Roadmap Enabling Vision and Strategy for
ICT-enabled Energy Efficiency

Deliverable 2.2
ICT4EE – Knowledge and Current Practices

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ACRONYMS AND TERMS

4E..... Efficient electrical end-use equipment
AEC..... Architecture, Engineering and Connection
API..... Application Programming Interface
BAS..... Building Automation Systems
BEMS..... Building energy management system
BIM..... Building Information Modelling
BMS..... Building Management Systems
CAD..... Computer Aided Design
CAE ..... computer aided engineering
CAM..... Computer Aided Manufacturing
CAPP..... Computer Aided Process Planning
CEP..... Complex Event Processing
CFD..... Computational Fluid Dynamics
CHP..... Combined head and power
CMM..... Capability Maturity Model
D&E..... designer and engineer
DALI..... Digital Addressable Lighting Interface
DEM..... District Energy Management
DER ..... Distributed Energy Resources 14
DG..... distributed generation
DMS ..... Distribution Management Systems
DMU..... Digital Mockups
DSM..... Demand side Management
DSO ..... Distribution system Operators
DXF/DWG..... Drawing Interchange File Formats
EAM..... Enterprise Asset Management
EC ..... European Commission
ECBCS..... Energy conservation in buildings and community systems
ECMS..... Energy Control Management Systems
ECTP..... European Construction Technology Platform
EE..... Energy Efficiency
EEB..... Energy Efficiency in Buildings
ELC 2009..... European Lamp Companies Federation
EMS..... Energy Management Systems
ENO..... energy neutral operation
EPBD..... Energy Performance of Buildings
EPIs..... Energy Performance Indicators
ERP ..... Enterprise Resource Planning
ETP..... European Technology Platform
EULUMDAT..... Data format to describe the light distribution of luminaries
EuP..... Energy using Products
FEM..... Finite Element Method
FM..... Facility Management

GDP.....	gross domestic product
GeSI	Global e-sustainability Initiative
GHG.....	greenhouse gas
GWP.....	Global Warming Potential
HVAC.....	heating, ventilation, air conditioning
HW.....	Hardware
I3CON.....	Industrialised, Integrated, Intelligent Construction
iBMS.....	Intelligent Building Management System
ICT.....	Information and Communication technologies
ICT4EEB.....	Information and Communications Technologies for Energy Efficient Buildings
ICT4EE.....	ICT for energy efficiency
IDM.....	Information Delivery Manual
IES.....	Data format to describe the light distribution of luminaries
IFC.....	Industry Foundation Classes
ISA 95.....	international standard for the integration of enterprise and control systems
ITRI.....	Industrial Technology Research Institute
J2ME.....	Java 2 Platform, Micro Edition
KNX.....	Network communications protocol for intelligent buildings
LCA.....	Life cycle analysis
LEDs.....	Light emitting diodes
LITES.....	Led-based intelligent street lighting for energy saving
I/O.....	Input Output
LONtalk.....	Local Operating Network
LonWorks.....	Protocol for general purpose network
MBS	Multi Body Simulation
MES.....	Manufacturing Execution System
MMS	Market Management Systems
Modbus.....	Communication protocol, not standardised
MRO.....	Maintenance, Repair and Overhaul
NC.....	Numerical Control
NILM.....	Non-intrusive load monitoring
NIMBY.....	Not-in-my-Backyard
NIST.....	National Institute of Standards and Technology
NMS.....	Neighbourhood Management Systems
OAGIS.....	Open Application Group Integration Specification
OEE.....	Overall Equipment Effectiveness
OLAP.....	Online Analytical Processing
OPC.....	Operation Planning and Control
PDA.....	Personal Digital Assistant
PDM	Product Data Management
Pertola 2007.....	Possible energy savings of electric lighting by using redirected daylight
PLC	programmable logic controllers
PLM	Product Lifecycle Management
PPC	Production planning and control systems
RFID.....	Radio Frequency Identification
RFLP	Requirement, Functional, Logical, Physical
RM.....	Rapid Manufacturing

ROI……..	return on investment
RSS……..	Really Simple Syndication
SCADA …….	Supervisory Control and Data Acquisition
SCM……...	Supply Chain Management
SEEMPUBS……..	Smart Energy Efficient Middleware for Public Spaces
SHC……..	Solar heating and cooling programme
SHP……..	Smart Hybrid Prototyping
SmartCoDe……..	Smart Control of Demand for Consumption and Supply to enable balanced, energy-positive buildings and neighbourhoods
SME.....	Small and medium enterprises
SOA.....	Service-oriented architecture
SPC……..	Statistical process Control
SSL……..	Solid State Lighting
SW.....	Software
TSO ……..	Transmission system Operators
UOR……..	University of Reading
VPC ……..	Virtual Product Creation
VPP ……..	Virtual Power Plants
VR……..	Virtual Reality
ZigBee……...	Communication protocols designed to use small, low power wireless networks
Zwave……...	Wireless remote control protocol for home electronics

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1 EXECUTIVE SUMMARY

In 2008, Commission President José Manuel Barroso stated *"...the real gains will come from ICT as an enabler to improve energy efficiency across the economy. ICT matters for energy reduction, especially in transport and the energy intensive sectors. ICT's ability to organise and innovate is a key factor.* In a 2010 key communication from the Commission 'A European strategy for smart, sustainable and inclusive growth' the importance of ICT in transport was again reiterated with the communication also stating that at a national level, *'Member States will need: To incentivise energy saving instruments that could raise efficiency in energy-intensive sectors, such as based on the use of ICTs'*. The central role of ICT in enabling energy and sustainability goals is evident.

This review that follows is a main deliverable of WP2 - Impact assessment of ICT for Energy efficiency. It is a "state of the knowledge and practice" type report detailing that which is homogenous, heterogeneous and synergetic across the four target sectors in terms of ICT enabled Energy Efficiency. The four sectors covered are Smart Grids, Smart Building, Smart manufacturing and Smart Lighting. It is important to note that the important sector of transport as identified above is not the focus of REViSITE but would need to be included in any holistic review of ICT4EE at a macro level and with regard to policy.

Deliverable D2.2 begins with a recap of deliverable D2.1 'ICT4EE Data Taxonomy: A common methodology to assess the impact of ICT developments'. The methodology and SMARTT taxonomy where used throughout D2.2 as an integrative classification system and as an aid to cross sector ICT4EE impact assessment.

Each partner/sector then details a distinct and individual review of their sector, describing its defining 'smart' characteristics, individual energy profile, sectorial framework and usage of ICTs. The ICT's are categorised using the SMARTT taxonomy to assist in cross-comparison. The initial review is concluded by identifying relevant current state-of-the-art and sector specific RTDs of European and national research projects.

Having completed the individual sector specific reviews the document then focuses on identifying gaps, commonalities and synergies leveraging cross-sectorial heuristics. Each sector describes the most significant links, as they see them, to the other sectors. There is then a focus on the most promising ICTs as each sector aims to identify points of reference for other sectors, while investigating potential adoptions that can benefit their own sector in terms of ICT4EE.

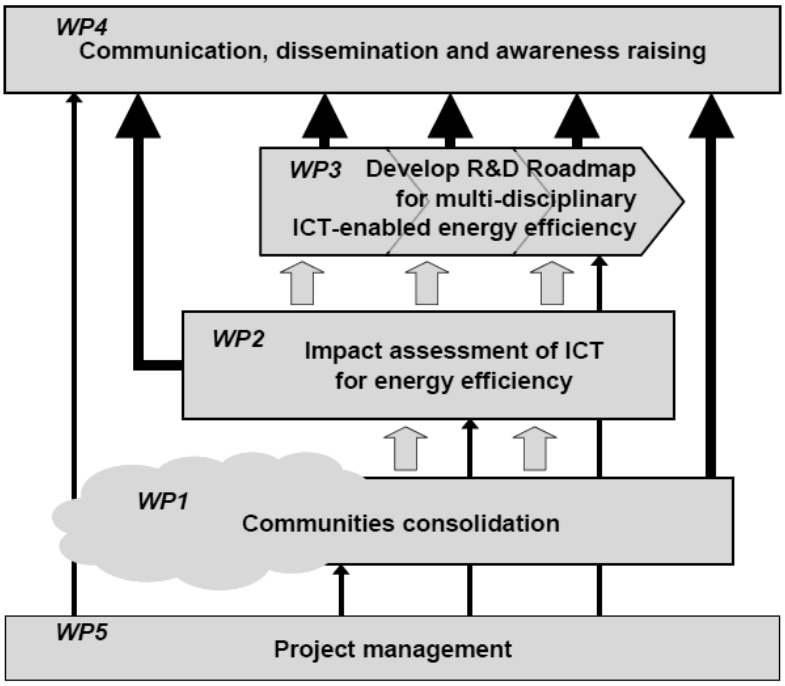
The document concludes with a synthesis/conclusion section that provides a narrative explaining the common themes, potential synergies and most significant ICTs and fields of research across the sectors. It is envisaged this initial synthesis together with the overall output of this deliverable will feed directly into deliverable D2.3 ICT4EE impact assessment model and WP3 RTD roadmap development in the area of ICT4EE

2 INTRODUCTION

2.1 Purpose

2.1.1 Purpose of the REViSITE Project

It is envisaged that REViSITE will contribute to the formation of a European multidisciplinary 'ICT for energy-efficiency' research community by bringing together the ICT community and four important and complementary application sectors: Smart Grids, Smart Buildings, Smart Manufacturing and Smart Lighting. The REViSITE work package structure is outlined below:



The REViSITE project will co-ordinate co-operation and communication within the ICT4EE research community in Europe. The core of this community will be formed from the European Technologies Platforms (ETPs) that represent RTD in these sectors: ARTEMIS, ECTP, MANUFUTURE, PHOTONICS21, SMARTGRIDS.

