Multi-disciplinary Strategic Research Agenda for ICT-enabled Energy Efficiency 2012

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Table of Contents

Listing of Figures

Acronyms and Terms

3D	3 Dimensional
4D	4 Dimensional
6LoWPAN	Internet Protocol version 6 over Low power Wireless Personal Area Networks
ARTEMIS	Advanced Research & Technology for EMbedded Intelligence and Systems
ATIS	Alliance for Telecommunications Industry Solutions
BACnet	Building Automation and Control networks
BACS	Building Automation and Control System
BIM	Building Information Model
CABA	Continental Automated Buildings Association
CAD	Computer Aided Design
CFD	Computational Fluid Dynamics
CHP	Combined Heat and Power
CIM	Common Information Model
CMF	Capability Maturity Framework
CRM	Customer Relationship Management
CSTB	Centre Scientifique & Technique du Bâtiment
DER	Distributed Energy Resources
DSO	Distribution System Operator
DTH	Technical Dictionary of Harmonised Properties
EC	European Council
ECTP	European Construction Technology Platform
EE	Energy Efficiency
eeBDM	Energy Efficient Building Data Model
EMS	Energy Management System
ERP	Enterprise Resource Planning
ETP	European Technologies Platform
ETSI	European Telecoms Standard Institute
EU-27	European Union (27 states from 1 January 2007)
FM	Facility Management
GDL	Geometric Description Language

Acronyms and Terms (Continued)

GeSI	Global e-Sustainability Initiative
HAN	Home Area Network
HVAC	Heating Ventilation and Air Conditioning
HVDC	High Voltage Direct Current
IAP	Implementation Action Plan
ICT	Information and Communication Technology
ICT4EE	ICT for Energy Efficiency
IEA	International Energy Agency
IEC	International Electrotechnical Commission
iNEMI	International Electronics Manufacturing Institute
IaaS	Infrastructure as a Service
IPR	Intellectual Property Rights
IPV6	Internet Protocol Version 6
ISO	International Organisation for Standardisation
ISP	Integration/Internet Service Platform
ITU	International Telecoms Union
KNX	A network communications protocol
KPI	Key Performance Indicators
LAN	Local Area Network
LC	Life Cycle
LCA	Life Cycle Assessment
LEED	Leadership in Energy and Environmental Design
LonTalk	A network communications protocol
MANUFUTURE	The European Technology Platform for Manufacturing
NFC	Near Field Communication
OECD	Organisation for Economic Co-operation and Development
OSI	Open Systems Interconnection
PAS-2050	PAS 2050:2011 is a publicly available specification providing a method for assessing the life cycle greenhouse gas (GHG) emissions of goods and services (jointly referred to as "products")
PDM	Product Data Management
PHOTONICS21	The European Technology Platform for photonics
PaaS	Platform as a Service
PLC	Power Line Communication
PLM	Product Life Cycle Management
QoE	Quality of Experience
QoS	Quality of Service
REG	REViSITE Expert Group
REViSITE	Roadmap Enabling Vision and Strategy in ICT-Enabled Energy Efficiency
RFID	Radio Frequency IDentifier
RSS	Rich Site Summary/Really Simple Syndication
RTD	Research and Technology Development
SaaS	Software as a Service
SCADA	Supervisory Control And Data Acquisition
SMARTGRIDS	The European Technology Platform for electricity networks
SMARTT	Specification & design ICT; Materialisation ICT; Automation and operational decision-support; Resource and process management; Technical integration; Trading/transactional management ICT
SMS	Short Message Service
SOA	Service Oriented Architecture
SRA	Strategic Research Agenda
TCP/IP	Transmission Control Protocol / Internet Protocol
TSO	Transmission System Operators
VE	Virtual Enterprise
VR	Virtual Reality
VPP	Virtual Power Plant
WAN	Wide Area Network
W3C	World Wide Web Consortium
WSN	Wireless Sensor Network
ZigBee	A low data rate, low-power, wireless networking standard/protocol

Executive Summary

Energy efficiency is paramount in ensuring the energy security and sustainability of Europe, and Information and Communication Technology (ICT) has a fundamental role to play in delivering that energy efficiency. However, while the enabling role of ICT is clear, understanding which technologies are best positioned to deliver meaningful impact is less clear, as is understanding where future research and associated funding should be directed.

REViSITE (**R**oadmap **E**nabling **V**ision and **S**trategy in **I**CT-Enabled **E**nergy Efficiency) is a coordinated action, part-funded by the European Commission (EC), to promote cross-sectoral synergies in understanding which technologies 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.

The main objectives of the project were to develop:

- A **multidisciplinary community** to promote ICT for energy efficiency (ICT4EE) across the sectors
- A **common means of assessing the impact of ICT on energy efficiency** across the sectors
- A **cross-sectoral ICT4EE roadmap**, outlining a common vision, strategic research agenda (SRA) and implementation action plan (IAP) for multi-disciplinary, ICT-enabled energy efficiency
- A **set of recommendations for standards** to address interoperability barriers to ICT4EE

The collective heuristics of the multi-disciplinary community, coupled with a common means of assessment, formed the basis for all other project objectives and outputs. The sections that follow summarise the outputs that were produced to achieve the objectives.

Aside from the ultimate objective of positively impacting on the 20-20-20 goals, the envisaged business value of the project is based on the premise that many ICT and ICT4EE tools and systems are generic and can serve different industry sectors with no or reasonable adaptation. This offers opportunities for larger markets for ICT providers and better services for ICT users. Additionally, synchronised development of energy management systems for different sectors offers opportunities for energy trading via energy information exchange.

Introduction

In 2008, European Commission President José Manuel Barroso stated "...the real gains will come from ICT as an enabler to improve energy efficiency across the economy... especially in ... energy intensive sectors."

In 2011, President Barroso suggested "Since our best source of energy is in fact energy efficiency, and also considering the prices of energy, I think it is important from all points of view to achieve real progress of energy efficiency very soon...".

In short, energy efficiency is paramount in ensuring the energy security and sustainability of Europe, and Information and Communication Technology (ICT) has a fundamental role to play in delivering that energy efficiency. However, while the enabling role of ICT is clear, understanding which technologies are best positioned to deliver meaningful impact and where future research and associated funding should be directed is less clear.

About REViSITE

The REViSITE project, part-funded by the European Commission (EC), was established to identify common research priorities in the domain of ICT for Energy Efficiency (ICT4EE). The project focused on four target sectors—Grids, Manufacturing, Buildings, and Lighting—and sought to develop a generic means of assessing the impact of ICT across these sectors. By leveraging the heuristic and domain expertise of different stakeholders, the project sought to outline a common vision for multidisciplinary, ICT-enabled energy efficiency; identify a strategic research agenda (SRA) focused on critical, cross-sectoral research questions; and develop the associated implementation action plan (IAP) to address those research questions.

The following partners constitute the REViSITE consortium:

- Loughborough University, UK (Built Environment /Project Coordinator)
- KEMA consulting, Holland (Grids)
- Centre Scientifique & Technique du Bâtiment, France (Built Environment)
- The Fraunhofer Institute for Production Systems and Design Technology IPK, Germany (Manufacturing)
- VTT Technical Research Centre, Finland (Lighting)
- Intel Labs Europe, Ireland (ICT)
- Innova SpA, Italy (ICT)

The geographical frame of reference for the project is the EU-27. The time frame for the SRA and IAP is present-day to 2020.

Need for a Common ICT4EE Community and Vision

Often industry bodies act as the custodians of the Research and Technology Development (RTD) strategy for their respective sectors. The Grid, Buildings, Manufacturing, and Lighting sectors are no different, with a number of European Technologies Platforms (ETPs), such as SMARTGRIDS, ECTP, ARTEMIS, MANUFUTURE, and PHOTONICS21, representing their respective RTD interests. Aside from ETPs, many other initiatives lobbying to shape future research also exist. So, given the existence of such initiatives, why form yet another community?

Cross-Sectoral Focus

One of the prime objectives of the ETPs is to identify RTD priorities, but what generally happens is that each sector tends, understandably, to prioritise the research topics that are perceived to be the most important for their sector. As recognised by the EC, in many cases, this leads to overlapping RTD effort and increases the likelihood of potentially impactful RTD activities being discounted. The REViSITE premise is that many ICT and ICT4EE tools and systems are generic and can serve different industry sectors with no or reasonable adaptation. Given the potential for wasteful overlap which can create barriers to interoperability and given the REViSITE premise, it was felt there was a justifiable need for a cross-sectoral effort in identifying complementary areas for ICT4EE research trajectories.

Multidisciplinary Community

To encourage cooperation and co-ordinate towards achieving a multi-disciplinary ICT4EE Strategic Research Agenda, a prime objective of REViSITE was to develop a multi-disciplinary community. It was envisaged that the core of this community would be formed from like-minded members from the existing ETPs. The initial step in building this community involved forming a small, dedicated, expert group (the REViSITE Expert Group, or REG), the purpose of which was to provide input and feedback to the REViSITE consortium on its work. Over time, this expanded into the REViSITE community, a virtual forum for communication and interaction. The members of the community are drawn from different companies/organisations in the target sectors which have an interest in ICT4EE. Figure 1 shows the structure of the REViSITE community.

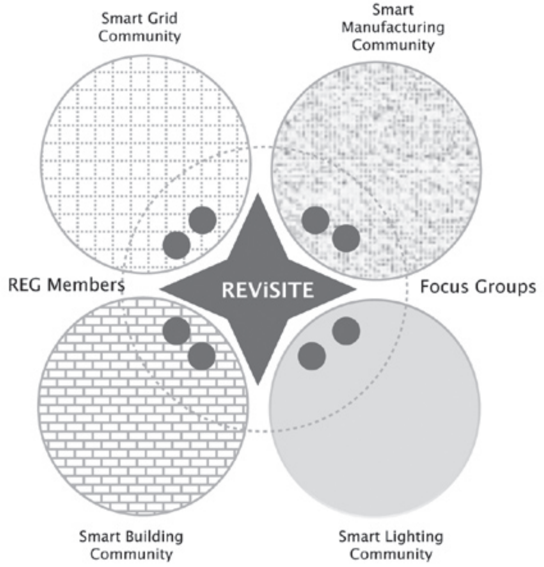

Figure 1: REViSITE community topology

Need for a Common Assessment Framework

The potential offered by ICT in enabling 'real-gains' in energy efficiency across Europe's economy is well understood. However, progress in realising that potential has, at times, been laboured, and as recognised by the EC and organisations such as the ITU, ETSI, and GeSI, often the issue is not a lack of technological options, but a problem in understanding which choices will have the greatest impact. To measure ICT impact across the sectors and to enable accurate comparisons to be made, there is a real need for a common means of assessing the impact of ICT on energy efficiency. 'Common' is an important word in the context of REViSITE, as any adopted approach needed to be applicable across the four sectors: Grids, Buildings, Manufacturing, and Lighting.

Project Structure

The ultimate objective of the REViSITE project was to develop a cross-sectoral roadmap outlining how ICT could be used to enable and promote energy efficiency. This section outlines how the REViSITE project was structured to achieve its aims.

