for identity management in WSN.	Wide scale deployment of secure, fault / delay tolerant communication networks allowing for service provisioning & manageability including authentication & use of Cyber Security best known ICTs & methods.	Incorporated anticipatory logic, context aware user preferences including privacy & security. Seamless edge to cloud data processing, through real time & user based participatory sensing.	Systems learn & adapt to user preference via incorporated anticipatory logic. Secure wired/wireless & optical sensor networks act as a common backbone to the Energy grid.

4.4 SRA for resource and process management ICTs

This category focuses on supporting holistic energy efficiency management and decision making regarding processes/resources that span life cycle phases, organisational functions and indeed organisations. Table 4 below shows details about an SRA for resource and process management ICTs.

Table 4: Resource and process management ICTs

RTD topic	State of the art	Short term ~3yrs	Medium term ~6yrs	Long term ~9yrs	Vision
Inter-enterprise coordination	Diverse, often proprietary based systems in terms of ERP, CRM type systems exist. Standalone ICT technology is relatively sophisticated interconnectedness is the prime issue.	Augmentation relates more to technical & semantic interoperability. Contract & supply network mgmt, process planning, ERP, logistics, procurement, production etc. need to embed EE criterion in technology, practices & policy.	Methods for virtual enterprise (VE) & network setup & evolution. Short to medium-term development in terms of dependable, scalable & extensible networks platforms to support new devices & services in terms of knowledge & value creation.	Following the scalable platform / network theme, fully validated machine readable service level agreement technologies with Se-mantic based contract management & enactment.	Enhanced knowledge creation, sharing & management including: Infra-structure, data mining & analytics, semantic map-ping, filtering, consolidation algorithms, distributed data bases, catalogues of re-usable EE solutions etc.
Business process integration	Business process modelling & re-engineering methods. Fairly sophisticated ICTs in terms of business process integration from a - purchase / deliver interface, collaboration support, groupware tools, ERP (front end) systems, electronic conferencing, distributed systems, social-media, business work flows - perspective.	Augmentation in terms of business integration with respect to operational processes: design production, on/off-site production and make-v-buy etc. Increased functionality in terms of social media & crowd sourcing type research /validation with respect to energy data sharing / integration.	Integration of heterogeneous data/ info sources in order to build inference type applications that add valued extensions aligning to KM sub-cat.	Standards & interfaces for model / semantics based inter-enterprise collaboration.	Wide availability of ICT based services & infra-structure. Enhanced value-driven business processes & ICT enabled business models.
Information/ knowledge management & analytics	Technologies in the Knowledge management space exist however augmentation relates to the interconnectedness of info relating to elements within smart district, inter-enterprise & production systems domains. With additional improvement required in terms of data mining, analytics, modelling & visualisation given the anticipated increase in sensor data that will result from realizing smart 'X' vision's & in improving information reliability.	Semantic & ontology engineering in terms of agreed data modelling best practise in describing energy flow at the district & intra-enter-prise level. Strong links to technical integration. Methods for knowledge consolidation & distribution. Cross-organisational repositories. Research also required in terms of links to technical & semantic integration of relevant information touch points to improve analytics / modelling capability & accuracy Community forums for discussion. Digital catalogues of products /sensors/services containing parametric information.	Strategies / technologies to link & process heterogeneous energy data & semantic information relating to entire life cycles & districts in producing holistic scalable /extensible analytics for energy optimisation. Easy access to knowledge about energy efficiency which is modelled according to standards & easily accessible. User awareness tools (syndication). Open accessible analytics in terms of energy consumption & optimisation, pattern identification, predictive diagnostics etc.	Incremental improvement over medium term with respect to Increased accessibility, extensibility & scalability of semantic information, energy data, analytics & compute which will underpin innovative energy services Template solutions based on good practices; ubiquitous & context-based access to inter-organisational knowledge platforms	ICTs to facilitate virtual enterprise business relationships. ICT integrated processes are adopted for EE (including: models developed within RTD initiatives, human, legal, contractors, economics, business models, liability). Video conferencing, groupware, social media & collaboration ICTs support process integration & new services reducing needs for transport & commuting while allowing for knowledge / value creation.

4.5 SRA for technical and semantic interoperability ICTs

Semantic interoperability and technical integration are central to a holistic energy management strategy and arguable links to all categories and subcategories of ICTs. Semantic interoperability is equally as important as technical integration, but the main focus from a technical perspective is integration technologies / ICTs. Table 5 breaks slightly from REViSITE's ICT focus to also describe some more abstract/semantic points for consideration, given the level of importance 'interoperability' has for the domain of ICT4EE and for leveraging cross-sectoral synergies.