- WP1 - REViSITE will identify complementarities between the four target sectors: grids, buildings, lighting and manufacturing in the area of ICT for energy efficiency (ICT4EE), harmonising common RTD priorities for ICT4EE in the four sectors, and establishing a cross-sectorial "community" with links to different industry sectors and related ETPs.
- WP2 - REViSITE will develop a common approach to assessment across the sectors and will compile a state-of-current-practice review of same. REViSITE will develop a causal model of how ICT can impact on energy consumption in 4 key sectors, based on available statistical data and where such data is not available estimations by experts. WP2 essentially aims to identify RTD priorities for ICT4EE.
- WP3 - The project will engage key stakeholders from the 4 sectors via a 'focus group' and a dedicated concise 'expert group' to compare and analyse sector specific RTD agendas such as Strategic Research Agendas (SRAs) of the relevant European Technology Platforms (ETPs), European and national RTD initiatives etc. A consolidated roadmap

will be derived as a synthesis. This will catalyse synergetic RTD and innovation in multiple sectors by pointing to cross-sectorial RTD opportunities in common areas of interest that have the highest potential impact.

2.1.2 Purpose of the document

The main aim of work package 2 is to assess the potential impact of ICT on energy efficiency in the four focus areas using a common methodology in order to highlight opportunities for adoption of ICT in different areas which are non-sector specific. The objectives of this work package are to:

- Undertake a state of the art review and critical analysis of recent and current RTD and industry efforts of ICT in energy efficiency;
- Gather information on breakdown of energy consumption levels under various conditions
- Deduce an impact assessment model to estimate the impact of specific ICTs on energy efficiency in the four focus areas.

The different levels of impacts of ICTs and the identified gaps within the critical analysis will shape and influence the development of the roadmap and strategic research agenda in WP3.

Deliverable D2.2 “ICT4EE – Knowledge and Current Practices" is a key deliverable of work package 2 and can be divided in two parts. The first part (chapter 4-7) is a distinct description of the project' sectors: Smart Grid, Smart Manufacturing, Smart Building and Smart Lighting. It starts with a description of the characteristics of each sector, its energy profile and framework. Main purpose are the following sector specific studies of latest developments in the field of ICT enabled energy efficiency considering current work of international and national research projects as well as developments in industry. By using the REViSITE SMARTT taxonomy (Deliverable D2.1) as an integrative classification system across all sectors, it identifies the state of the art as well as promising research topics currently under investigation.

The second part (chapter 8) focus on describing that which is homogeneous, heterogeneous and synergetic between the 4 sectors. It points out the most important intersections and links of each sector with the other 3 sectors and provides a crosssectorial and synthesised view as to the ICTs best positioned to deliver positive meaningful impact on energy efficiency. Those ICTs/RTDs will be further examined in D2.3 Impact assessment model.

2.2 Contributions of partners

The REViSITE project consortium consists of academic and industrial partners throughout Europe. This document is a joined deliverable of all project partners contributing with their individual expertise and expert knowledge in the projects 4 sectors.

- Fraunhofer IPK, one of the leading institutes for applied research and developments in future-oriented technologies for processes in factories and service companies, is the lead author of this document and represents also the Manufacturing sector *(chapter 1,2,5 and 8)*.
- INTEL Innovation Open Lab’s mission is to facilitate and enhance open research and innovation opportunities. INTEL is work packages leader and contributes to the document by providing the project's methodology and taxonomy *(chapter 3)* and with reviews and suggestions especially from the Manufacturing perspective *(chapter 4, 8 and 9)*.

- The Smartgrid sector *(chapter 5 and 8)* is represented by KEMA, an international independent research and test organisation, originating from and part of the Dutch electricity and heat supply organisation.
- CSTB (Centre Scientifique & Technique du Bâtiment) is a public research establishment in the construction sector and responsible for the Smart Building sector *(chapter 6 and 8).*
- Paragraphs related to the Lightning sector *(chapter 7 and 8)* are authored by VTT (Technical Research Centre of Finland) an independent multidisciplinary technology research institute and its subcontractor Aalto University.
- The project is coordinated by Loughborough University, Department of Civil and Building Engineering, which contributed to this document with reviews and suggestions from the Building and Manufacturing perspective *(chapter 9).*

3 OVERVIEW OF USED METHODOLOGY/TAXONOMY

The REViSITE research is clear that emerging 'best practice' in assessing ICT impact on energy efficiency utilises some form of Life Cycle Assessment (LCA) or 'life cycle thinking'. The REViSITE approach is hybrid methodology that seeks to combine simplified 'Life cycle assessment' or rather 'Life cycle thinking' and an adapted 'Capability Maturity Model' (CMM). By combining existing secondary data, sector specific standards and heuristics it is believed REViSITE can build an 'informed view' (see figure 1) regarding those ICTs best positioned to positively impact on energy efficiency/consumption. The value in utilising CMM is that it allows REViSITE partners to quantitatively estimate and illustrate what is essentially inductive qualitative research based on case studies and expert opinion/heuristics in their sectors. The approach cannot and is not intended to replace a more detailed expansive LCA or other detailed quantitative assessment. Such LCA's consider all life cycle phases, the toxicity of the offering and its wider effect on acidification, eutrophication, or land use. The approach is merely to build an informed view that can assist roadmap development.

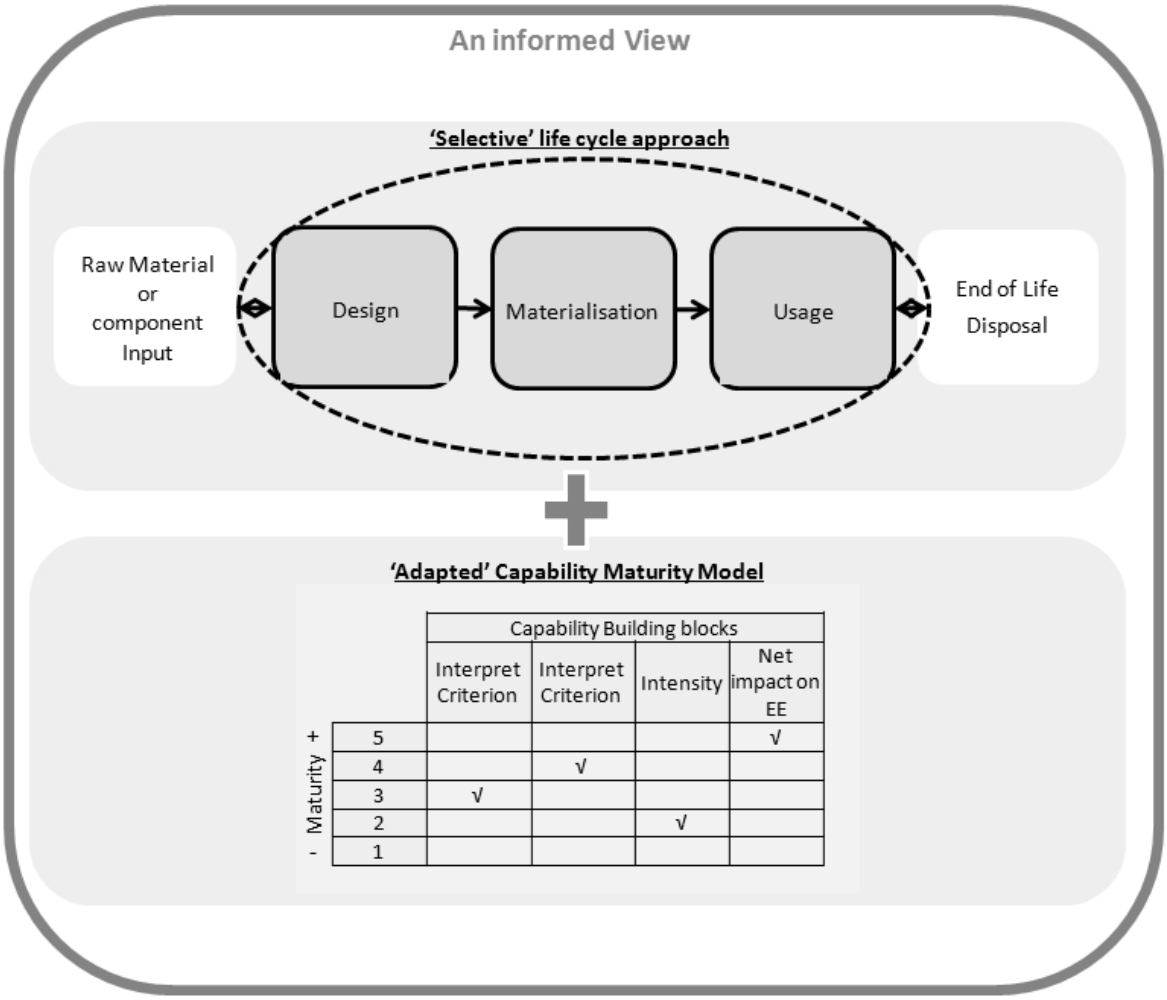


Figure 1. The REViSITE approach, an informed view

The REViSITE developed SMARTT taxonomy utilises six high level categories with sub-categories nested within these. Both categories and sub-categories are fixed and deemed to cover the scope of the ICT4EE domain allowing for common categorisation of ICT's and

RTD's across sectors. Sector RTD/ICT topics are nested within the sub-categories and are defined by the partners for their sector.