Project Deliverables

Figure 2 illustrates the project structure and its deliverables, which are represented as dark blocks. Details of the process used to create the various deliverables are outlined in the next section, *REViSITE Methodology.*

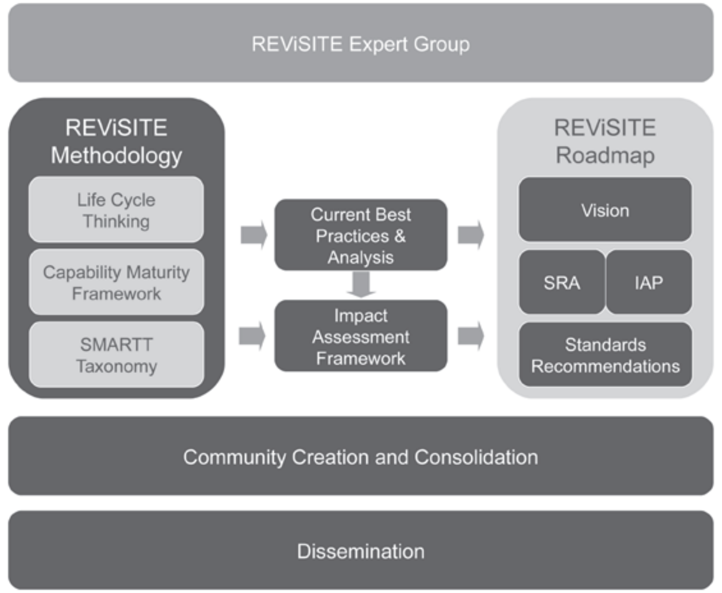

Figure 2: REViSITE project structure

REViSITE Methodology

This section outlines the methodology used in developing the cross-sectoral ICT4EE roadmap.

Life Cycle Thinking

In identifying 'a common methodology', the research collected for the deliverable D2.1, ICT4EE – Data Taxonomy, was clear: emerging best practice for assessing the impact of ICT on energy efficiency used some form of 'Life Cycle Assessment' (LCA) or 'Life Cycle Thinking' (see 1) and the overall trend and need is towards a focus on quantifying the enabling effects of ICT, not just its direct effects.

Body	Method	Direct Effects	Enabling Effects
ITU (International Telecoms Union)	Hybrid LCA	Yes	Yes
ETSI (European Telecoms Standard institute)	Hybrid LCA (National level)	Yes	Yes
iNEMI (International Electronics Manufacturing Institute)	Process-LCA	Yes	No
IEC (International Electrotechnical Commission)	Process-LCA	Yes	No
Ericsson	Process-LCA	Yes	Yes
ATIS (Alliance for Telecom Industry Solutions)	Process-LCA	Yes	Yes
GeSI (Global e-Sustainability Initiative)	Hybrid	Yes	Yes
ISO LCA **standards** 14040/44 & British standards Institute PAS-2050			

Table 1: ICT impact assessment utilises some form of life cycle approach

Assessments of best practice gathered while researching the deliverable *D2.1, ICT4EE – Data Taxonomy*, also suggested that the capacity to quantitatively assess ICT impact, while desirable, was in practice an arduous task. Situations where an existing system and a replacement ICT-enabled system can be directly measured are not very common. Where this does arise, the task is often complicated by the fact that the replacement system frequently differs from the old in more ways than just the ICT element. For this reason, it can be difficult to apportion energy savings as being ICT-enabled or otherwise. Abstracting this information further to the sector level is an even more onerous process. In short, determining if the energy savings are solely attributable to a change in ICT can be very difficult.

Adapted Capability Maturity Framework/REViSITE Framework

In scenarios where the opportunity for direct quantitative comparison is limited, some form of heuristics-based approach is typically used for estimating. In such situations, part-measurement, secondary data, specialist knowledge, etc., all play a part. In that vein, REViSITE developed a qualitative-based framework to identify the RTD strategies and ICT implementations most likely to have a positive impact on energy efficiency. The REViSITE framework, shown in Figure 3, was based on a combination of 'Life Cycle Thinking' and on an adapted 'Capability Maturity Framework' (CMF). It used a 'triangulation' approach to assess the impact of ICT by combining heuristics obtained from domain experts with data available from quantitative and qualitative sources.

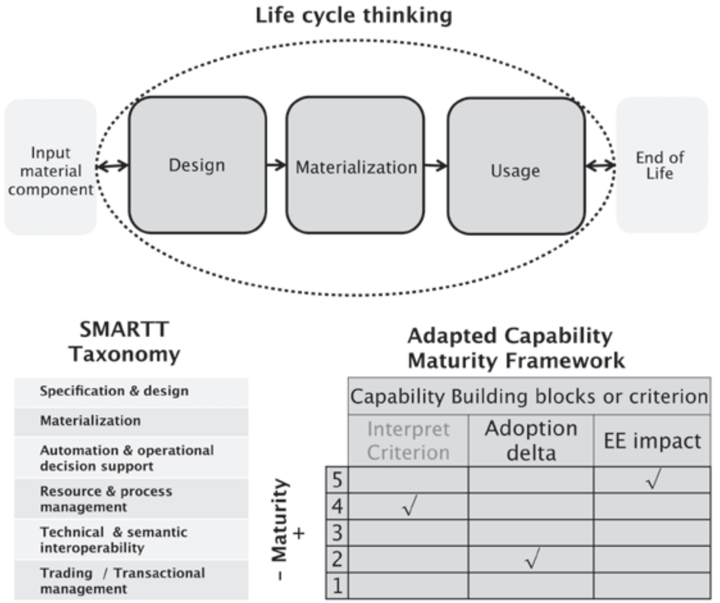

Figure 3: REViSITE framework

SMARTT Taxonomy

Before the four target sectors could begin to make comparisons across their respective domains, it was essential to speak a common technical language. The first stage of framework development focused therefore on developing a common taxonomy. The output was the SMARTT taxonomy, which comprised six high-level categories (bounded by the dashed lines in Figure 4) and 23 sub-categories (as shown in Figure 5), which together were deemed to cover the scope of the ICT4EE domain. The high-level categories were aligned to the generic, bounded life cycle shown in Figure 3. Both the categories and the sub-categories were fixed, allowing for common categorisation of ICT and RTD strategies across sectors. Sector RTD/ICT topics, defined by the partners, were nested within the sub-categories.

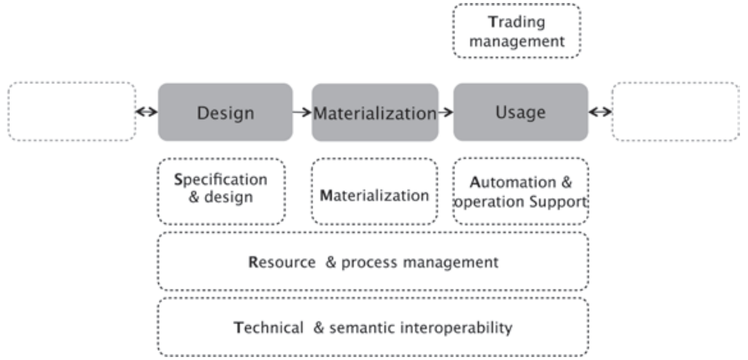

Figure 4: SMARTT taxonomy categories mapped to life cycle phases

The full SMARTT taxonomy is shown in Figure 5. The SMARTT taxonomy was used throughout the REViSITE project as an integrative classification system and as an aid to cross-sector ICT4EE assessment.

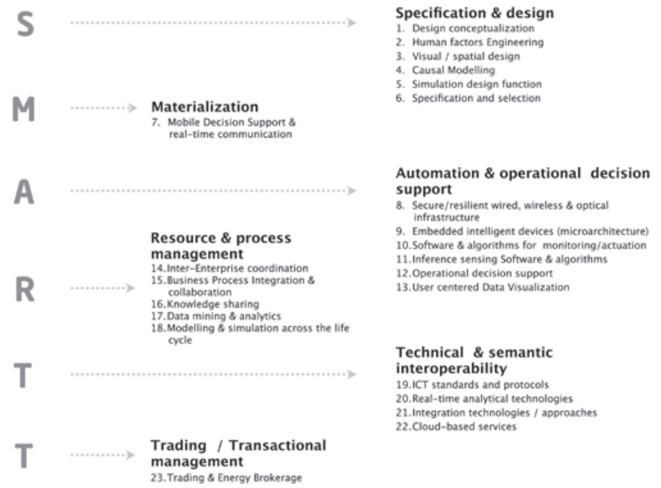

Figure 5: SMARTT taxonomy categories and sub-categories

Using the REViSITE Framework and SMARTT Taxonomy to Identify Research Themes

When conducting research for the deliverable *D2.2, ICT4EE – Knowledge & Current Practices*, the SMARTT taxonomy was used to classify the themes into 23 sub-categories. The adapted CMF was then used to assess how relevant each theme was in terms of defining a strategic research agenda (SRA). An online questionnaire was distributed to individual respondents, who assessed the 23 ICT themes based on a combination of heuristics and their own expertise within their defined sectors. During our subsequent analysis, each theme was mapped to a score based on the CMF-derived impact and adoption maturity scale shown in Figure 6. This enabled us to build sector-specific views about the theme's relevance to a strategic research agenda, where 'relevance' was determined using the formula; Relevance = Potential Impact * [Potential Adoption Score – Current Adoption Score].

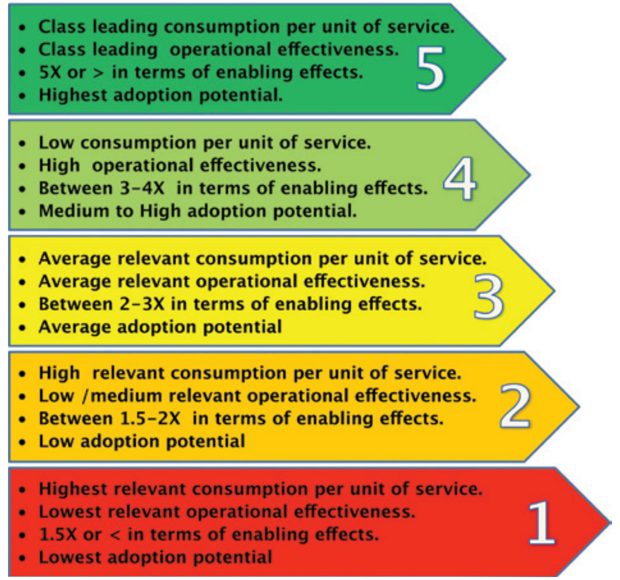

Figure 6: Impact and adoption maturity scale

Figure 7 shows an example of the output produced for each sector during the analysis phase. The numbers along the bottom edge of the graph identify the 23 sub-categories, while the letters represent the six high-level categories of the **SMARTT** taxonomy, where:

S = Specfication & Design ICT;

M = Materialisation ICT;

A = Automation and Operational Decision-Support;

R = Resource and Process Management;

TE = Technical Integration;

TR = Trading/Transactional Management ICT

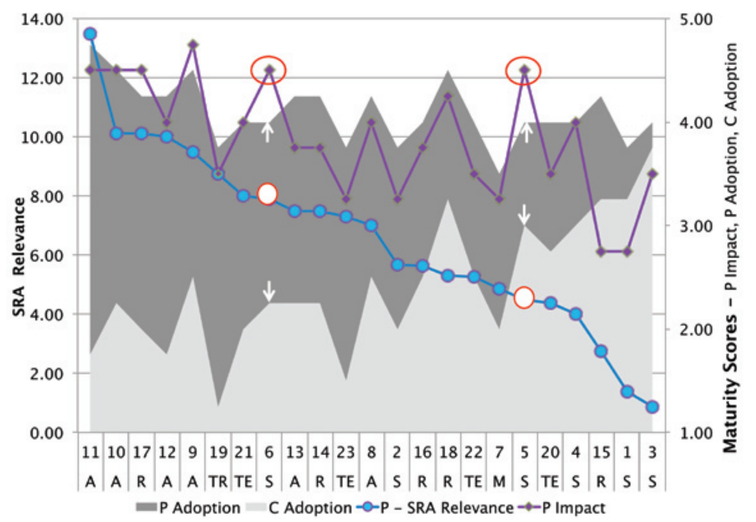

Figure 7: Determining SRA relevance for the manufacturing sector

From this diagram, it can be seen that while two ICT themes may score as equally important in terms of potential impact, due to their respective adoption delta scores (Potential Adoption Score – Current Adoption Score), they might differ in terms of their SRA relevance. Using a re-orderable matrix technique, we then examined cross-sectoral trends (for more details, see *D2.3, ICT4EE – Impact Assessment Model*). This analysis, coupled with the sector-specific outputs, offered the basis for workshops and consortium discussion and as described in the next section, shaped the tables and narratives for the deliverable *D3.2, Multi-disciplinary Strategic Research Agenda (SRA) for ICT-enabled Energy Efficiency.*

Developing The Strategic Research Agenda (SRA)

The deliverable *D3.2, Multi-disciplinary Strategic Research Agenda*, essentially consisted of six 'roadmap' tables aligned to the SMARTT categories and sub-categories.