Table 5: Technical integration ICTs

RTD topic	State of the art	Short term ~3yrs	Medium term ~6yrs	Long term ~9yrs	Vision
Integration technologies & infrastructures	Wide variety of systems/components/interfaces/technologies. They are limited (no holistic management). Level of knowledge sharing is very low (because of incompatibility among media, file format, language, etc...)	Systematic adoption of Service Oriented Architectures (SOA). Definition of Integration Service Platforms (ISPs). Definition / extension of common open models and languages from the semantic to the physical level allowing integration of information regarding energy efficiency.	Continued adoption of SOA & event driven architectures. Enriched smart aggregation of Services on ISP, allowing the management of complex systems in a more efficient secure way. Development & mgmt. of dependable/trust-worthy, open, scalable & extensible platforms. Development of a holistic ontology / data model & methodology for understanding energy flows / energy data in districts / cities. Definition of unified open communication standards for managing complex systems (e.g. in the built environment at building or district level) from an EE perspective.	Specification of an international framework defining the way services could be developed to be integrated / added to such ISPs. Integration of gateways from this Open Communication Standard towards other domains (like Transportation). Cross infrastructure and systems data exchange leading to shared managed infrastructure (Energy, Water etc...)	ICTs support compliance to regulations and standards. Integrated infrastructures are implemented to support all ICT tools and systems for EE: collaborative distributed design & engineering, sensing/monitoring, automation, control, operation, services, energy trading etc. Universal control and communication protocol standards for system integration and interoperability are agreed and adopted.
Interoperability & standards	Because of the variety of solutions, there are today too many non-interoperable solutions. Interoperability among standards is partially implemented.	Definition / extension of common open models and languages from the semantic to the physical level allowing integration of information regarding energy efficiency. Harmonisation of ontologies behind different building information models (BIM, BACS, FM, etc. & non building sector models e.g. the grid CIM. Open data, Linked data initiatives Governments & users combine data sources provided enhanced information sharing & decision making.	Definition of unified open communication standards for managing complex systems (e.g. in the built environment at building or district level) from an EE perspective. Development of building side information models related to Smart Grids to enable load and production controls and the communication with smart grid.	Integration of gateways from this Open Communication Standard towards other domains (like Transportation).	Interoperability is achieved for all stakeholders over all life cycle stages. True system integration is achieved. Middleware to facilitate interoperability amongst different devices and systems. Ability to share information in model based collaboration ensuring data security and appropriate accessibility / authentication.

4.6 SRA for trading management ICTs

This category relates to technologies and practices required to support an economic negotiation driven relationship between energy grids (both regulated operators and competitive market parties) and prosumers in both the manufacturing and building/lighting domains. The topic has been divided and described in terms of four energy management levels.

Table 6: Trading/transaction management ICTs

RTD topic	State of the art	Short term ~3yrs	Medium term ~6yrs	Long term ~9yrs	Vision
Regional energy management	Regional energy mgmt. has a long tradition. New developments mainly related to market integration & sector liberalisation. Most energy mgmt. systems (EMS) conform to international standards.	Generic ontology's, use cases and standards that support plug-&-play functionality for control centres, resources and interoperability.	Integrated infrastructures, market models and applicable legislation that take environmental aspects, market responsibilities and ethical concerns into account.	Stable energy supply on a continental scale using distributed resources, full network integration, long distance supply and distributed control.	Regulatory frameworks take environmental, economical and ethical aspects into account and common metrics enable univocal transparent assessments of energy efficiency measures.
District energy management	Energy management on a regional / district neighbourhood scale is largely non-existent except for large industrial sites, university campuses and commercial areas.	District energy management systems for DER, intermittent loads & local generation. Optimisation of these resources for market conditions and the local energy balance.	Optimisation of wide area DER and bidirectional power flow control mechanisms (Volt-VAR control, Load flow, state estimation etc.) to ensure grid stability.	Seamless integration of top-down and bottom-up energy management control strategies. Self-healing (micro) grid components.	Distributed energy management functions enable the integration of DER, Storage, HVDC, Demand Response, micro-grids and Smart appliances in large inter-connected grids.
Facility energy management	Facility energy management systems exist for considerable time, both as manufacturing (plant-wide) systems and in building systems. Here, with a wide range of user organisations and user sectors, standardisation is not widely accepted. Facility energy management systems are usually vendor-specific.	Enhance existing legislation with regard to the building EE & the audit / verification process. Building optimisation includes energy consumption, local production & energy market interactions (buy/sell). Integration of Facility Energy Management systems in regional information systems, enabling regional energy balance optimisation.	Integrated building / grid ontology's & interoperability standards. Smart appliances & generic infrastructures that allow direct device coordination, market & users. Market & grid balance optimisation via distributed decision support functions. Data quality mgmt. via automated validation tools based on fast & flexible data exchange facilities (cloud).	Facility energy management systems would "negotiate" with Regional or District energy management systems on their energy consumption, taking energy markets, product markets, economical, technical and human factors into account.	Integrated information networks warrant secure and reliable distribution grids while managing energy exchanges from the continental scale to the building & individual prosumer level.
Personal energy management	Personal energy management systems e.g. for households will be common. Some of the higher end premises use home-control systems. Such systems however hardly ever include specific energy management functions.	Raise awareness regarding new roles (e.g. prosumer) in the energy arena & support the transition towards energy mgmt. Basic personal energy information systems, based on remote meter reading architectures, to include energy consumption monitoring functions, invoicing, settlement & report on individual devices consumption	Regulatory frameworks that ensure privacy & transparency for participants in general & the end-user (prosumer) in particular. Personal energy mgmt. systems enhanced with advisory functions that allow individual consumers to monitor & influence consumption & generation patterns & automatic context aware control actions	Personal energy management systems control household energy exchanges according to profiles, rules and preferences. User friendly interfaces and specific functionalities that allow for distributed automated decisions, user preferences and constraints.	Advanced (cloud-based) balancing functions use (near) real-time measurement data and advanced control algorithms for the optimization of resources, loads and grid capacities.