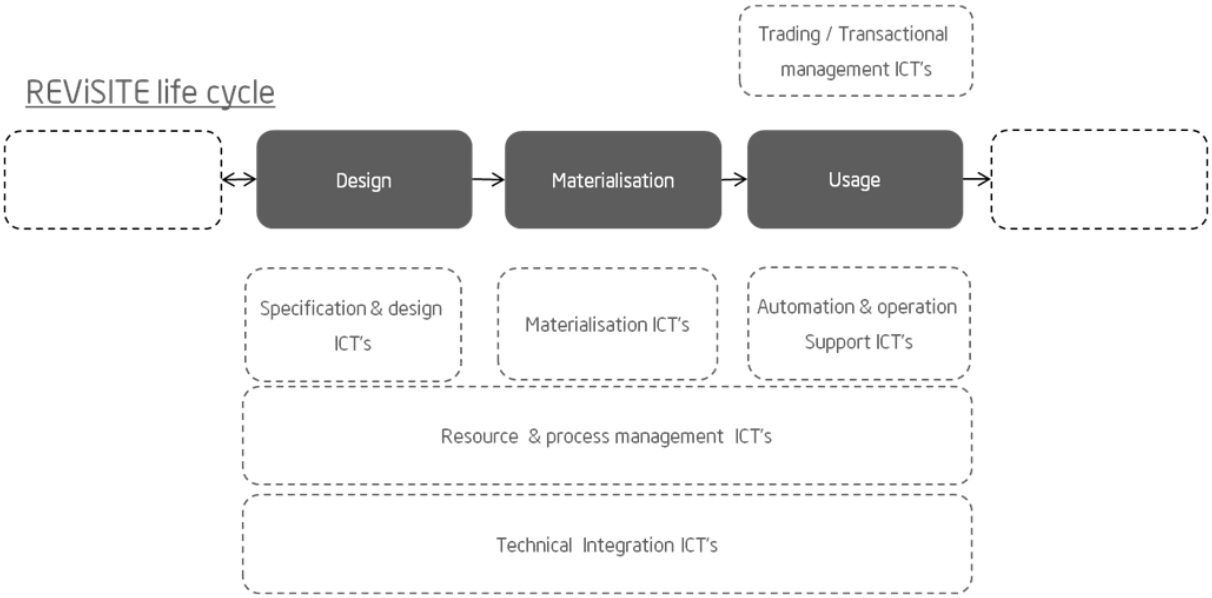


Figure 2. The SMARTT Taxonomy mapped to Life Cycle phases

The categories 'Specification & design ICT's', 'Materialisation ICT's' and 'Automation & operation support ICT's' all vertically align to the bounded life cycle phases. 'Resource & process management' together with 'Technical integration' are themes that align horizontally. 'Trading / transactional management ICT's' aligns primarily to the 'usage' life cycle phase.

The interface to the 'pre-design' phase and the 'end of life' phase in all sectors is still supported here. For example the REViSITE process would consider ICTs that allow for embodied energy information of materials/sub-components to be accessible to downstream design and manufacturing tasks without having to assess the energy efficiency within the 'raw material extraction' industry itself.

The Taxonomy has three levels –

1. **Main category** aligned to the Life cycle phases and following the SMARTT acroynom.

    a. **Sub-category** allowing for more granular categorisation

        i. **RTD's & ICT's** detailing the specfic areas of research and possible devleopment giving existing or envisaged ICT exemplar's

For further details on the taxonomy and approach methodology view REViSITE deliverable D2.1 'ICT4EE- Data Taxonomy: A Common Methodology to assess the impact of ICT developments' [3].

In summary, the REViSITE approach is holistic in nature. Where there are gaps in available analysis and data, individual REViSITE partners will make an assessment of the impact of ICTs based on heuristics and expertise within their defined sectors. This is where the simplified/adapted CMM maturity analysis comes into play. By understanding the respective

'maturity level' of specific ICTs, with regard to defined criteria, it is envisaged the REViSITE methodology will prove useful in identifying areas for development and ICTs best placed to deliver meaningful impact. The real advantage comes in the cross-sectorial sharing of the information.

The methodology and taxonomy were utilised in conducting the research of D2.2. The REViSITE consortium, deem the taxonomy and methodology outlined to be a useful and feasible means of qualitative common assessment. The approach is posited as a framework in which more detailed quantitative measures can be positioned and one which may prove useful to the wider community.

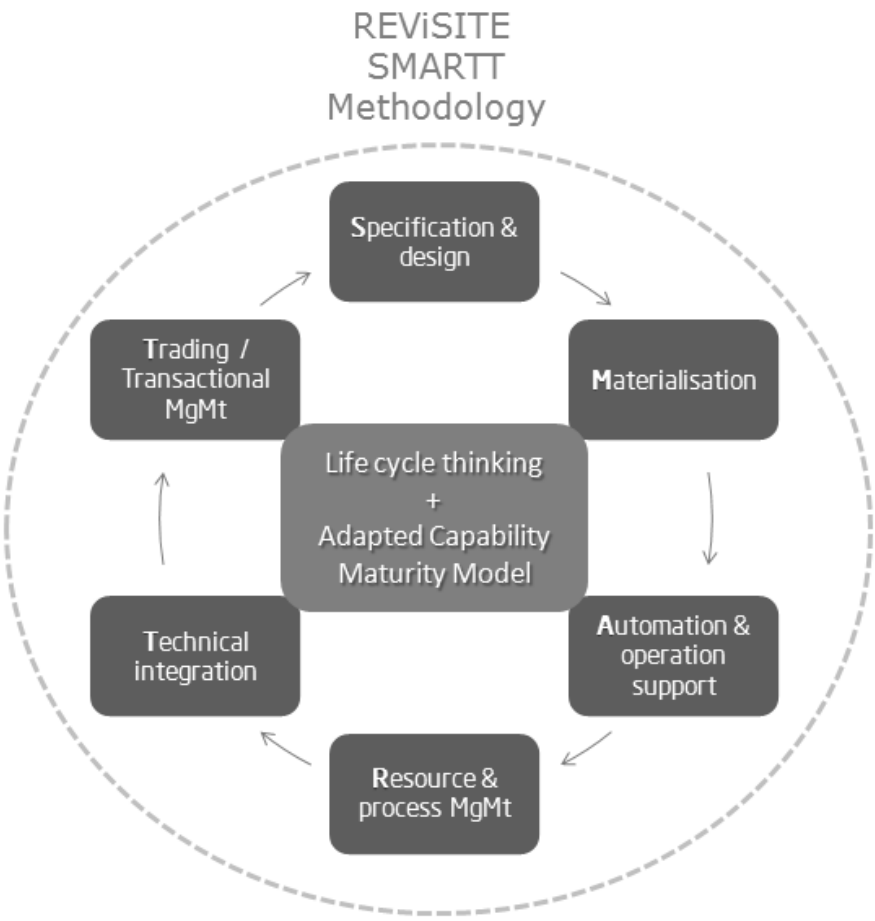


Figure 3. The REViSITE Methodology and SMARTT Taxonomy

4 ICT DEVELOPMENTS IN SMART GRIDS

4.1 Characteristics of Smart Grids

In this section we will focus on smart grids, identify new developments, and then focus on the role of Information and Communication Technology in these new developments.

A smart grid is described as an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies [1].

4.1.1 Grid Energy Profile

The electricity generation sector is a transformation sector, transforming a variety of fuels into electrical energy. The EC publication "Trends to 2030" [2] lists the amounts of energy used in the transformation and the total amount of electricity generated.

The following data:

Table 1. ForecastsTrends to 2030 on electricity generation

1.1	2010	2015	2020	2025	2030
Fuel Inputs thermal power gen GWh	4.793.909	4.940.959	5.097.627	5.074.995	4.896.812
Gross electricity generation GWh	3.311.797	3.553.832	3.795.425	4.012.917	4.191.941
Self Consumption and grid losses GWh	397.688	423.813	459.082	508.456	559.012

Wherein:

- "Fuel Inputs thermal power gen" is fossil fuel use in power plants and Combined head and power (CHP) plants (only non-renewables), converted from Tonne Oil Equivalent to GWh.
- "Gross electricity generation" figures are inclusive renewables
- "Self Consumption and grid losses" include E-sector consumption as well as transport and distribution losses.

The fossil fuel input to the electricity generation process is meant to decrease over time. This is planned to be achieved by raising the fraction of renewable energy generation.

The network losses (transport and distribution losses) can possibly be decreased to a certain degree by improving transport and distribution networks and techniques. However the increase of local distributed energy resources, and small scale generation units, will increase the load on low voltage (distribution) networks and thereby increase distribution losses.