As outlined previously, the SMARTT taxonomy was used as an integrative classification system and as a framing structure for deliverable *D2.2, ICT4EE- Knowledge and current practices*, which focused on identifying what was considered to be 'state-of-the-art' ICT. The output of this deliverable was further analysed in the deliverable *D2.3, ICT4EE - Impact Assessment Model*, in which a CMF-based methodology was used to propose the most relevant ICT in terms of 'Impact' and 'SRA relevance'. Deliverable *D3.1, Vision for multi-disciplinary ICT-enabled Energy Efficiency*, took these previous deliverables, the community discussion, and the consortium's own expertise as inputs to identify an ICT4EE vision for each of the SMARTT main categories and associated sub-categories. Together, these deliverables informed *D3.2, Multi-disciplinary Strategic Research Agenda*, which aimed to identify how to move from the current 'state-of-the-art' towards the vision by the year 2020. Figure 8 shows how each of these deliverables informed the six 'roadmap' tables that made up the SRA.

Note: The six tables are reproduced in the following pages. In the original deliverable, they were accompanied by a short narrative.

Each table briefly described:

- The ICT that is currently seen as state-of-the-art in each sub-category
- Short-term research priorities (*~3 years to industrial usage; adaptation, testing, and 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*)

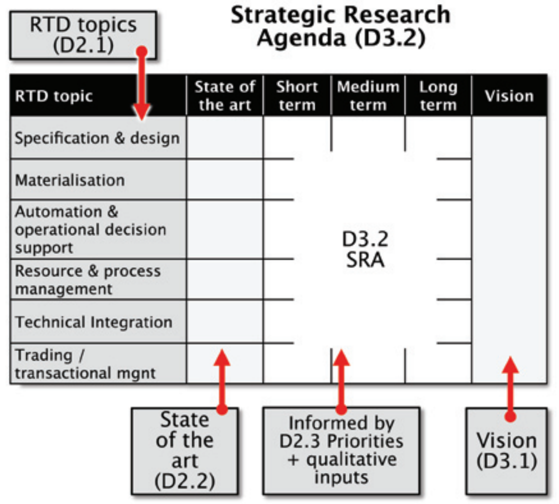

Figure 8: How the deliverables combined to inform SRA development

1. Specification and design ICT

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.	Holistic design of the interactions between different subsystems. Interoperability between CAD tools, applications for design, performance analysis, simulation, visualisation, libraries, etc.	Generation of requirements from related system models. Context-aware, visualisation-based EE criteria, with context-specific content suggestion, all rendered based on device capability and user preferences.	Integrated ICT for holistic design, modelling, and assessment, covering energy interaction between the different subsystems, technical, commercial, sustainability, and regulatory factors. Interoperability of design ICT in model-based information-sharing. Libraries of re-usable design solutions with rich search capabilities. Standardised data models covering energy-related aspects. Standardised energy performance indicators. Models of stakeholder profiles, requirements, energy consumption, market dynamics, etc. Certified software for compliance assessment. Evidence-based knowledge about the impacts of ICT on energy efficiency.
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.	
Modelling	Evolving model-based tools for mostly isolated design and 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, optimisation, simulation, etc.) and object libraries.		Functional (beyond data) product/system objects, enabling new object-oriented applications.	
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.	
Simulation	Tools for simulating energy consumption, generation, markets, CFD. CAD/design tools that include simulation. 2D/3D/4D visualisations.	Simulation methods for design and 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 and user experience/perception.	
Specification and product/ component selection	Limited sector-specific specification methods and tools, e-procurement.	Specification templates. Catalogues of materials, products, and suppliers. E-market tools.	Specification models. Model-based product libraries. Selection tools.		Optimally automated component selection and procurement.	

2. Materialisation ICT

RTD TOPIC	STATE OF THE ART	SHORT TERM -3YRS	MEDIUM TERM -6YRS	LONG TERM -9YRS	VISION
Decision- support and visualisation	Manufacturing/process simulation tools. 4D visualisation/animation of processes, e.g., in construction. Life-cycle assessment of different construction/manufacturing options.	Tools to process data in real-time and display that data in visually compelling ways that will drive decisions. Energy-related aspects included into decision-support to select production strategies, e.g., off-site/on-site production and materials. Tools and e-commerce platforms for waste re-use.	Tools and interfaces using data from multiple ICT systems (e.g., BIM/PLM/ERP) to analyse and visualise (e.g., in 3D/4D/VR) data such as current-state, energy-related information, environmental impact, 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 of 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.	ICT to optimise or select production/materialisation/procurement methods based on optimum energy consumption. ICT to rationalise materialisation processes (in terms of planning and control) for energy efficiency (e.g., logistics, sequence, etc.). Real-time communication in the materialisation phase. Tracking and visualisation of the materialisation process in virtual planning models.
Management and control	Generic project planning tools (Gantt charts, cost estimation, etc.). ERP, BIM, and PLM systems.	Energy-related aspects integrated into planning tools (finance, logistic, scheduling) to define energy targets for production.	Support for costing the whole life cycle. Automated tools for testing energy performance and 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	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 and status of components, enabling near-real-time manufacturing.	Pervasive, context-aware multimedia content provided to workers on portable devices and back office systems.	Direct feedback of changes into planning models/simulations.	

3. Automation and Operational Decision-Support ICT

RTD TOPIC	STATE OF THE ART	SHORT TERM -3YRS	MEDIUM TERM -6YRS	LONG TERM -9YRS	VISION
Automated monitoring and control	Existing software algorithms, embedded microcontrollers, sensor/actuation hardware, variable-speed drives, remote lighting, heating, and appliance control, etc. Standalone component technology is relatively sophisticated; the issues are with its integration and interoperability.	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 versus cloud-based control services for automated control and monitoring.	Virtual sensors, inference technology, and non-intrusive load monitoring. Increased levels of autonomous diagnostics and machine-learning. Advancement again aligns to Technical Integration space. Dynamic, dependable combination of local versus cloud-based control services for automated control and monitoring.	Autonomous machine-level diagnostics, prediction, and optimisation, real-time monitoring of streamed data, full integration and interoperability of sensor and actuation devices with optimised use of ambient resources [ambient light, passive cooling] and increased use of renewable energy and water through integration with Smart Grid/water networks.	Embedded ICT permeates sectors, providing the "intelligence" to monitor and control energy resources in sustainable ways. ICT systems facilitate user control through integrative data visualisations that sustain user interest. ICT acts as learning systems, providing reliable, secure, and affective decision-support to prosumers. Building operating systems and district energy management systems automatically install software and services in buildings/ districts similarly to PCs now. Predictive control algorithms perform real-time optimisation. Systems learn and adapt to user preference via incorporated anticipatory logic. Secure wired/wireless and optical sensor networks act as a communications backbone to the energy grid.
Operational decision-support and visualisation	Existing information systems, Building/home energy management devices, decision-support dashboards. Visualisation technologies/ methodologies.	Energy dashboards and real-time communications regarding usage. Based on HFE, data visualization and cognitive work analysis principles. Ability to cope with 'Big Data' and diverse data sources via semantic ontologies, cloud-based data services, and real-time streaming data processing. Streamlining the design process by simplifying data acquisition, manipulation, and assignment to graphical components.	Intuitive, easily deployable, easily usable, dynamically adaptable visualisations incorporating streamed and asynchronous data and 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 and information consumption preferences.	Visual programming of performance indicators. Full integration and optimised data visualisation of diverse systems, e.g., weather, security, energy, price information, etc. Moving towards autonomous and automated 'context-aware' decision-support.	
Secure wired/ wireless sensor networks and Quality of service	High-speed wired/wireless networks, sensor hardware/ software essential for sub-metering strategies and for linking to HAN, LAN, or WAN technologies such as 6LoWPAN, ZigBee, PLC, etc.	Secure communications with defined QoS, QoE, and privacy in terms of grid infrastructure and at-the-edge devices Self-configuring, scalable, secure, and adaptable WSN. NFC for identity management in WSN.	Wide-scale deployment of secure, fault/delay-tolerant communication networks allowing for service provisioning and manageability including authentication and use of cybersecurity best-known ICT and methods.	Incorporated anticipatory logic, context-aware user preferences, including privacy and security. Seamless edge to cloud data processing, through real-time and user-based participatory sensing.	

4. Resource and Process Management ICT

RTD TOPIC	STATE OF THE ART	SHORT TERM -3YRS	MEDIUM TERM -6YRS	LONG TERM -9YRS	VISION
Inter- enterprise coordination	Diverse (often proprietary-based) systems exist in terms of ERP/ CRM systems and similar. Standalone ICT technology is relatively sophisticated. Interconnectedness is the prime issue.	Augmentation relates more to technical and semantic interoperability. Contract and supply network management, process planning, ERP, logistics, procurement, production, etc. Need to embed EE criteria in technology, practices, and policy.	Methods for virtual enterprise (VE) and network setup and evolution. Short to medium-term development in terms of dependable, scalable, and extensible network platforms to support new devices and services in terms of knowledge and value creation.	Following the scalable platform/network theme, fully validated, machine-readable, service level agreement technologies with semantic-based contract management and enactment.	Enhanced knowledge creation, sharing, and management including: Infra-structure, data mining and analytics, semantic map-ping, filtering, consolidation algorithms, distributed data bases, catalogues of re-usable EE solutions, etc. Wide availability of ICT-based services and infra-structure. Enhanced, value-driven business processes and ICT- enabled business models. ICT 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, group-ware, social media, and collaboration ICT solutions support process integration and new services, reducing the need for transport and commuting, while allowing for knowledge/value creation.
Business process integration	Business process modelling and re-engineering methods. Fairly sophisticated ICT in terms of business process integration from the perspective of purchase/delivery interfaces, collaboration support, groupware tools, ERP (front-end) systems, electronic conferencing, distributed systems, social-media, and business work flows.	Augmentation in terms of business integration with respect to operational processes: design production, on-site/off-site production and make-versus-buy, etc. Increased functionality in terms of social media and crowd-sourced research/validation with respect to energy data sharing/integration.	Integration of heterogeneous data/information sources in order to build inference type applications that add valued extensions aligning to KM sub-cat.	Standards and interfaces for model/ semantics-based inter-enterprise collaboration.	
Information/ knowledge management and analytics	Technologies in the knowledge management space exist. However, augmentation relates to the interconnectedness of information relating to elements within smart district, inter-enterprise, and production system domains, with additional improvement required in terms of data mining, analytics, modelling, and visualisation, given the anticipated increase in sensor data that will result from realising smart 'X' visions and in improving information reliability.	Semantic and ontology engineering in terms of agreed data modelling best practice in describing energy flow at the district and intra-enterprise level. Strong links to technical integration. Methods for knowledge consolidation and distribution. Cross-organisational repositories. Research also required in terms of links to technical and semantic integration of relevant information touch points to improve analytics/modelling capability and accuracy. Community forums for discussion. Digital catalogues of products/sensors/services containing parametric information.	Strategies/technologies to link and process heterogeneous energy data and semantic information relating to entire life cycles and districts in producing holistic scalable/ extensible analytics for energy optimisation. Easy access to knowledge about energy efficiency which is modelled according to standards and easily accessible. User awareness tools (syndication). Open accessible analytics in terms of energy consumption and optimisation, pattern identification, predictive diagnostics, etc.	Incremental improvement over medium term with respect to increased accessibility, extensibility, and scalability of semantic information, energy data, analytics, and compute power which will underpin innovative energy services. Template solutions based on good practices; ubiquitous and context-based access to inter-organisational knowledge platforms.	