Table 6 above shows potential trajectories towards achieving the REViSITE vision and also includes a short description of the current state-of-the-art for the four energy management levels. The references to energy management in the listed levels refer mainly to two specific areas: 1) Facilitation of distributed energy resources, interruptible loads and local storages while maintaining a secure and reliable network operation, warranting network stability and power quality (the responsibility for transport/distribution network operators) and, 2) facilitation of a level playing field for a competitive energy market for energy and flexibility products (suppliers, aggregators, etc.).

5. CONCLUSIONS

In this paper, a multi-disciplinary SRA for ICT-enabled energy efficiency has been introduced. The SRA consists of six 'roadmap' tables based on the six main categories and 21 sub-categories of the REViSITE SMARTT taxonomy and provides a holistic cross-sectorial view of where ICT4EE research should focus on from short term, medium term and long term respectively. The SRA concludes that the target research domain consists of complementary areas that need to proceed in a balanced way in order to achieve sustainable long term impacts. The overall expectation is that ICTs will contribute to applications with higher level of semantics, knowledge sharing, system integration and interoperability. The impacts of ICT on energy efficiency are subject to complex causal interdependencies of many different systems over several life cycle stages. This fact in itself calls for research to model and quantify ICT impacts for decision making about investments in ICT research and use.

ACKNOWLEDGMENTS

REFERENCES

Barroso, J. M. (2008) "ICT Industry has a Major Role to Play in the European Economy of the 21st Century." Document available at:
http://europa.eu/rapid/pressReleasesAction.do?reference=SPEECH/08/120&format=HTML&aged=0&language=EN&guiLanguage=en.

Ellis, K. and Hannus, M. (2011) "REViSITE Deliverable D2.1: ICT4EE – Data Taxonomy." Document available at: http://revisite.eu/docs/REViSITE_deliverable_D2.1_main_report.pdf.

Ellis, K. and Sheridan, C. (2011) "REViSITE Deliverable D2.3: ICT4EE – Impact Assessment Model." Document available at: http://revisite.eu/docs/REViSITE_deliverable_D2.3_main_report.pdf.

EU Commission (2009) "Mobilising Information and Communication Technologies to Facilitate the Transition to an Energy-Efficient, Low-Carbon Economy." Document available at:
http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0111:FIN:EN:PDF.

EU Council (2007) "Europe – Succeeding Together Presidency Conclusions." Document available at:
http://register.consilium.europa.eu/pdf/en/07/st07/st07224-re01.en07.pdf.

Fouchal, F. et al. (2011) "REViSITE Deliverable D3.1: Vision for Multi-disciplinary ICT-enabled Energy Efficiency." Document available at:
http://revisite.eu/docs/REViSITE_deliverable_D3.1_main_report.pdf.

Gartner (2007) "Gartner Estimates ICT Industry Accounts for 2 Percent of Global CO_2 Emissions." Document available at: http://www.gartner.com/it/page.jsp?id=503867.

Kuhn, D. et al. (2011) "REViSITE Deliverable D2.2: ICT4EE – Knowledge and Current Practices." Document available at: http://revisite.eu/docs/REViSITE_deliverable_D2.2_main_report.pdf.

REViSITE (2011) "The REViSITE Project." Information available at: http://www.revisite.eu.

Ye, J. et al. (2010) "ICT for Energy Efficiency: Towards Smart Buildings, Manufacturing, Lighting and Grids." *In proceedings of the 27th International Conference on Applications of IT in the AEC Industry*, 55-63.

Ye, J. et al. (2011) "an Approach to Impact Assessment of ICTs for Energy Efficiency." *In Proceedings of the 28th International Conference on ICT-based Solutions for Smart Buildings and Cities,* Paper ID: 98.