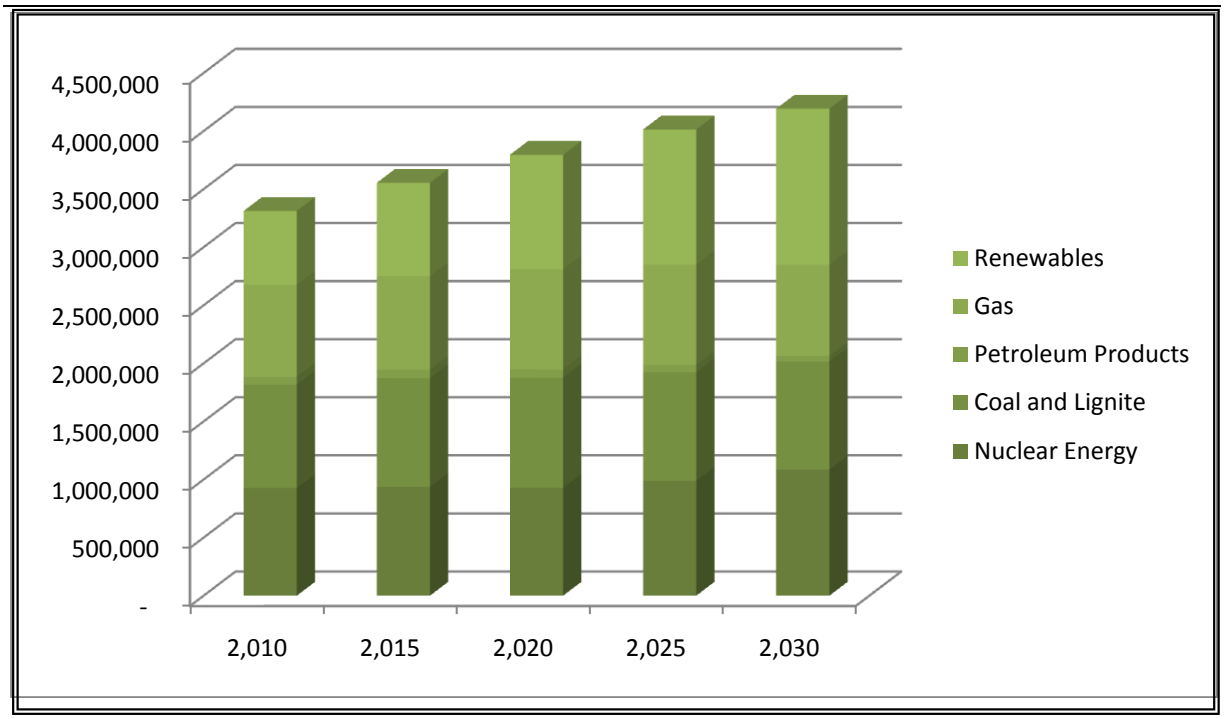


Figure 4. Electricity Generation by Fuel Type (GWh)

The Trends to 2030 report [2] give the forecast for energy generation by fuel type (Figure 4).

The percentage of energy generation by fuel type is included in Table 2.

Table 2. Electricity Generation by Fuel Type

1.2	2010	2015	2020	2025	
Nuclear Energy	28%	26%	24%	25%	26%
Coal and Lignite	27%	26%	25%	23%	22%
Petroleum Products	2%	2%	2%	2%	1%
Gas	24%	23%	23%	21%	19%
Renewables	19%	23%	26%	29%	32%

The increase of renewable energy, and the reduction of thermal power generation, will lead to a serious increase in relatively small scale generation units (solar power, wind power).

This shift from fossil fuel powered generators to renewable energy sources will lead to an estimated reduction of CO_2 emission [2]:

Table 3. Estimated reduction in CO_2 emission

	2010	2015	2020	2025
CO2 emission relative to 2009:	99%	95	91	-

4.1.2 Smart Grid Description and framework

A Smart Grid employs innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies to:

- better facilitate the connection and operation of generators of all sizes and technologies;
- allow consumers to play a part in optimizing the operation of the system;
- provide consumers with greater information and choice of supply;
- significantly reduce the environmental impact of the whole electricity supply system;
- deliver enhanced levels of reliability and security of supply.

Smart Grids deployment must include not only technology, market and commercial considerations, environmental impact, regulatory framework, standardization usage, ICT (Information & Communication Technology) and migration strategy but also societal requirements and governmental edicts.

The NIST [1] adopted the approach of dividing the Smart Grid into seven domains, as described in the Table 4 and shown graphically in Figure 5.

A conceptual model of a smart grid consists of several domains, each of which contains many applications and actors that are connected by associations, through interfaces.

Table 4. Domains and actors in smart grids

Domain	Actors in the Domain
Customers	The end users of electricity. May also generate, store, and manage the use of energy. Traditionally, three customer types are discussed, each with its own domain: residential, commercial, and industrial.
Markets	The operators and participants in electricity markets.
Service Providers	The organizations providing services to electrical customers and utilities.
Operations	The managers of the transmission of electricity.
Bulk Generation	The generators of electricity in bulk quantities. May also store energy for later distribution.
Transmission	The carriers of bulk electricity over long distances. May also store and generate electricity.
Distribution	The distributors of electricity to and from customers. May also store and generate electricity

Applications and functions of actors are described in more detail in the appendix 11.5.

4.1.3 Smart Grid Benefits

Anticipated benefits of Smart Grids are (e.g.)

- Optimises use of Distributed Energy Resources (DER, also referred to as on-site generation, dispersed generation, embedded generation, decentralized generation, decentralized energy or distributed energy)
- Facilitates expanded deployment of renewable energy sources
- Enables use, or rather charging, of electric vehicles
- Averts construction of back-up (peak load) power plants
- Improves power reliability and quality
- Enhances capacity and efficiency of existing electric power networks
- Improves resilience to disruption
- Enables predictive maintenance and “self-healing” responses to system disturbances
- Automates and optimises maintenance and operation

- Presents opportunities to improve grid security
- Enables transition to new energy storage options
- Increases consumer choice

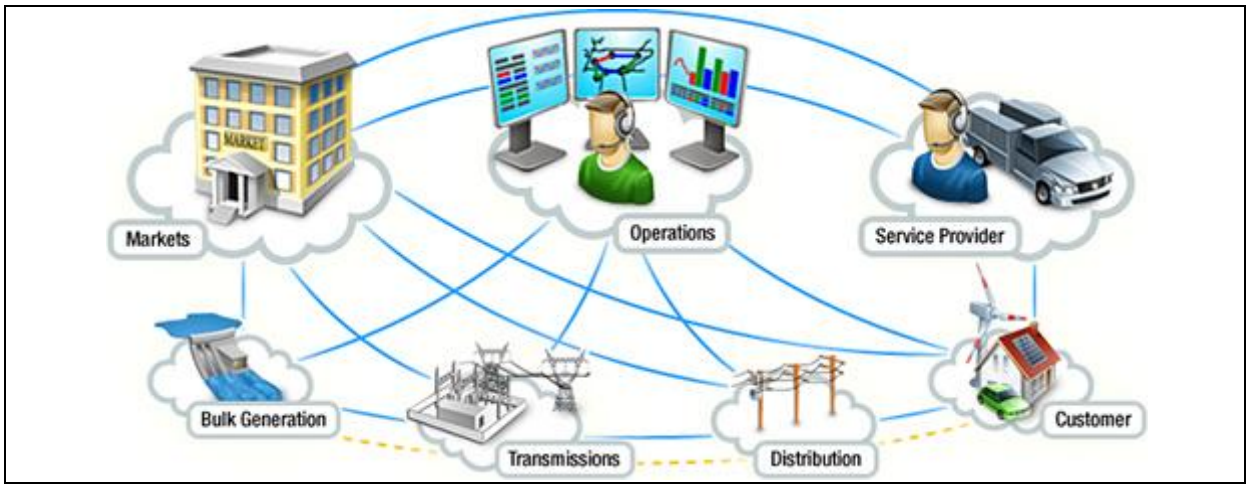


Figure 5. Smart Grid overview

4.1.4 Building smart grids

Electricity grids date back to the mid 20th century, although enormous improvements were made in the early 21st century, e.g. on remote monitoring and control, and standardisation of applications and communications. Still, the Smart Grid effort is unprecedented in its scope and breadth, and thus it will demand significant levels of cooperation to achieve the ultimate vision. All efforts directed toward enabling interoperability among the many diverse components of the evolving Smart Grid must address the following issues and considerations.

Defined Architectures

An architecture models the structure of a system and describes the entities and interactions within the system. A defined architecture helps enable technical and management governance and can be used to direct ongoing development work as well as to guide decision making on how to achieve a functional fit within a system (in this case, the modernized electric power infrastructure). An architecture is also a tool used to help developers and users understand a system.

For the Smart Grid, which like the Internet is a loosely coupled system of systems, a single, all-encompassing architecture is not practical. Rather, the Smart Grid architecture will be a composite of many system and subsystem architectures developed independently or in concert with other systems. This will allow for maximum flexibility during implementation and will simplify interfacing with other systems.

Different Layers of Interoperability

As there is no single, all-encompassing and centrally defined architecture, but rather a set of complex systems meant to cooperate, there is a need for different layers of interoperability, from a standardised plug or a wireless connection to compatible processes and procedures for participating in distributed business transactions.

Levels of interoperability are:

- Organisational: emphasises the pragmatic aspects of interoperation, representing the policy and business drivers for interactions.

- Informational: emphasises the semantic aspects of interoperation, focusing on what information is being exchanged and its meaning.
- Technical: emphasises the syntax or format of the information, focusing on how information is represented within a message exchange and on the communications medium.

Standards and Conformance

Standards are critical to enabling interoperable systems and components. Mature, robust standards are the foundation of mass markets for the millions of components that will have a role in the future Smart Grid. Standards enable innovation where components may be constructed by thousands of companies. They also enable consistency in systems management and maintenance over the life cycles of components.

Sound interoperability standards are needed to ensure that sizable public and private sector technology investments are not stranded. Such standards enable diverse systems and their components to work together and to securely exchange meaningful, actionable information.

Clearly, there is a need for concerted action and accelerated efforts to speed the development of high-priority standards. But the standards process must be systematic, not ad hoc.

Moreover, while standards are necessary for achieving interoperability, they are not sufficient. A conformance testing and certification regime is essential.

4.1.5 Identified developments

The following main areas, where new developments are required, were identified (1):

1. Optimise Grid Operation and Usage
2. Optimise Grid Infrastructure
3. Integrate Large Scale intermittent generation capacity
4. Build Active Distribution Networks
5. Deploy new market places
6. Enhance Information Processing and Communication Technology

Optimise Grid Operation and Usage

This deployment priority is about decentralized but well coordinated grid operation, operational security and market-based treatment of electric power flows.