5. Technical Integration ICT

RTD TOPIC	STATE OF THE ART	SHORT TERM -3YRS	MEDIUM TERM -6YRS	LONG TERM -9YRS	VISION
Integration technologies and infrastructures	Wide variety of systems/ com-ponents/interfaces/ technologies that 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 and event-driven architectures. Enriched, smart aggregation of services on ISP, allowing the management of complex systems in a more efficient, secure way. Development and management of dependable/ trustworthy, open, scalable, and extensible platforms. Development of a holistic ontology/ data model and 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 (such as transportation). Cross-infrastructure and cross-system data exchange, leading to shared, managed infrastructure (energy, water, etc.)	ICT supports compliance to regulations and standards. Integrated infrastructures are implemented to support all ICT tools and systems for EE: collaborative, distributed design and 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 and standards	Because of the variety of solutions, there are 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.) and non-building-sector models (e.g., the grid CIM). Open data and linked data initiatives, where governments and users combine data sources, providing enhanced information-sharing and decision-making.	Definition of unified, open com-medication 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 communication with the smart grid.	Integration of gateways from this Open Communication Standard towards other domains (such as 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.

6. Trading/Transactional Management ICT

RTD TOPIC	STATE OF THE ART	SHORT TERM -3YRS	MEDIUM TERM -6YRS	LONG TERM -9YRS	VISION
Regional energy management	Regional energy management has a long tradition. New developments mainly relate to market integration and sector liberalisation. Most energy management systems (EMS) conform to international standards.	Generic ontologies, use cases, and standards that support plug-and-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, economic, and ethical aspects into account and common metrics enable 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, and 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 have existed for a 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 and the audit/verification process. Building optimisation includes energy consumption, local production, and energy market interactions (buy/sell). Integration of facility energy management systems in regional information systems, enabling regional energy balance optimisation.	Integrated building/grid ontologies and interoperability standards. Smart appliances and generic infrastructures that allow direct device coordination. Market and grid balance optimisation via distributed decision-support functions. Data quality management via automated validation tools based on fast and flexible data exchange platforms (cloud).	Facility energy management systems would "negotiate" with regional or district energy management systems on their energy consumption, taking energy markets, product markets, economic, 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 level of the building and individual prosumers. Advanced (cloud-based) balancing functions use (near) real-time measurement data and advanced control algorithms for the optimisation of resources, loads, and grid capacities.
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 and support the transition towards energy management. Basic personal energy information systems, based on remote meter-reading architectures, to include energy consumption monitoring functions, invoicing, settlement, and reporting on the consumption of individual devices.	Regulatory frameworks that ensure privacy and transparency for participants in general and the end-user (prosumer) in particular. Personal energy management. systems enhanced with advisory functions that allow individual consumers to monitor and influence consumption and generation patterns and 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.	

Developing the Implementation Action Plan (IAP)

Having established a menu of 23 potential ICT4EE research trajectories, attention turned to formulating the work into a format that clearly identified the ‘target outcomes’, ‘expected impacts’, and potential ‘actionable items’.

Figure 9 below illustrates how the various elements of the tables in *D3.2, Multi-disciplinary Strategic Research Agenda (SRA) for ICT-enabled Energy Efficiency*, informed the tables of *D3.3, Implementation Action Plan (IAP)*. The elements were refined and specific stakeholder actions were identified. These tables were then used as inputs to qualitative discussion and analysis at a community workshop designed to sanity check the recommendations and identify specific ‘standards recommendations’ for the final main deliverable *D3.4, Recommendations for new standards to overcome interoperability barriers.*

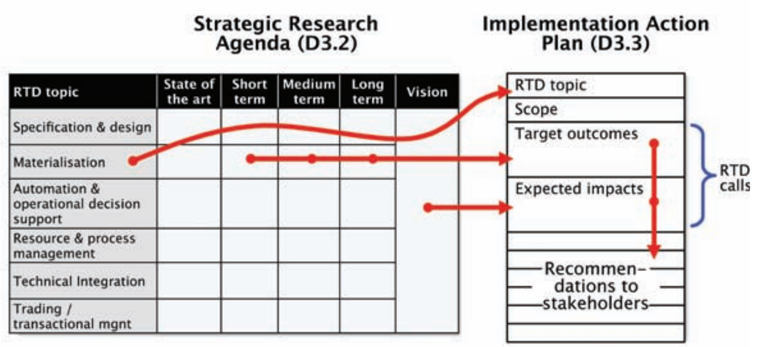

Figure 9: How the SRA tables informed the IAP

The interim output of the REViSITE IAP was 23 succinct tables that detailed:

- The scope of each RTD topic
- The target outcomes pertaining to any future research funding call
- Expected impacts of achieving the identified target outcomes
- Specific recommendations for various stakeholders
- Policy makers and regulators
  - RTD funding organisations
  - Researchers
  - Industry
  - Education and training institutes

The table on the page opposite, is taken from the IAP, of a populated table for the sub-category/RTD topic ‘operational decision-support and visualisation’.

Life cycle phase	Operational/Usage	
SMARTT category	3.0 Automation & Operational Decision-Support	
Sub-category	3.2 Operational decision-support & visualisation	
Technical content/scope	Operational visualisation decision-support ICT solutions that integrate diverse systems such as safety, security, weather, and energy at different levels of abstraction, e.g., plant, building, or district. To include SCADA, Business Activity Modelling, Management Dashboard Systems, and methodologies for analysing situation awareness in complex sociotechnical and First-Of-A-Kind systems.	
Target outcomes	Technology, standards, and strategies supporting: • Ability to understand Big Data volumes and diverse data sources via visualisation • Intuitive, dynamically adaptable visualisations, incorporating streamed (real-time) and asynchronous data sources for effective, energy-related decision-support • Contextual rendering of data visualisations based on end-user device capabilities and information consumption preferences, again supporting effective EE-related decisions	
Expected impacts on EE	Improved energy performance management via integrative data visualisation and decision- support that augments automated management systems	
Codes of related SRA topics under other taxonomy sub-categories (and add a linking statement if any)	• Interoperability between CAD tools, applications for design, performance analysis, simulation, libraries, etc. Generation of requirements from related system models tying data sources to graphic components. Visual programming of performance indicators • Connection to automated sensing and control technologies in the operational phase, together with horizontally applicable themes (knowledge management, process/supply chain/ life cycle simulation and modelling)	1.1-1.5 3.1 4.1-4.4
Comments		
Recommended implementation actions by different stakeholders		Time scale S, M, L ↓
Policy makers	Encourage the adoption/application of standards to improve productivity and exploitation, e.g., W3C	S M L
Research and innovation funding organisations	• Encourage applied projects in the energy efficiency space that will test visualisation state-of-the-art technologies in real-world scenarios • Encourage the adoption of user-centred design process when engaging in use-case driven projects to ensure closer collaboration with end-users/industry	S S
Research performers Industry	• Visual programming of performance indicators • Methodologies for identifying user requirements in a manner that is directly relevant for visual design • Streamlining the design process by simplifying data acquisition, manipulation, and assignment to graphical components	M S S
Standardisation bodies (D3.3)	Expand on the current ISO standards on usability and user-centred design to include process roadmaps and assessment criteria, e.g., ISO 9241-151 and work of ISO/TC 159	M
Education & training (D.4.4)	Generate exemplars that clearly show the design process applied in context	M
Other stakeholders:		
Corresponding Enablers		
Author	Date	/ /

An example populated IAP table ‘operational decision-support and visualisation’.

Proposed Call Themes

The 23 theme-tables outlined in the IAP were intended as a menu from which potential research call themes could be chosen. While any of the 23 could potentially inform a research call, the consortium, based on their own expertise and inputs from the wider community, consolidated the 23 themes into 11 proposed call themes. This section outlines the 11 research themes defined by the REViSITE consortium and details the scope, target outcomes, and expected impacts of each theme.

1. Integrated Design

1.1 Technical Scope

The lifetime performance of a product/system is largely determined in the design phase. This is especially the case when new products/systems are designed. Design for the retrofitting of existing systems is also crucial, as many products are renewed several times throughout their lifetime. Complex systems need to be optimised based on multiple and often conflicting criteria. The degree of energy efficiency potential that can be achieved through integrated design depends on the downstream life cycle stages (materialisation, operation). Integration between different information sources, stakeholders, and stages is, therefore, of fundamental importance for design.

1.2 Target Outcomes

The main targets for integrated design are the interoperability of various ICT applications and the ability to share information at a high semantic level between stakeholders throughout all life cycle stages:

- Enhancement of existing design, analysis, and simulation applications, as well as catalogues with energy-related attributes and interoperable interfaces based on standards.
- ICT platforms to facilitate sharing of design information within and between organisations and to facilitate negotiations about the design as it evolves. The challenges include, e.g., providing open access to relevant stakeholders, presenting information in context-driven ways, supporting both the agreed inter-organisational transactions and internal workflows of each organisation, and protecting the intellectual property rights (IPR) of semantically rich information.
- Holistic optimisation of the interactions between different subsystems, taking into account technical, commercial, sustainability, and regulatory factors.
- Methods for collaborative development of early-stage design concepts and decision-support with context-driven visualisations.
- Tools for modelling existing products/systems/facilities that enable design to be retrofitted, e.g., by scanning.
- Collaborative configuration design and customisation, based on reference solutions, adaptation rules, and catalogues of parametric objects.
- Methods and services for long-term data archival and recovery over generations of standards, tools, and storage media.

- Simulation-based systems for refining requirements for highly interdependent complex systems and for validating the contributions of different subsystems to the overall energy performance in areas such as major infrastructures.
- Definition of standardised energy performance indicators which can be calculated from available design and operation data. ICT-based validation. Certification of performance-assessment software and methods.
- New design processes and collaboration mechanisms/platforms.

1.3 Expected Impact

Integrated design has a direct impact on both the design process itself and on the subsequent life-cycle stages which depend on design information. The energy performance of the target system depends ultimately on the combined impact of design, materialisation, and operation.

- Engagement and empowerment of relevant stakeholders in the design and decision-making process.
- Enhanced use of proven, reference design solutions, with less reinvention.
- Awareness and improved understanding among stakeholders about the impact of various design options and about the impact of ICT on energy efficiency in general.
- Improved quality of design with respect to compliance to requirements, consistency, number of errors, and predictable and optimised life-cycle performance.
- Better information support to downstream life-cycle stages (materialisation, operation).

2. Component Catalogues

2.1 Technical Scope

Catalogues of materials and components are needed to support the design of products/systems, as well as procurement for materialisation. These catalogues should provide access to various commercial and technical information (including, e.g., properties relating to energy efficiency). The catalogue content should be at an abstract/semantic level to meet the requirements of increasingly model-based design tools.

2.2 Target Outcomes

- Catalogues with semantic information for materials, components, and re-configurable design solutions. Parametric objects to support configuration/adaptation of component types for specific applications.
- User interfaces for semantic search and filtering, to enable user-specific data delivery.
- Standards-based interfaces/web-services for interoperability with various CAD tools and engineering applications for design, performance analysis, simulation, visualisation, etc.
- ICT solutions for brokering information from several sources, e.g., combining manufacturer-specific catalogues to serve specific information users.
- Standardised data models of catalogue contents, particularly for energy-related data, e.g., embodied energy.
- Toolkits for catalogue authoring and maintenance.
- New business and service models for information providers and brokers.

2.3 Expected Impact

- Improved efficiency and quality of design through re-use of existing information.
- Improved energy efficiency through availability and re-usability of energy-related data.
- Wide information coverage in key application areas in order to stimulate take-up.

3. Data Models

3.1 Technical Scope

Achieving energy efficiency requires holistic management of information from many stakeholders over the product's lifetime. Common concepts and language are prerequisites for communication, both between humans and ICT systems. Agreed data models (ontologies) are needed to bridge the gaps and to enable information-sharing and re-use without error-prone interpretation, manual data re-entry, and loss of data.

3.2 Target Outcomes

- Common cross-disciplinary concepts by aligning sector-specific ontologies to support balancing of energy provision (e.g., grids) and consumption (e.g., buildings).
- Definitions of metadata for shared information in distributed, collaborative design and engineering, and in catalogues of materials and products.
- Standardised representation of functional/parametric product/system objects with embedded configuration/customisation logic.
- In the short term, to extend existing data models for various application domains to include concepts specific to energy efficiency.
- In the long term, convergence of agreed models and ontologies for different inter-related application areas, leading to standardised data models which cover energy-related aspects in a broad range of applications.
- Test cases, methods, and procedures to validate if software tools and shared data comply with the agreed data models (ontologies).
- Forums bringing together developers of data models (ontologies) from inter-related application areas (e.g. buildings, process plants, grids, etc.) to join forces to harmonise ICT standards relating to energy efficiency.

3.3 Expected Impact

- Standardised data models (ontologies) covering energy-related information and interactions within and between related application areas.
- Improved ease of access to energy efficiency knowledge through a common ontology.
- Interoperability of design software through compliance to standardised data models.
- Improved energy efficiency through holistic integration of information.

4. Application Tools

4.1 Technical Scope

ICT solutions for design include general-purpose CAD tools with sector-specific add-ons and a variety of specific tools for engineering analysis, life-cycle performance estimation, simulation, visualisation, etc. The main research needs are related to issues such as early-stage design and decision-making, enhancing the scope of existing tools to support design for energy efficiency, increased utilisation of existing good design solutions, information-sharing between various ICT tools through interoperability, and reducing the gap between predicted and actual energy performance of systems.

4.2 Target Outcomes

- Concept design: Profiles of user groups, covering their requirements and energy consumption behaviour. Tools for early-stage conceptual design, life-cycle energy performance estimation based on reference data, visualisation and decision-support of design options. Methods (e.g., based on simulations) to derive detailed requirements from models of complex systems.
- Detail design: Configuration design based on templates, reference solutions, parametric adaptation rules, and intelligent component catalogues. Modelling existing facilities for retrofitting design, e.g., using scanning. Context-aware visualisation of the evolving, detailed, design solution, to facilitate cross-disciplinary decision-making.
- Engineering analysis and simulation applications: Domain-specific application tools, enhanced with energy-related attributes and interoperable, standards-based interfaces. New tools for integrated assessment and visualisation of costs, environmental impacts, comfort, etc. Holistic simulators for complex systems, such as major infrastructures. Procedures and test cases for certifying software tools.
- Supply network management, production planning, and management: Decision-support for selection of materials, components, and production strategies (e.g., off-site versus on-site production). Simulation-based, real-time production management. Context-related multimedia content provided to workers on portable devices. Inter-enterprise ICT supporting coordination towards contractual goals, including energy efficiency.
- Visualisation and decision-support: Besides informing stakeholders about real-time progress towards energy efficiency objectives and highlighting trade-offs between environmental and economic concerns, ICT should also proactively suggest options for decision-making.

4.3 Expected Impact

- Awareness and ability of stakeholders to make grounded decisions about design and production options.
- Reusability of proven solutions through model-based design technology, interoperability, configuration design, and intelligent catalogues.
- Improved quality of design through holistic consideration of the interactions between various subsystems.
- Certified software tools reducing the gap between predicted and actual system performance.

5 Life-Cycle Energy Modelling and Estimation

5.1 Technical Scope

To promote energy efficiency targets, it is necessary to continuously monitor/estimate energy consumption at every phase in the system's life cycle. In early design, there is a need for planning and testing, as this has a high impact on the system's overall energy consumption. Later stages require performance indication, data processing, and visualisation, as a foundation for management, decision-making, and control. A holistic (cross-sectoral) perspective needs new ways of integrating the different energy efficiency evaluation methodologies used across the respective sectors. Multiple new approaches are, therefore, needed to address energy efficiency metrics, measurement and analysis methods, systems integration, and knowledge repositories.

5.2 Target Outcomes

- Metrics and validation methods for holistic, static performance: technical, economic, and environmental. Standardised energy performance indicators. Quality of Service and Service Level Agreements.
- New incentives and market propositions that drive efficiency measures.
- Inclusion of energy-related aspects in decision-support ICT solutions for selecting production strategies, e.g., off-site/on-site production and materials.
- Tools and interfaces using data from multiple ICT systems (e.g., BIM/PLM/ERP) to analyse and visualise (e.g., in 3D/4D/VR) data such as current-state, energy-related information, environmental impact information, etc.
- Simulation-based, real-time production management. Real-time target/actual performance comparison.
- Direct feedback of changes into planning models/simulations.
- Cross-sector ICT solutions supporting innovation and optimisation of energy efficiency across the entire life cycle, aimed at achieving a win-win situation for the various stakeholders by moving beyond the traditional division of roles between disciplines and the focus on lowest-first investment cost per participant.
- Support for costing the whole life cycle.
- Causal-modelling ICT solutions used to describe/predict relationships in physical systems, such as computer-aided diagramming (e.g., Sankey diagrams, cause and effect diagrams, influence diagrams, etc.) and life-cycle modelling.
- Established strategies/technologies to access, integrate, and process diverse energy efficiency data and information relating to entire life cycles and entire districts, etc.
- Increased technical and semantic integration of relevant information touch points used to improve analytics/modelling capability and accuracy.
- Knowledge-sharing ICT solutions, such as knowledge management systems, knowledge repositories, knowledge mining and semantic search, linked data, long-term data archival, and recovery at enterprise or inter-enterprise level.

5.3 Expected Impact

- Awareness among stakeholders about the implications their decisions have on energy efficiency.
- Better access to information on energy efficiency.
- Holistic design of the interactions between different subsystems. Interoperability between CAD tools and applications for design, performance analysis, simulation, visualisation, libraries, etc.

- Improved energy efficiency enabled by these libraries and data models.
- Using a central hub to measure/monitor energy efficiency in buildings will help conserve energy and improve efficiency, based on market options and incentives.

6. Metrics and Methods for Assessing Energy Efficiency and the Impact of ICT

6.1 Technical Scope

As discussed in previous sections, one of the primary barriers to adopting ICT for energy efficiency is assessing which solutions will have the greatest impact. Much has been done already in developing a common framework for understanding the direct impact of ICT on energy efficiency: for example, the ITU, in cooperation with other standardisation organisations such as ISO, IEC, ETSI, and ATIS, have proposed a new methodology which is aligned with the European Commission's Digital Agenda. However, while somewhat addressed in this new methodology, there is still a requirement for research to identify a) a common means of assessing the impact of ICT on energy efficiency and b) a common means of assessing energy efficiency in the first instance, as an accepted, common method does not currently exist.

Common metrics and measurement methods are required for comparison. Proposed methodologies for measurement, such as those used in residential buildings, are a good starting point, but continued research is required into ICT-enabled measurement, common assessment, verification/certification, best-practice sharing, and knowledge generation.

6.2 Target Outcomes

- Agreement on the extension of existing methodologies for common metrics and measurement methods.
- Agreed metrics and best practices for costing the whole life cycle.
- Holistic metrics and validation methods for static performance: technical, economic, and environmental.
- Energy/resource KPIs for a neighbourhood/city.
- Agreed methods for the analysis of measurement systems.
- Repositories of information on best-practice metrics and measurement.
- 'Use case' repository and knowledge exchange forums to demonstrate real-world examples of ICT impact on energy efficiency.
- Self-diagnostic calibration of measurement systems.
- Causal models and logic used to describe and predict the resource/energy impact of relationships in physical systems.
- Increased technical and semantic integration of relevant information inputs used to improve analytics/modelling capability and accuracy.
- Tools to process data in real-time and display that data in visually compelling ways that will drive decisions.
- Means of dynamically evolving KPIs through links to analytics for energy efficiency optimisation, pattern identification, and predictive diagnostics, etc.
- Development of digital catalogues which contain parametric information for products/sensors/services. These catalogues should include, for example, quantitative data from developer/manufacturer specifications to support assessment of the impact of ICT solutions/implementations on energy efficiency.
- Trading and energy brokerage ICT solutions, e.g., consumer/producer forecasting algorithms, energy source tracking, consumption/price negotiation.

6.3 Expected Impact

- Awareness among stakeholders about the implications their decisions have on energy efficiency.
- Evidence-based knowledge about the impact of ICT solutions on energy efficiency.
- Understanding of how different design parameters impact the energy efficiency of the resultant system.
- ICT solutions to optimise or select production/materialisation/procurement methods based on optimum energy consumption.
- Enhanced creation, sharing, and management of energy-related knowledge, including infrastructure, data mining and analytics, semantic mapping, filtering, consolidation algorithms, distributed databases, catalogues of re-usable solutions for energy efficiency, etc.
- Smart loads, decentralised generation, local storage, and local decision-making by market actors. This improves the efficiency of renewables when grid management operations are able to align with configuration changes.
- Energy management and demand-side management functions will increase the efficiency of renewable resources and reduce load variations greatly. It might be fair to say these functions are required for the large-scale integration of intermittent resources.
- Using a central hub to measure/monitor energy efficiency in buildings will help conserve energy and improve efficiency, based on market options and incentives.

7. Data Visualisation and Decision-Support

7.1 Technical Scope

The ever-increasing digitisation of modern life is fuelling a rapid, upward trend in data. A move towards an 'internet of things' can only amplify that trajectory. Compelling data visualisation and decision-support ICT will be paramount in navigating the increased volume and complexity of data, including energy and resource efficiency data at the individual, home, enterprise, and district level. In the context of future sustainable cities, there will be a need for novel data visualisation and decision-support solutions in coping with diverse, complex data and in ensuring sustained user interest/engagement. Greater volumes of heterogeneous data will require dynamically-adaptable visualisations. A basic requirement of this call theme is the expanded use of cognitive data visualisation principles. The scope of ICT solutions includes, but is not limited to, the integration of diverse systems (safety, security, weather, energy, etc.) at different levels of abstraction, SCADA, business activity modelling, management dashboards, and methodologies for analysing situation awareness in complex systems.

7.2 Target Outcomes

- Ability to understand Big Data via visualisation; use data sources for effective, energy-related decision-support.
- Intuitive, dynamically-adaptable visualisations, incorporating streamed (real-time) and asynchronous data.
- Contextual rendering of data visualisations, based on end-user device capabilities and information-consumption preferences, again supporting effective, energy-related decisions.
- Ability to create a digital representation/model of a building, where the digital model dynamically adjusts over time to accurately reflect the changing usage and performance of the building.

- Visual programming of performance indicators.
- Methodologies for identifying user requirements in a manner that is directly relevant for visual design. Moving towards influencing for sustained interest.
- Operational, decision-support ICTs that integrate high-level diverse systems, such as safety, weather, and energy, etc. at individual, building, or district level, for near-real-time or real-time decision-support.
- Tools to process data in real-time and display that data in visually compelling ways that will drive decisions.
- Decision-support/recommendations to solve trade-offs between environmental and economic concerns.
- Energy-related aspects integrated into/illustrated in planning tools (finance, logistic, scheduling) to define energy targets for production.
- On-the-fly visualisations of operational energy consumption, based on streamed data.
- Dynamically-adaptable planning models/simulations, based on automatic feedback.
- Mobile, decision-support ICT solutions and device-aware visualisations that use real-time communication to facilitate in-the-field decision-making, particularly in construction or civil engineering tasks.
- Compelling visualisation and decision-support ICT solutions, incorporating holistic energy-consumption data at the neighbourhood level.