In order to manage the ever increasing demands for energy trading and security of supply, the existing transmission and distribution networks require improved integration and coordination across Europe. To control electric power flows across Europe and/or national borders, advanced applications and tools, that are already available today, should be deployed to manage the complex interaction of operational security and trading and to provide active prevention and remedy of disturbances.

Optimise Grid Infrastructure

This deployment priority is about building new infrastructure, improving and optimizing use of existing facilities.

Rather than being only deterministic, coordinated planning should be based on scenarios and include the necessary elements of risk management in order to cope with the increased volatility and uncertainty in location and size of generation and growing intermittent generation.

Integrate Large Scale intermittent generation capacity

This deployment priority is about integrating large scale on-shore and off-shore intermittent generation, notably wind power.

Large-scale forms of generation, e.g. wind farms and in the future (concentrated) solar thermal generation, require networks to enable efficient collection of the power generated and enable system balancing, either by energy storage, conventional generation or by demand side participation. Off-shore wind energy needs marine power collection networks and reinforcement of the European terrestrial networks. This deployment priority is hence also about promoting and fostering the large-scale integration of renewable energy resources in a manner that meets the requirements of grid security while considering economic efficiency.

Build Active Distribution Networks

This deployment priority details the change in the distribution network, from being "passive" and dependent on human operator's intervention to an "active" one. This is required due to the increasing complexity of network operations, to the wide deployment of distributed generation and to the increasing challenges in ensuring security and quality of supply.

Transmission networks have always provided a balancing and management role in the electric power supply chain, whereas distribution networks have been designed to be passive ("fit-and-forget") in operation. The challenge is now to provide many of the services found in transmission grids, such as power flow and constraint management, contingency analysis, balancing, in distribution networks. This is required not just because of the increasing deployment of distributed generation, but also because of emerging intelligent building services in both residential and commercial premises, the need for utilizing local generation to support the local network at times of stress on the main grid and because of the anticipated future wide usage of electrical transportation vehicles.

Deploy new market places

This deployment priority is about bringing customers as the focus and first line of interest of Smart Grids.

Diminishing of the differences between transmission and distribution in areas such as ancillary services, grid connection and access, but also quality and security of supply is one of the important characteristics of the whole Smart Grids concept. At the same time, such "democratization" and "decentralization" requires enhanced and strengthened control and management. This is not only necessary to operate the grid securely – adequate control and management solutions are also required to deploy a number of new and emerging concepts successfully and effectively such as the Virtual Power Plants and end-user energy management concepts.

Enhance Information Processing and Communication Technology

This deployment priority is about defining the tasks and implementing the necessary standards for Information and Communication Technology solutions in future SmartGrids. The application of ICT is a pre-requisite for data exchange between the different market players in the electricity supply chain and for the secure, economic and environmentally benign operation of Smart Grids. . As such, this is a support for the developments described in the previous sections is not, and cannot be, an activity on its own.

ICT enables the market players to receive data from the network and to send out data for its control and/or influence. Different market participants need information about power consumption and generation for various purposes e.g. for billing (suppliers), for monitoring of

network load (Transmission System Operator (TSO) and Distribution System Operator (DSO)) or e.g. for real time dispatch of the production of Virtual Power Plants (VPP) as an aggregator of Distributed Generation (DG), storage and Demand Side Management (DSM).

4.1.6 ICT developments

As identified in Figure 6, the area of Information and Communication Technology covers all stakeholders and virtually all market participants. A comparative overview of the ICT challenge in terms of status quo and future needs is presented in Figure 7.

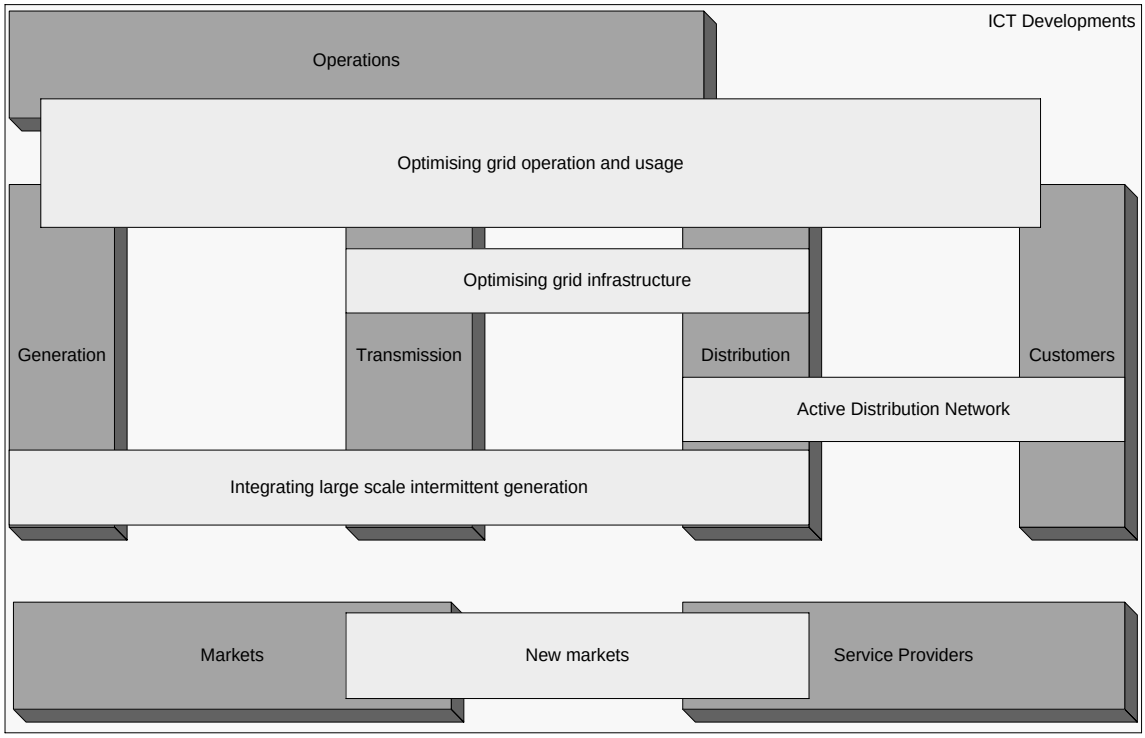


Figure 6. Overview of required new developments

Today ICT is applied at the transmission and sub-transmission level and ends at the bus-bars of the sub-transmission (110 kV)/medium voltage substations. Different standard protocols at various voltage levels and for different kinds of equipment are used. By large, the medium and low voltage levels are characterized by limited ICT, for economic reasons (left side in Figure 7).

Standardized, open information models and communication services for all data exchange within the whole electricity supply chain and electric power supply system are needed. Different ICT technologies should be investigated and tested on site with the goal towards the introduction of ICT into the distribution level relying on the existing communication infrastructure (radio, power line, copper or fibre optics), applied in a cost effective way (right side of Figure 7).

Deployment and large-scale implementation should follow a stepwise approach at a rate determined by the needs of other Smart grids deployment priorities, of the different market players and by relevant developments of the electricity market in Europe.

Furthermore, technology development in ICT will drive this deployment priority to ensure interoperability between various devices of different vendors.

Key elements and priority components

- Simple, robust, secure and flexible communication infrastructure to allow monitoring, management, control and dispatching operations at all levels down to the distribution and customers. This development started in the late 1990s and continues with the development and deployment of standard communication protocols, e.g. TASE.2, and 61850.
- Common information and data models for all information building blocks, in order to ensure consistent database management, need to be defined at all levels of the power system and electricity supply chain. This development started in the early 2000s, with the development of the Common Information Model, and its extensions for e.g. market definitions
- Well functioning ICT solutions are essential for maintaining the security of supply and for the efficient interaction of the market players
- Standardized interfaces are needed between different market participants, generators, TSOs, DSOs, VPPs, traders, customers.

A truly competitive situation for all kinds of products relying on multi-vendor strategies can only be achieved with well defined and standardized ICT solutions.