7.3 Expected Impact

- Greater understanding in terms of behavioural science and human factors with regard to the use of ICT4EE.
- Intuitive data visualisation, based on cognitive principles, that sustains human interest.
- Improved energy management via integrative data visualisation and decision-support that augments automated management systems and sustains user engagement. Strong links to 'automated monitoring and control' in moving towards learning systems that provide reliable, secure, and affective decision-support to energy producers and consumers.
- Increased support for optimising production/materialisation/procurement decisions based on optimum energy consumption.
- Improved urban planning visualisations, incorporating heterogeneous data sources.
- Augmented decision-support in rationalising materialisation processes (in terms of planning and control) for energy efficiency (e.g., logistics, sequence, etc.).
- Tracking and visualisation of the materialisation process in virtual planning models.
- Ability to dynamically visualise complex data streams to assist in making decisions about operational resource consumption.
- More effective decision-support systems for making operational decisions about resources at the neighbourhood/municipal level.

8. ICT for New Business Models and Work Practices for Improved Energy Efficiency

8.1 Technical Scope

There is a need for new business models and work practices to support the paradigm shift towards energy-efficient delivery of products and services throughout the whole life cycle. These may include (but are not limited to):

- New types of contractual relationships, such as performance-based contracts that require tools and methods for estimating and modelling energy consumption and enable energy performance to be evaluated with respect to the contract.
- E-commerce tools and collaborative working environments that facilitate remote working.
- Incentives for environmentally-friendly, low-carbon/energy-efficient design that requires supporting ICT tools.
- Methods of modelling and simulation to estimate the appropriate incentive, and deliver transparent energy consumption data facilitated by data visualisation.

8.2 Target Outcomes

- Tools and interfaces using data from multiple ICT systems (e.g., BIM/PLM/ERP) to analyse and visualise (e.g., in 3D/4D/VR) data such as current-state, energy-related information, environmental impact information, etc.
- Visualisation of trade-offs between environmental and economic concerns.
- Sending of automated alerts about deviations in the production process to the persons in charge.
- Tools and e-commerce platforms for waste re-use during materialisation.
- Pervasive, context-aware multimedia content provided to workers on portable devices and back office.
- Cross-sector ICT solutions supporting innovation and optimisation of energy efficiency across the entire life cycle, aimed at achieving a win-win situation for the various stakeholders by moving beyond the traditional division of roles between disciplines and the focus on lowest-first investment cost per participant in support of whole life cycle cost analysis.
- Embedding energy efficiency criteria in technologies to support contract and supply network management, process planning, ERP, logistics, procurement, and production.
- Methods and tools for virtual enterprise (VE) and network setup and evolution.
- Short- to medium-term development of dependable, scalable, and extensible network platforms to support new devices and services in terms of knowledge and value creation.
- Inter-enterprise ICT solutions for supporting coordination, e.g., contract and supply network management in the context of reduced energy consumption.
- Ubiquitous, context-based access to inter-organisational knowledge platforms, with template solutions based on best practices.
- Development of new services relating to energy efficiency.
- New coordination agreements to ensure the stability and reliability of the interconnected network.
- New functions for recovery and outage management through fault detection and self-healing equipment to reduce energy overheads during downtime.
- Trading and energy brokerage ICT solutions, e.g., consumer/producer forecasting algorithms, energy source tracking, consumption/price negotiation.

- Use of cloud-based services for tasks such as data management, monitoring, and analysis, to assist remote working.
- Integration technologies/approaches, such as service orientation and event-driven architectures, to facilitate heterogeneous device data interoperability at enterprise, network, and environment level.

8.3 Expected Impact

- Expected impact primarily relates to energy abatements brought about through reduced waste due to leaner (more streamlined) inter-enterprise processes, e.g. in logistics.
- Promoting and facilitating virtual enterprise business relationships, instead of traditional working practices, which require large amounts of energy.
- Adoption of ICT-enabled integrated processes for energy efficiency (including models developed within RTD initiatives, including human, legal, economics, contractor, liability, and business models).
- Following the scalable platform/network theme, adoption of fully validated, machine-readable service level agreement technologies with semantic-based contract management and enactment
- Improving stability and reliability of the connected grid structures in cases where operational proceedings and fault management procedures are coordinated. As a result, far greater amounts of distributed resources (both wind and solar) are acceptable in grid management operations.
- Using a central hub to measure/monitor energy efficiency in buildings will help conserve energy and improve efficiency, based on market options and incentives.

9. Cloud Computing and Network-Enabled Energy Services

9.1 Technical Scope

Trusted network infrastructure and network architectures will be paramount in underpinning the sensors, actuators, and analytics so crucial to energy and resource efficiency services. Additionally, 'cloud computing', which encompasses Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS), is transforming the software and service industry, and will have a profound impact on the ICT strategies of multiple sectors. Much in terms of augmentation with regard to cloud computing and future networks is essentially independent of a 'sustainability' context. However, if not addressed, more generic issues, such as those related to adoption[1] identified below, will negatively impact on cloud-based energy and resource management services, which are highly pertinent to sustainability.

The top four actions that are important to most groups (from small- and medium-sized enterprises to large enterprises) in terms of cloud computing adoption are:

- Greater accountability and liability for security by providers of cloud-based services.
- Ensuring portability between cloud services.
- Improving internet connections (important to non-users of the cloud overall and also to limited users).
- Security certification of vendors of cloud-based services.

Add to this the important role data privacy will have for the adoption of energy-related offerings and one begins to understand the immense role context-independent issues, such

1. IDC interim report on 'Quantitative estimates of the demand for cloud computing in Europe and the likely barriers to take-up' Feb 2012, [available] online at http://cordis.europa.eu/fp7/ict/ssai/study-cc_en.html

as dependability, scalability, flexibility, and privacy of data, will have for energy- and resource-related services. Trusted networks and cloud computing will be essential in providing dynamically-scalable access to energy-specific knowledge, knowledge management systems, knowledge repositories, knowledge mining and semantic search, long-term data archival and recovery, as well as data/information mining and analytics.

9.2 Target Outcomes

- Innovative architectures supporting flexibility, scalability, dependability, and privacy.
- Dependable infrastructure: reliable, robust, secure, efficient, fault- and delay-tolerant networks and communications.
- The ability to move between different clouds, i.e., increased federation and interoperability.
- Ability to dependably process/support/manage 'Big Data' volumes and diverse data sources.
- Optimised cloud versus edge processing, based on client-aware logic.
- Fully validated, machine-readable, service level agreement technologies, with semantic-based contract management and enactment.
- Automated support of mobile and context-aware technologies/ services.

9.3 Expected Impact

- Increased accessibility, extensibility, dependability, and scalability of semantic information, energy data, analytics and compute power. This is paramount to enabling innovative energy services.
- True enterprise-level, dependable, cloud management and energy services.
- Increased adoption of cloud computing across sectors and organisational levels.
- Guaranteed Quality of Service, security, experience, and privacy with respect to energy data services.
- Agreed architectures, frameworks, and systems supporting the interoperable interconnection of sensors, actuators, and analytics.

10. ICT for Nodal Energy Management

10.1 Technical Scope

It is commonly agreed that the main concern in relation to Grid management is the need to balance demand with the production of energy. With the emerging distributed methods of producing energy over the grid (in contrast to the current, unidirectional organisation from power plants to consumers), balancing demand and supply will become more important, but also more difficult, in the future. Smart buildings, smart districts, and smart cities will be the building blocks of the future smart grid, and ICT is seen as the enabler that will make energy management possible. To describe the different nodes of the smart grid, a common model, known as a Virtual Power Plant (VPP), is used. The VPP model contains a generic set of characteristics to allow connection and interaction between the building blocks of the smart grid. The objectives of this call for research are, therefore, to investigate the different facets of the VPP model and to prepare for migration towards open platforms, which will enable energy to be managed on different scales, such as at the building level, at the district level, and at the city level, etc.

10.2 Target Outcomes

- Development of the VPP model(s): Extension of existing sectoral data models to encompass the ability of devices/ buildings/districts, etc., to act as a power plant.

- Development of the service-oriented architecture and platforms which are able to host the services needed to act as information nodes for energy management and grid balancing. From a service-oriented point of view, this development will also:
    - Provide open solutions that ensure that sectors/customers are not locked-in by proprietary solutions.
    - Develop common concepts by aligning sector-specific ontologies.
- Development of new functions to allow alignment of centralised energy management (EMS) functions with distributed (local) decision-making equipment.
- Development of new distributed functions for real-time energy demand-supply management, coordination with the regulated operators of the distribution network (DSOs), and interaction with competitive energy market parties (suppliers, aggregators).
- Development of support tools that enable the integration of renewable energy sources, both for large-scale production (e.g., wind and solar farms) and massively distributed production (e.g., residential and tertiary buildings).
- Development of innovative new methodologies for the bi-directional connection between storage systems, smart grids, and buildings, to guarantee power quality.
- Development of new functions for configuring and maintaining the control constraints and preferences of local, energy management functions.

10.3 Expected Impact

- Smart loads, decentralised generation, local storage, and local decision-making by market actors. This improves the efficiency of renewables when grid management operations are able to align with configuration changes.
- Energy management and demand-side management functions will increase the efficiency of renewable resources and reduce load variations greatly. It might be fair to say these functions are required for the large-scale integration of intermittent resources such as distributed energy resources (DER).
- Optimisation of underlying energy management control loops will improve the reliability of the infrastructure.
- Using a central hub to measure/monitor energy efficiency in buildings will help conserve energy and improve efficiency, based on market options and incentives.
- Reliable and accurate information will improve the awareness of end-users and producers. It will cause prosumers to influence consumption and production behaviour according to market options, incentives, and comfort preferences.

11. Integrated Monitoring and Control for Improved Energy Efficiency

11.1 Technical Scope

ICT solutions supporting intelligent sensing/control with respect to energy-efficient building, industrial, and grid resource automation are required. The scope of this research call includes sensing/control software and hardware, control and optimisation algorithms, embedded microcontrollers, etc.

11.2 Target Outcomes

- Information architectures and (embedded) intelligent devices for operational control, sensing, and actuation at machine, plant, or building.

- Tools to process data in real-time and display that data in visually compelling ways that will drive decisions.
- Tools and interfaces using data from multiple ICT systems (e.g., BIM/PLM/ERP) to analyse and visualise (e.g., in 3D/4D/VR) data such as current-state, energy-related information, environmental impact information, etc.
- Visualisation of trade-offs between environmental and economic concerns.
- Automated alerts to persons in charge on deviations in the production process.
- Automated tools for monitoring energy performance and validating compliance to energy-related requirements.
- Automatic calculation of energy consumed during production.
- Full integration and interoperability of sensor (sensor fusion) and actuation devices with optimised use of ambient resources (energy harvesting) while promoting energy efficiency in host systems.
- Autonomous, local-level diagnostics, prediction, and optimisation, virtual sensors, inference technology, and non-intrusive load monitoring.
- Embedded intelligent devices (micro architecture) for operational control, sensing, and actuation at the machine, plant, or building level.
- Software and algorithms for operational monitoring and actuation of devices at the machine, plant, or building level.
- Inference sensing software and algorithms for pattern and signal identification at the machine, plant, or building level.
- ICT solutions for data mining and analytics in terms of energy consumption and optimisation, pattern identification, predictive diagnostics, and analytics at the enterprise or network level.
- Data management infrastructures to allow electricity production and consumption to be accurately measured, reported, and controlled (and eventually credited or billed).
- Home energy management hubs to collect energy consumption data from smart household appliances, distributed resources, and local storage, and to enable intelligent automation.
- Use of cloud-based services for tasks such as data management, monitoring, and analysis.

11.3 Expected Impact

- ICT solutions to optimise or select production/materialisation/procurement methods based on optimum energy consumption.
- Real-time communication in the materialisation phase.
- Tracking and visualisation of the materialisation process in virtual planning models.
- Optimisation of underlying energy management control loops will improve the reliability of the infrastructure.
- Energy consumption and production facilities under local energy management control will be better managed to prevent power quality issues and help ensure reliable and secure network operations.
- Reliable and accurate information will improve the awareness of end-users and producers. It will cause prosumers to influence consumption and production behaviour according to market options, incentives, and comfort preferences.

Having identified 11 potential call themes, stakeholder-specific recommendations were made within the IAP. What follows is a detailed example of stakeholder-specific recommendations that centre on an area of special focus within REViSITE: namely, recommendations for standards in addressing barriers to interoperability.

Proposed Recommendations for Standards

Deliverable D3.3, Implementation Action Plan, focused on identifying potential call themes/text and on stakeholder-specific actions. The focus of D3.4, Recommendations for new standards to overcome interoperability barriers, centred on specific actions of relevance to Standards Organisations. The recommendations that follow are based on consortium heuristics and an iterative consultation process.

1. Extension of Existing Ontologies for Energy Efficiency

A number of ontologies for energy efficiency exist, but these existing ontologies are very specific to the sector for which they were developed; even where there is some overlapping among the models, there is no alignment between the concepts that overlap. An efficient approach to identify these overlapping areas is, therefore, required.

Virtual Power Plant Model

A possible solution to this issue is to use the concept of a Virtual Power Plant (VPP). The concept of a VPP is not new: it comes from the Grid sector and has been advanced as a generic model to represent all elements or devices concerned in the field of Energy production (Pudjianto et al, 2007) [24]. A VPP is a kind of 'identity card' that should contain structured information (basically, a generic set of characteristics) to allow connection and interaction between the smart grid and the building sector. From the point of view of the building sector, the VPP model can be seen as a specific facet of the Building Information Model (BIM) and eeBDM (energy efficient Building Data Models) methodologies.

REViSITE Recommendation

The REViSITE proposal is to extend the notion of VPP to include all 'artefacts' concerned with both the production and the consumption of energy.

VPP models are well-suited to represent the needs of both the smallest possible energy generating device (e.g., a battery) and the most complex (e.g., the energy grid as a whole). In between these two extremes, VPP models can be applied at different scales. For example, you could create a VPP for a building (which would aggregate a number of smaller VPPs, such as washing machines, combined heat and power (CHP), electric vehicles, solar panels, etc.), a VPP for the districts (which would aggregate all the buildings in that district), a VPP model for smart cities (which would aggregate all the district VPPs), and so on.

In a recent report (*ICT Applications for the SmartGrid – 2012*) [25], the OECD also mentioned the VPP approach as an enabler to reshaping the energy system by giving rise to scenarios and transactions that can only be solved by digital, continuous, integrated exchanges among prosumers. As a simple tool which can handle the complexity of energy systems, VPP models can be used to tackle the gradual decentralisation of power generation.

2. Energy Performance Indicators (Metrics)

Performance targets, driven by politics or company standards, are required in order to provide incentives to design buildings and production systems, etc. in a more energy-efficient way. The parameters which constitute a target are defined by certain metrics which need to be continuously monitored to ensure that target values are reached. However, as mentioned previously, there are no cross-sectoral standards available for energy efficiency metrics, and even within the sectors, the maturity of standards is generally on a low level. Research about the statistical advantages and drawbacks of different indicators and evaluation methods is still ongoing, with the result that several frameworks can be used to measure the energy efficiency of a building or device. It is very difficult to compare two solutions that have been assessed by two different frameworks. As a result, concrete metrics and methodologies which are consistent across different sectors or even across different companies are difficult to find. These methodology barriers also prevent benchmarking and the diffusion of best practices since it is not possible to find who has the most efficient technologies.

Currently, there are two main methods for assessing energy efficiency: indicator-based evaluations and energy systems. Each of these methodologies is described below.

Indicator-Based Evaluations

Energy indicators are ratios of energy consumption or emissions of carbon dioxide equivalent in relation to some physical or economic dimension. "There is no unequivocal quantitative measure of "energy efficiency'. Instead, one must rely on a series of indicators relevant to the context..." [11].

The International Energy Agency (IEA) developed a hierarchical overview of how energy indicators can be structured according to the level of their respective aggregation. Highly-aggregated indicators usually reflect the economic perspective of energy use to compare different sectors, countries, etc. in terms of their energy efficiency (kwh/GDP). On the lowest level of aggregation, indicators measure the efficiency of machines, processes, different subsystems of buildings, etc. [11]. Within the REViSITE scope, performance measurement at the plant or building level seems sufficient. Nevertheless, indicators at this level of aggregation are usually based on a physical unit related to a specific sector. 'Energy Use Intensity' is the most often used example in this category. It simply relates energy consumption to the unit of outcome, e.g., kwh/square meter in the building sector or Gj/ton of product produced in manufacturing [18].

While the efficiency of buildings, lighting, and grids can be determined using the same indicator, manufacturing cannot be integrated easily, since the most significant ratios are related to the physical units used within their respective sectors (kwh/square meter vs. kwh/unit produced). Nevertheless, some indicators (e.g., energy saved per year) may be applicable across all four sectors [18]. Table 1 shows a selected number of indicators defined in different research projects.

Rating Systems

As an alternative to indicator-based evaluation schemes, rating systems can be used to evaluate energy efficiency. In contrast to indicators, rating systems do not produce real values or ratios as a result. Instead, a metric which consists of different energy efficiency classes/categories is used. Prominent examples in the building sector are 'LEED' [19], developed by the US green building council, and the 'Code for sustainable homes'], developed by the UK government. Since the result is not directly linked to a sector, rating systems could potentially be used as an integrated means for assessing energy efficiency across multiple sectors. Because of the result's independence from physical values, rating systems may have a higher potential for cross-sectoral efficiency evaluation. The criteria which lead to an efficient outcome for each sector (for example, electrical efficiency of power supply, efficiency of machines and production facilities, etc.) could be integrated in catalogues evaluating the performance of the building itself.

REFERENCE	INDICATOR	INDICATOR TYPE	APPLICATION	FORMULA/UNIT
(Phylipsen et al., 1997)	Energy intensity	Economic	Aggregated level	Energy consumption/economic term
	Specific energy consumption	Physical	Disaggregated level	GJ per t
(Irrek and Thomas, 2006)	Energy intensity	Macro-economic	Aggregated level	Energy consumption/monetary variables (GDP)
	Degree of effeciency	Engeneering view	Aggregated level	Net Energy/used primary energy
	Final energy efficiency improvement	Physical	National level	Energy savings per year
(Patterson, 1996)	Thermodynamic energy efficiency	Thermodynamic	Measurements derived from the science of thermodynamics	Actual energy usage related to an'ideal' process
	Physical-thermodynamic energy efficiency	Hybrid	Measure the service or delivery of the process	Actual energy usages/tonnes or passenger miles
	Economic-thermodynamic energy effeciency	Hybrid	Measure the service or delivery of the process	Energy usage in conventional thermodynamic units/output in terms of market place
	Economic Energy Efficiency	Economic	Measure in terms of market value	Energy input in monetary terms/output in monetary terms
(Farla et al., 1997)	Energy efficiency measurement	Economic	Activity of a sector	Energy consumption/value added or value of shipments
	Specific energy consumption	Physical	Process level, cross country comparison	Energy use/physical unit of production
(IEA, 2008a)	Thermal energy efficiency of equipment	Physical	For single equipment	Energy value available for production/input energy value
	Energy consumption intensity	Physical	Broader than thermal indicator: companies, etc.	Energy consumption/physical output value
	Absolute amount of energy consumption	Physical	With indication of production volumes	Energy value
	Diffusion rates of equipment	Physical	Focusing on specific energy efficient technology	Rate of deployment of technology
(IEA, 2007a)	Industrial energy intensity	Physical	Comparisn of efficiency data on a sub-sector level between countries	Energy use/unit of industrial output, e.g., GJ/t
	Specific energy consumption	Physical	On sector level	e.g., GJ/t
(Boyd et al., 2008)	Energy performance indicator	Statistical	On plant level	Percental ranking of the energy efficiency

Table 2 : Examples of EE Indicators

REViSITE Recommendation

To establish an integrated approach, a common and harmonised set of metrics is needed. The entire chain of measurement also needs to be defined to ensure not only the reliability/accuracy of the data collected but also to ensure that the meaning of the data is correctly understood and that any privacy settings are preserved. In this context, the potential of synergies for the four target sectors also needs to be assessed.

Although the composition of indicators/rating schemes seems simple, it is the result of a complex measuring process. Different methodologies are used (e.g., embodied/operational energy assessment, calculating with on-site or off-site energy, different system boundaries, etc.) which makes comparisons difficult and often leads to misunderstandings. Therefore, there is a clear need for standardisation. Harmonisation of metrics and test procedures, and the integration of frameworks for different sectors, may lead to an EU-wide or preferably global methodology for assessing energy efficiency. International working groups and expert forums need to be formed in order to support dialogues about best practices and standardisation opportunities. An example of efforts in this direction is the Common Carbon Metric [22] programme in the building sector, developed by the *United Nations Environment Programme* (UNEP). This programme is currently being evaluated by the ISO to determine its applicability as a new standard and could be an example for other sectors.

3. Product Catalogues that Include Energy Dynamics

Information on available, real products is needed during the design stages when specifying the actual components or modules used in constructing the designed functional units. If the design tools are CAD-based, the product information has to be modelled in a format that is compatible with the CAD tool in use.

To improve the usability and attractiveness of their tools, CAD tool providers usually develop extensive add-on product catalogues/libraries for their tools. These add-ons have a great competitive importance for tool provider companies. Alternatively, product manufacturers may develop data models for the CAD tool providers, to increase support for their products. These product models may be published on the web so that users (tool providers and end-users) can download and install them in their design environments.

Examples of Product Catalogues

The following are examples of existing product catalogues, mostly targeted at the building sector:

- **ArchiCAD** is a GDL (Geometric Description Language)-based parametric object technology which contains all the information necessary to completely describe building elements as 2D CAD symbols, 3D models, or as text specifications for use in drawings, presentations and quantity calculations. ArchiCAD includes tens of thousands of intelligent objects, which are in use around the world. For more information, see http://www.graphisoft.com/products/archicad/parametric_objects.
- **Autodesk® Seek** is a web service that enables designers to discover, preview, and download BIM models, drawings, and specifications covering the following product libraries: Revit MEP, AutoCAD MEP, Revit Structure, Revit Architecture and AutoCAD Architecture. For more information, see http://seek.autodesk.com.

- **SMARTBIM Object Catalog** is a collection of over 45,000 generic and manufacturer-specific product families and types (based on Autodesk® Revit®). Where appropriate, the objects are parametric, representing different types of the same product. Objects are available free of charge. For more information, see http://www.smartbim.com.
- **MagiCAD** is a building services design tool based on AutoCAD and Revit MEP. It has a database containing hundreds of thousands of 3D models of real products. The models use the correct dimensions and contain the technical data needed to make accurate calculations. For more information, see http://www.magicad.com/en/content/design-real-products.
- **Edibatec** is a suite of tools which facilitate data exchange among construction professionals. Its main components include a product dictionary, product database, and related web-based services. The dictionary contains more than 250 classes of products (heating, cooling, ventilation, electrical equipment, insulation, doors, windows, glazing), while the public online database contains more than 50000 products along with their technical data, images, and documentation, and is updated by the manufacturers. The web-based services include an interface which enables building professionals to access the technical database. For more information, see http://www.edibatec.com/.
- **Modelica** is a non-proprietary, object-oriented, equation-based language to conveniently model complex physical systems containing, e.g., mechanical, electrical, electronic, hydraulic, thermal, control, electric power, or process-oriented subcomponents. Libraries with a large set of dynamic models are available. The open source Modelica Standard Library contains about 1280 model components and 910 functions from many domains. Modelica represents an extension to pure data modelling. See https://modelica.org.