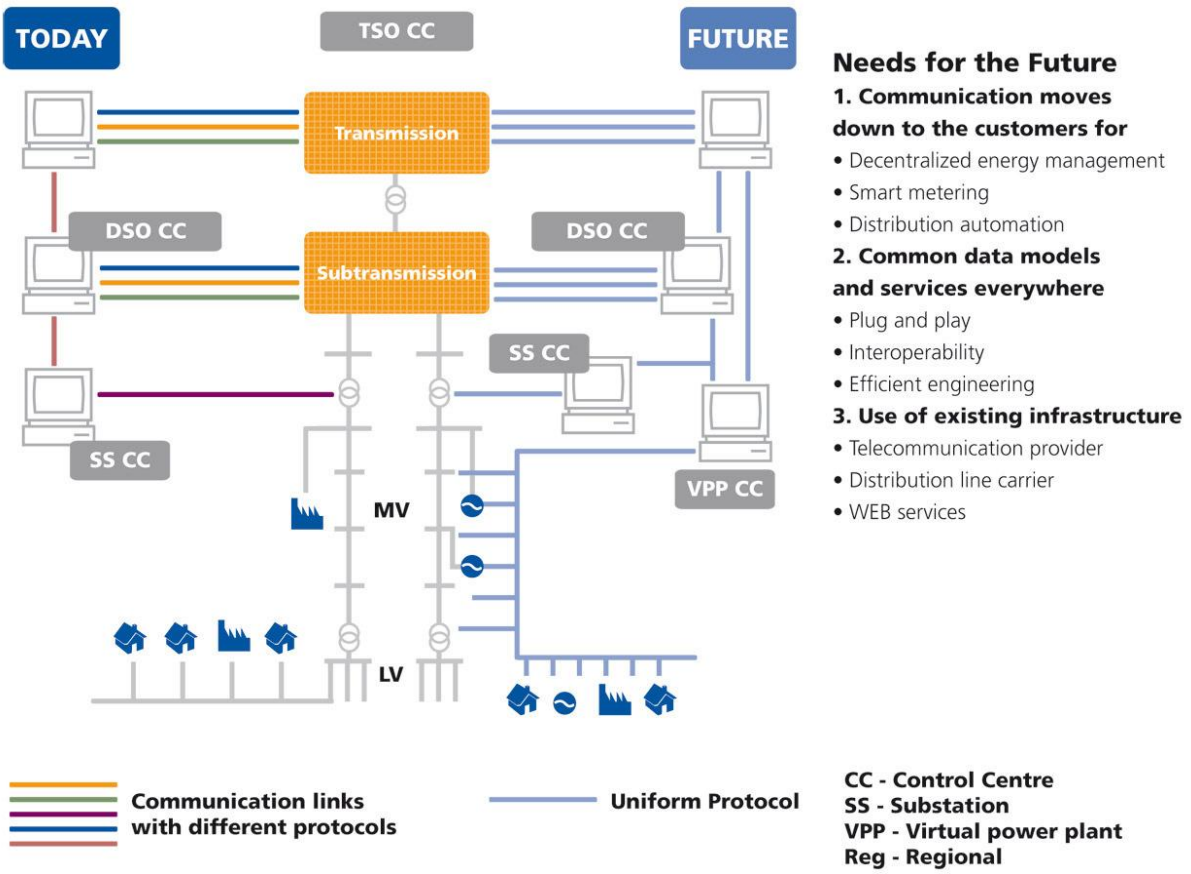


Figure 7. Current status and future needs for ICT application

ICT systems in smart grids, and their status

The following systems are examples of systems that must be implemented for smart grids to be feasible:

- Monitoring and Control systems, for the Transmission and Distribution Operators usually referred to as SCADA (Supervisory Control And Data Acquisition) systems. Such systems are operational with all major operator companies. New developments are required to enable e.g. Optimise Grid Operation and Usage, Optimise Grid Infrastructure, Integrate Large Scale intermittent generation capacity, Build Active Distribution Networks and Deploy new market places.
- Energy exchange registration and billing, and to a certain degree control of exchange through smart meters with remote switches. A smart meter infrastructure is not defined, and not yet fully available, although several pilot and demonstration projects are being developed. Additional effort is required to Optimise Grid Operation and Usage and Build Active Distribution Networks. Build Active Distribution Networks. IT developments are required to e.g. register consumption data and analyse consumption data. Communication developments are required to transport massive amounts of data from meters to storage and processing systems. The metering infrastructure should also have functionality to register energy generated (e.g. by micro-generation systems).

Current smart meter generation is typically a traditional meter with communication options. There have been calls for greater functionality e.g. act as an inference device, provide advice on energy tariff and time of use acting as a type of learning aid to users. Time of use, and tariff analysis would be most useful if electric vehicle charging stations are connected. Smart meters should be part of a local infrastructure integrating home or building buses, HMI and logic to optimise energy consumption, and production, as applicable.

4.2 Evaluation of RTD topics

Smart Grids are too complex to design, or to operate, without ICT support. The development of Smart Grids has two components:

1. Design of new technology to generate, store or transport electricity
2. Design of new technology to control the generation, storage or transport of electricity.

Except for aiding the process of design itself item (1) above is out of the scope of the REViSITE project. Item (2) is exclusively based on ICT developments, the results will be ICT based products.

The following section describes the design and operations of Smart Grid related ICT products in term of the SMARTT taxonomy defined in the REViSITE deliverable D2.1 and as summarised in section 3 above [3].

4.2.1 Specification & design ICT's:

Design conceptualisation

Smart Grid related developments may use these tools in early design stages. It is not a focus point from technical point of view, however the resulting descriptions may make common agreement and understanding of the developments easier. Topics are (e.g.)

- Requirement Engineering tools, mainly to collect and structure a great number of requirements for complex multivariable systems.
- Graphical design tools (e.g. planning wind farms), mainly systems to show what installations will look like, and how they will fit in their environment to overcome "NIMBY" objections.

Most of these tools are well known, and to a degree standardised. Little or no specific new tools are required for Smart Grid developments.

Detailed Design

Smart Grid related software development uses standard software design tools. Regular software and system design tools are most often used. We do not envisage the development, or the use, of specific smart grid related design tools: regular software development tools will be sufficient. Multimedia has limited technical use, however it may have the same considerations as above, overcoming the "NIMBY" objections.

Modelling

Modelling smart grid functions and functionality is wide spread and common used technology. The model is then a formalised and abstract description of attributes and behaviour of the modelled object. Examples of usage include modelling of:

- equipment behaviour,
- user (prosumer) behaviour,
- market responses.

Several modelling tools are being used, most of them readily available on the market. Main usage of the models is in performance estimation and simulation.

Performance estimation

Performance, including calculating or estimating of technical and / or financial parameters, is key function in smart grid developments. Performance often refers to

- technical performance: resilience and reliability during normal operations and during emergency situations;
- financial performance: not just cost/benefits but also energy market effects.

Most often pay-back time of any investment or development is calculated. Some pilot projects are initiated exclusively to enable more accurate performance estimates. This topic is closely linked to the Simulation topic. Performance of a smart grid is usually determined using simulation scenarios.

Simulation

Simulation of the behaviour of the power system, of generating units, and of the energy market, are usually performed in an early stage of any smart grid development. Power System Simulation is a well known technology. Simulation of generating units, and of energy markets, is new as far as renewable generations, and markets supporting renewable energy sources or interruptible generation or consumption are concerned. Typical components include:

- state estimators and grid simulation logic
- consumption forecasts that include market behaviour, prosumer behaviour.

Specification & Product / component Selection

For smart grid developments these steps include Requirement Specification, technical and functional specification, preparation of tender dossier and tender evaluation methods, and tender evaluation processes. These actions are governed by EU rules and regulations, in some cases with additional rules by national organisations or financing organisations. These are all well known procedures and processes, and all of the sector can adopt these to either small scale or large scale smart grid roll-outs.

4.2.2 Materialisation ICT's:

We consider materialisation of a Smart Grid as the installation of local smart grid equipment, including communication infrastructure as well as monitoring, and controlling systems. Installation of decentralised generation equipment (DER) would give added value.

Materialisation of Smart Grids and Smart Grid components is mainly a logistics issue, due to the number of installations, the geographical spread and the rather common requirement not to interrupt electricity supply while installing new components. ICT support is limited to planning tools and Enterprise Resource Planning software. These are well known applications and ICTs in this space could be assumed common to the materialisation/construction management in any context and this is addressed in a more obvious context within the smart building section of this report.

The massive scale of any major roll-out of Smart Grid systems and related systems is sometimes mentioned as one of the factors that delay such roll-out. Note that even for a relatively small country like the Netherlands, a full roll out would comprise upgrades to around 6 million households, and probably 3 million industries and office buildings. In the first few years we expect relatively small pilot projects, growing to several hundred thousand households.

Decision support & Visualisation

Little or no activities of this kind specifically aimed at materialisation of grids. Any development has limited technical use, however it may have the same considerations as in the previous section, overcoming the "NIMBY" objections.

Management & control

Little or no activities of this kind specifically aimed at materialisation of grids, besides regular project management techniques. This is a key factor in operation of Smart Grids, not so much in the process of deployment (or roll out) of Smart Grid components.

Real-time communication

Little or no activities of this kind specifically aimed at materialisation. Real Time application is a key factor in operation of Smart Grids, not so much in the process of deployment (or roll out) of Smart Grid components.

4.2.3 Automation & operational decision support ICT's:

Automated monitoring & control

Automated monitoring and control is the key issue in Smart Grid development. This ranges from small scale monitoring and control of a single household's energy exchange, block or building wide supervisory control and monitoring, to distribution grid wide supervisory control and monitoring. Individual generators or consumers may be monitored and controlled, their parameters or setpoints determined on a per-block basis, and on a per-grid basis. Monitoring and control of transport and distribution grids is well known to all parties involved. The scale on which smart grid operations are to be monitored and controlled however, is wildly different from any existing technology, in that geographical spread, number of installations, and interactions in between systems, are far more complex than in any existing traditional infrastructure. Typical applications are:

- SCADA / EMS: SCADA systems with integrated logic to serve as Energy Management System (EMS). These systems are mostly based on well known technologies and are in

use by the operators of high voltage electricity transport systems. Applications most often include
  - Consumption forecast and planning
  - Generation forecast and planning (specifically for wind farms)
  - Market interfaces to ensure that the energy flows that would result from an unrestricted energy market can be supported by the physical transport grid
  - Load Balancing facilities to balance supply and demand on national scale
  - Real-time state estimators to calculate the network state, specifically calculate values at locations where no measurements are available
  - Simulation software, e.g. to calculate what-if scenarios, to assess the resilience and robustness of the grid
  - Optimiser software to optimise energy flow through the grid.
- SCADA / DMS: SCADA systems with integrated logic to serve as Distribution Management System (DMS). These systems are mostly based on well known technologies and are in use by the operators of medium and low voltage electricity distribution systems. Applications most often include:
  - Consumption forecast and planning
  - Generation forecast and planning (specifically wind energy)
  - Load Balancing facilities to balance supply and demand on regional scale
  - Outage management systems to register instabilities, faults or interrupted supply to clients
  - Crew management systems to manage repair crews.
- Distributed Control Systems: including District Energy Management systems, Facility energy management systems, and personal energy management systems (ref section 4.2.6 page 30) to (e.g.) monitor and control Virtual Power Plants (VPP) and the consumption of local customers. Specific applications could include (e.g.)
  - Market interfaces to automatically bid on market supply or demand, optimising the local finances or optimising the local energy flows
  - Control algorithms that could optimise the generation by individual generators
  - Load Balancing facilities to balance supply and demand on local scale
  - Supply and demand forecast algorithms
  - User interfaces to allow individual users to control their share in the energy balance
  - Home automation or building automation interfaces.

The SCADA/EMS and SCADA/DMS are mostly well known applications. These need modifications to support the growing numbers of generators and the growing number of controls that result from that. Other systems, including the local control systems and home automation systems, are mostly in their present state too primitive to handle extensive Smart Grid functionalities.

Operational decision support & visualisation

Decision support and visualisation techniques are considered in the following:
- Prosumer reporting and decision support in energy trading, controlling of production and consumption
- Trading organisation reporting and decision support
- Distribution organisation reporting and decision support

Prosumers decisions on the selling or buying energy depend on (most often real-time) prices of energy on the market, as well as on the (most often real-time) prices of fuels. The number of variables influencing the decision whether to sell or buy energy on the market rises with the number of prosumers entering the market. This results in (1) extremely complex price

mechanisms, (2) hard to predict prices. Decision support mechanisms will include market modelling, consumption modelling and simulation logic.

Quality of service

Measuring and reporting of Quality of Service includes the following:

- Measurement and reporting on outages on a per client and per area basis
- Measurement and reporting on quality parameters of energy supply: frequency characteristics, voltage variations and more

Quality of service has two components: the continuity of service and the stability of voltage and frequency. Continuity of service, or rather the number of blackouts or brownouts, is influenced by the balance of generation / consumption. The stability of voltage and frequency is mainly influenced by the quality of the (local) Distributed Energy Resources (DER) and Distributed Generators (DGs). Research and development is required to produce systems that can measure and report on quality of service. Research and development is required to process large amounts of measurements and provide feedback to automated controllers that can improve quality of service.

Quality of service also includes parameters such as voltage, frequency, and harmonic distortion. We would suggest to determine these parameters not on a per household (or consumer) basis, but rather on at a distribution station level, mainly because the cost of measurements in every household are rather high, and the benefits are questionable, and the amount of data resulting from it is quite extreme. The cost of implementing measurements per household conflicts with the requirements to keep the cost of Smart Meters as low as possible. A brief and possibly incomplete inventory has shown that about one quarter of the distribution companies plan to measure these parameters on a per household basis, half on a per station basis in almost all distribution stations, and one quarter plan to measure ad hoc at selected locations within the distribution grid.

Wired/Wireless sensor networks

Wired and wireless communications include:

- Communications between metering devices and measurement collector (aggregator) devices
- Communication between metering devices and consumers to report usage (or production)
- Communication between measurement collection devices and back office organisations

In all cases wired, wireless or combinations are known to be used. Security issues such as integrity, security, confidentiality are relevant.

The communication networks that are to transport monitoring and control data, or power metering data, need to support large amounts of connected systems including distribution stations, DER, DG and prosumer meters. Metering data is used for billing and settlement of exchanged energy, so accuracy and security mechanisms must be strictly followed and implemented.

4.2.4 Resource & Process management ICT's:

Inter-enterprise coordination

This topic will typically include all data on the planning of electricity generation, based on short term and long term consumption forecasts, as well as planning of maintenance in grids and equipment.

The number of domains and actors in domains (ref section 4.2.6 page 30)) is fairly large and the coordination required between these actors is as yet not fully described. Factors influencing the complexity of this coordination are (e.g.) market structure and market processes.

This coordination topic is addressed on a limited scale by the pilot projects and implementation projects as far as are known now. Before coordination topics can be designed however, the market structure needs to be defined. The HiPerDNO project implements methods to move and analyse large quantities of data.

Technologies and techniques for this topic are mostly well known. Defining the functions and the data to be exchanged in this topic is the key issue here.

Process integration

The monitoring and control processes generate large amounts of data. These data should, for billing and settlement processes, be stored, analysed, aggregated and reported. This topic is addressed in very few pilot projects. The technologies and techniques for this topic are mostly well known. Defining the functions and the data to be exchanged in this topic is the key issue here. Specific issues are:

- Data Warehousing: storage and analysis of large quantities of data
- Data Aggregation: combining data on logical basis
- Multi-variable analysis

Knowledge sharing

The data gathered in monitoring and control, to be used in billing and settlement processes, can in general be used in short term and long term forecasts. Transporting the data, analysing it and moving it around, is a topic for investigation, possibly for research.

Key issues here are decisions on which data can, and should, be aggregated.

4.2.5 Technical Integration ICT's:

Technical integration & interoperability

Data collected from the field, mainly monitoring and control related including metering data, is a large volume on a per-prosumer basis. This data is to be transferred and processed by a multitude of systems; Supervisory control, billing and settlement, market administration, customer management and more. The effort in transporting and processing the hourly generated volumes is considerable.

Related topics are communication infrastructures, communication protocols, cyber security, data aggregation and analysis.

- Integration of energy consumption data in ERP systems: Metered data can be used for billing and settlement, for market analysis but also to base forecasts on.

- Share production figures of industrial prosumers: if industrial prosumers would allow restricted publishing of their production figures then a reliable forecast of energy balances could be made, based on actual production figures.

4.2.6 Trading / transactional management ICT's:

District energy management

This topic includes systems for the monitoring and control of the transport and generation of electricity in distribution grids, refer to the SCADA/EMS and DMS in section 4.2.3. These systems are all based on existing and well known technology, and include secure, smart interfaces with smart grids, Market Management Systems (MMS), Distribution Management Systems (DMS), transactional aspects of Energy Management Systems (EMS) etc

The functionality of these systems is not really different from existing systems, however the scale on which grids and equipment in grids is monitored and controlled, is larger.

Facility energy management

This topic refers to relatively small scale energy management systems, controlling e.g. the energy generation and consumption of a large or medium sized business, or building.

Facility Energy management systems usually exchange data with District Energy Management systems. Typical connected subsystems include smart metering infrastructure and protocols, Context Event Processing, on-demand energy management and optimisation, load and distributed energy resources forecast algorithms, smart appliances. Registration of CO_2 quota and CO_2 emission, trading of CO_2 quota, and the optimisation of those are relatively new applications for such systems.

Citizen (personal) energy management

The information systems this topic relates to are basically the same as those for facility energy management, but they operate on a smaller scale. This type of system is practically an extension to an home automation system, with energy management functions added. This topic relates to small companies, and private households. In order to make the large number of personnel energy management systems manageable, they need to be aggregated and controlled as a group. The control theory behind this method is as yet not fully tested and proven. Additional functionality to typical current geneartion smart meters will be requierd in terms of personall energy management. A promising area is the integration of context aware technology and service which can utilise existing technology utilising say mobile/cell phones as input/output devices.

4.3 Summary of current research activities

In the following section an alignment of several research and development projects on smart grid developments to the REViSITE Taxonomy is presented. Note that several projects are on the development of hardware, e.g. electricity storage equipment, station equipment and similar. The following list holds mainly European Community funded projects, selected on a main component of ICT development. A short description of the research projects can be found in Appendices 11.1.

Table 5.Alligment of smart grid related research projects with REViSITE Taxonomy

Acronym	Specification & Design ICT'S	Design conceptualisation	Detailed Design	Modelling	Simulation	Performance estimation	Specification & Product / component Selection	Automation & operational decision support ICT'S	Automated monitoring & controll	Quality of Service	Operational decision support & visualisation	Wired/Wireless sensor networks	Materialisation ICT'S	Decision support & Visualisation	Management & controll	Real-time communication	Resource & Process management ICT'S	Inter-enterprise coordination	Process integration	Knowledge Sharing	Technical Integration ICT'S	Technical integration & interoperability	Trading / transactional management ICT'S	Facility energy management	District energy management	Citizen (personal) energy management
Address		●	●				●		●		●	●		●	●	●			●			●		●	●	●
DLC+VIT4IP		●	●	●	●	●	●					●				●						●				
E-Price		●	●	●										●				●	●	●		●		●		
HiPerDNO		●	●						●			●		●	●	●		●	●	●		●				
Inovgrid		●	●				●		●		●	●		●	●	●		●	●					●	●	●
Integral		●	●				●		●	●	●	●		●	●	●			●	●		●		●	●	●
InteGris		●	●				●					●				●			●			●				
Miracle		●	●	●			●							●	●	●		●	●	●		●		●	●	●
Open Meter		●	●				●					●				●						●				●
Open Node		●	●				●		●	●	●	●		●	●	●			●			●		●	●	●
Rempli		●	●									●				●						●				
W2E							●		●						●	●						●		●		
Smart House							●		●		●	●			●				●			●		●	●	●

5 ICT DEVELOPMENTS IN SMART MANUFACTURING

5.1 Characteristics of smart manufacturing

Manufacturing includes all industrial activities to provide a customer with goods and or services. Manufacturing processes also involve activities within a supply chain, while the term production mainly addresses the process of making the actual product.

Enablers of manufacturing are human resources, materials, energy, infrastructures, ICT and knowledge. ICT is used in the planning, operation and control of manufacturing business. Traditionally the manufacturing sector focuses on the optimisation of economical aspects like productivity or quality. However sustainable aspects like energy efficiency will become increasingly important for the European industry not only driven by political requirements but also as an essential economical factor due to rising energy costs and customer demand.