The main standardisation committee in the field of product libraries (building domain) is the ISO technical committee ISO TC 59/SC 13 Organization of information about construction works, which is currently involved in several BIM-related initiatives. The working group WG 11 Product data for building services systems model is currently tasked with the work item ISO/CD 16757 Product Data for Building Services System Models, which is directly related to product libraries. This work is based on the German VDI 3805 standard, which describes catalogue information for building services products. VDI 3805 was developed over the last 20 years and comprises specifications for a large number of product groups. It uses a parametric, product-modelling approach, together with computational properties. Another new work item for the ISO technical committee TC 59/SC 13 relates to the French building product industry's Technical Dictionary of Harmonised Properties (DTH), which is attempting to standardise product descriptions and their properties.

Possible Structures for Product Data Catalogue Systems

Standards-based, product data catalogue systems generally have two different data repositories: a product data dictionary and a product data library. The data dictionary contains the metadata relating to the product type (such as attribute names) and the data library contains the instantiated product types (i.e., the attribute values). Figure 10 illustrates the concept.

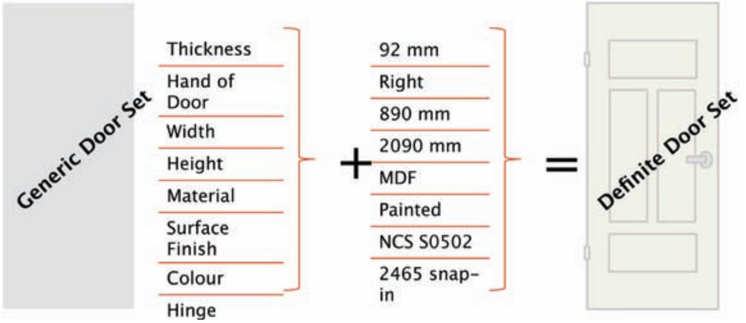

Figure 10: Illustration of data dictionary and product library concepts [23]

The data dictionary attributes (i.e., the values) are mapped directly to the attributes of the product type. In addition to these attributes directly inherited from data dictionary, the product catalogue item can have additional attributes to be computed or used as input to generate other attributes. The following alternatives were identified:

- The library and directory types have exactly the same attributes.
- The library type has computational attributes. These attributes are in addition to those inherited from the directory product type.
- The library type has computational attributes. Some of the inherited attributes are computational and generated from additional attributes through parameterisation.
- The library type has computational attributes. Some of the inherited attributes are computational and are generated from additional attributes using a set of rules (rule-based attributes).
- The product type contains dynamic model(s).

A specific requirement for the contents of product data models concerns energy-related attributes of the products. The new energy efficiency standards will increase demand for technical data. Each manufacturer or professional organisation must also use the same standard and the same method to describe construction product data.

REViSITE Recommendation

Proposed standardisation should consider the following:

1) The contents of product data model attributes needed for standardised, energy performance evaluation.

2) Standardisation application areas related to directory/library/1-1 mappings.

3) Standardisation application areas related to mature parametric applications.

4. Data Exchange Protocols

Any information exchange requires a set of conventions shared by the sender of data and its recipient: both must know when the communication begins, what procedure it follows, and when it ends. Such sets of conventions are called protocols. A data exchange protocol is a standardised format for transmitting data between two devices. The type of protocol used determines variables such as the error checking method, the data compression method, and end-of-file acknowledgements. If all networks and devices were constructed in the same manner and all networking software and equipment behaved similarly, only one protocol would be necessary to handle all data transmission/exchange needs. In reality, the ICT industry includes millions of different networks running a wide array of hardware and software combinations.

Current Issues

The main issue is that although most mechanical and electrical systems have embedded digital controls, these lower-level devices are low cost and/or low power and typically cannot support a full OSI stack, i.e., they are not directly controllable. At this physical layer, data exchange is handled by dedicated communications wiring or a wireless equivalent. Typically, these individual devices operate separately, without exchanging information, and as a consequence, the building or factory is not considered and controlled as one single system, but as a number of individual subsystems. This leads to sub-optimal results in terms of energy flow, comfort, cost, and controllability. The world of lower-level protocols is essentially a jungle of heterogeneous (often competing) offerings, and standards harmonisation at this level is extremely onerous and highly unlikely.

The most appropriate solution is the use of interoperable control systems, governing all HVAC, lighting, and other electrical applications and related sub-systems installed in a facility. However, as described above, integrating the myriad of sub-systems and devices, which are manufactured and often installed by different companies with different data interfaces and communication protocols, is an arduous process. Effectively and efficiently integrating all these sub-control systems into one intelligent application poses a major challenge.

Several well-established protocols (e.g., BACnet, KNX, LonTalk, etc.) used in BAS BMS type systems attempt to act as aggregators, allowing for homogeneity in terms of controlling lower-level heterogeneous devices. However, while these data exchange protocols can be used over TCP/IP networks, they themselves have challenges when dealing with other network applications with respect to interoperability, routers, firewalls, and security, etc.

REViSITE Recommendation

REViSITE would suggest that, while feasible and very much needed, harmonisation is not, all things considered, likely at the lower level. When considering connection from aggregators to the network, typically TCP/IP-compatible solutions are available, but more often than not, this requires adaptive coding because the structures of the messages exchanged are not standardised.

The most obvious way forward involves the development and standardisation of common ontologies, open interfaces, and XML/web-service based mechanisms. This would allow organisations to abstract away from the jungle of lower-level and less-crowded data exchange protocols (such as BACnet, KNX, etc.), enabling integrated communication between building systems and enterprise applications. REViSITE would, therefore, suggest that there is a need for research and standardisation with respect to:

- Non-alignment of open solutions, above the IP layer, as the structure/content of messages is not commonly defined.
- Defining a uniform approach towards application of building control systems.
- Investigating the interoperability of different information sources in buildings, i.e., further consideration with respect to harmonisation of data models between BIM and BACS.
- Understanding the advantages and disadvantages of traditional data exchange approaches (BACnet, LonTalks, KNX, etc.) and web-service based mechanisms, so industry can find the right balance in developing an optimised and standardised approach that addresses interoperability while allowing for heterogeneity and innovation.

But effort in this regard would not be starting anew and any effort should consider existing initiatives, which include, but are not limited to, the following:

- W3C
- OASIS Open Building Information eXchange (oBIX)
- CABA
- BuildingSmart
- BACNet XML working group
- LonMark interoperability association
- The XPL project
- BuildingSmart

5. Harmonisation and Extension of the IEC Ontology

The application of IEC 61970 and IEC 61968 Common Information Model (CIM) has expanded from its traditional usage in power system modelling and data exchange to encompass the role of a standardised semantic model for the Smart Grid. The Smart Grid Interoperability Road Map has identified the need for a semantically consistent framework on which to base the Smart Grid and has selected the CIM as a central element across many functional areas. One such area relates to how CIM works with the IEC 61850 for Power System Communication standard, which has also become an important part of the roadmap for substation communications and as the basis for other Smart Grid oriented communications. This has made harmonisation of CIM and IEC 61850 critically important to the goal of interoperability. [12]

REViSITE Recommendation

The IEC reference architecture originated from the technical operation of transport and distribution grids and therefore lacks support for more recent roles and responsibilities. Although ontology packages for competitive market roles have been designed, these are considered to represent a different maturity level than the core packages. In the smart grid vision, even newer roles and tasks such as the 'Aggregator' have been identified that are not yet represented in the existing ontologies [7]. The main items for expansion of the current ontologies include support for the following use-cases:

- Flexible energy prices, flexible grid tariffs, and the interfaces between consumers and producers, TSOs, DSOs, and suppliers/traders/aggregators
- Clearing, settlement, and interaction with data collection, data exchange, and electricity flows
- Products and features fostering producers' and consumers' flexibility in relation to capacity management, communication needs, etc.
- Efficient ways to communicate with customers, such as e-mail, SMS, signals to the meter, in-home display, digital TV, etc.
- Ensuring that consumers receive accurate, timely, understandable, and usable information relating to their energy consumption.

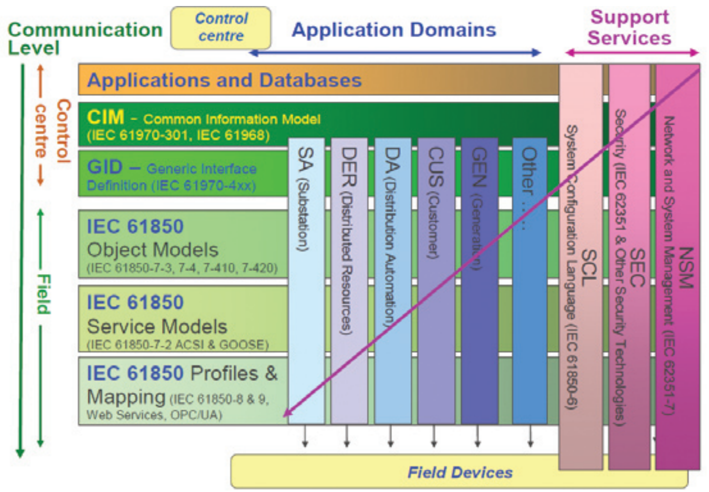

Figure 11: IEC 61850 models and the Common Information Model (CIM) [11]

A set of tools and rules is needed for cross domain information exchange and representation. Activities that have been happening in parallel in various sectors need to be able to converge in a controlled fashion. Standards already exist across the semantic and pragmatic boundaries. The challenge is to formalise these into an ontology that covers the domain of Energy Efficiency applications.

The semantics of the built environment and the grid are connected at a functional level as both domains are part of the same energy flows. The Smart Grid projects have already defined domain ontologies that have become part of an IEC standard. However, these ontologies have limited support for the built environment. In that respect, both ontology domains could benefit from each other on shared topics, such as energy efficiency measures. Ontology mappings may be required to effectively exchange information between the grid domain (infrastructure operators, energy market, etc.) and the built environment (developers, owners, occupants, etc.). A collaborative approach by experts in the grid and built environment domains could help interconnect the semantic definitions of the two sectors and prepare for collaboration in the field of energy efficiency [13]. The new emerging standards relating to the energy efficiency of buildings, general energy terminology, the carbon footprint standard (the future ISO 14067), and energy management systems (the future ISO 50001) will help establish global conventions [14].

Summary/Conclusion

The goal of the REViSITE project was to identify common research priorities in the domain of ICT for Energy Efficiency (ICT4EE). The project focused on four target sectors—Grids, Manufacturing, Buildings, and Lighting—and sought to develop a generic means of assessing the impact of ICT across these sectors. Through the involvement and contribution of many stakeholders across the four sectors, and drawing on the combined expertise of the REViSITE Expert Group, the direct contributors to this report, and the REViSITE community at large, the project achieved the following outcomes:

- A strategic research agenda (SRA) focused on critical, cross-sectoral research questions, and oriented around short-term, medium-term, and long-term research needs, was developed.
- A common vision for multi-disciplinary, ICT-enabled energy efficiency was outlined.
- The associated implementation action plan (IAP) to address those research questions was developed and an initial menu of 23 potential ICT4EE research trajectories was consolidated into 11 proposed call themes.
- A set of recommendations for standards to help overcome interoperability barriers was proposed.

This report provides a high-level summary of the methodology adopted and the outputs of each of the above processes. However, it must be noted that this report does not do justice to the body of knowledge compiled during this project or to the level of effort expended by the various contributors. To learn more about the REViSITE project, or to view full versions of the deliverables produced during each phase of the project, please see the project website: http://www.revisite.eu.

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Notes

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