In essence we are seeing a paradigm shift from purely economic – maximum profit for minimum capital – to – maximum value using minimum resources. Legislative and consumer sentiment means manufacturers must become ever more cognisant of the impact their processes and products have on sustainability. The manufacturing industry is a corner stone of European economic sustainability however the commitment is that the economic will not be to the detriment of social and environmental sustainability.

As such, within REViSITE 'Smart manufacturing is defined as the use of ICT technologies for the efficient and effective use of man, method, machine and material in ensuring the sustainability of the enterprise, its environment and the resources it consumes'

5.1.1 Energy profile

Industry is consuming a significant portion of the European energy. In high industrialised countries the production industry's share of the overall energy consumption is even more than the 21% reported in Figure 8 .

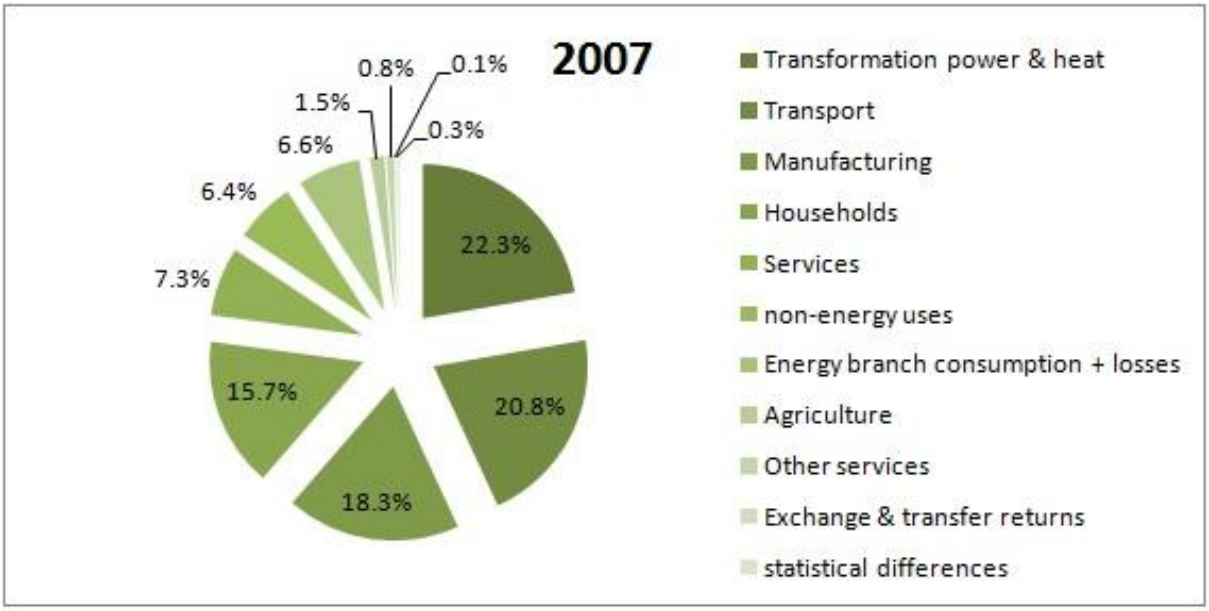


Figure 8. Prime energy breakdown EU27 (2007)

The sector 'Industry' is defined by Eurostat as all the industrial sectors, e.g. iron and steel industry, chemical industry, food, drink and tobacco industry, textile, leather and clothing industry, paper and printing industry, etc., with the exception of transformation (energy sector) and/or the own use of the energy producing industries. Small-scale craft industry is reported by Eurostat under household and services, with external logistics reported under transport. Figure 9 shows a detailed breakdown of industrial electricity consumption for Europe in 2007 .

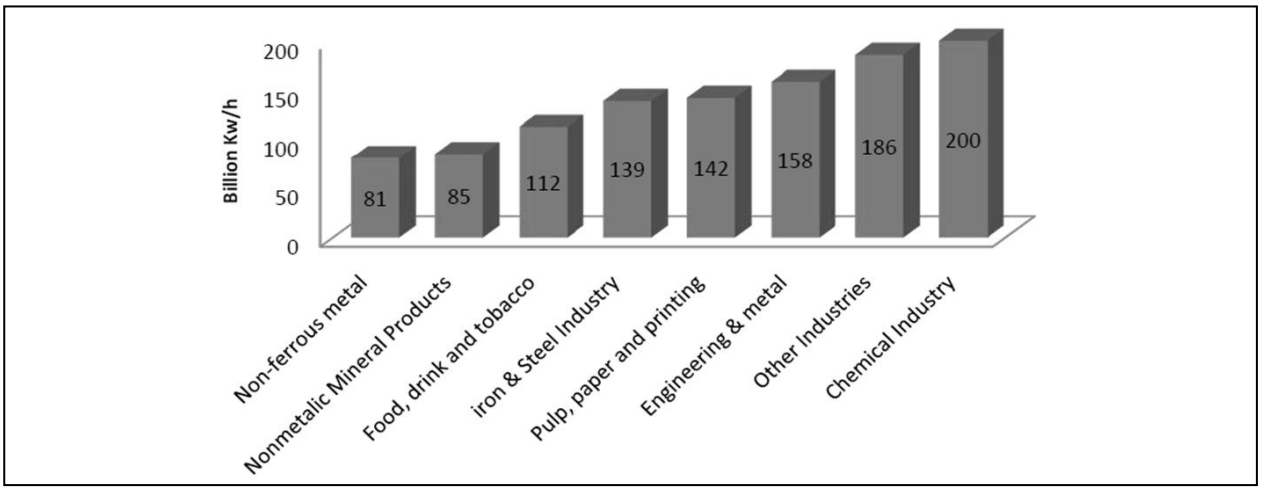
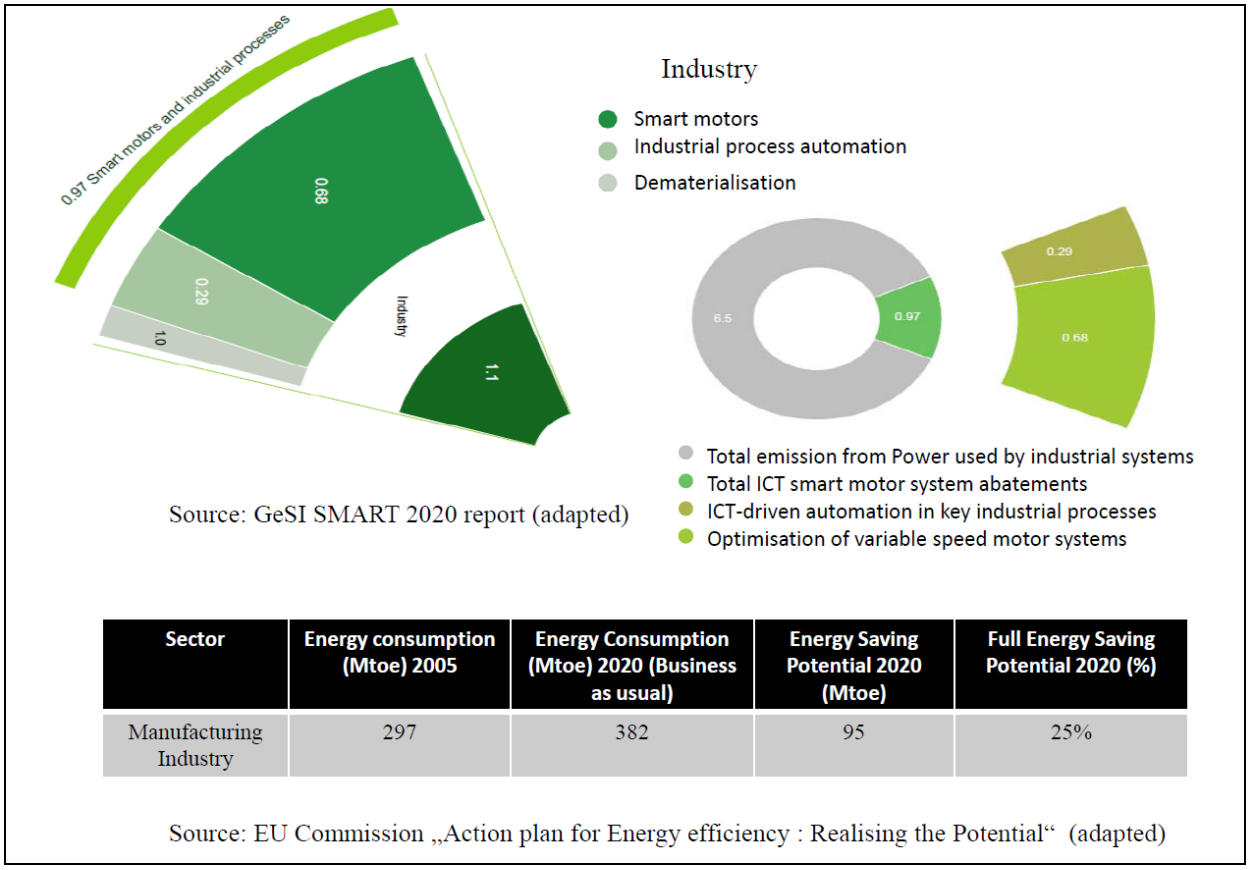


Figure 9. Industrial electricity consumption for Europe in 2007



Sector	Energy consumption (Mtoe) 2005	Energy Consumption (Mtoe) 2020 (Business as usual)	Energy Saving Potential 2020 (Mtoe)	Full Energy Saving Potential 2020 (%)
Manufacturing Industry	297	382	95	25%

Source: EU Commission „Action plan for Energy efficiency : Realising the Potential" (adapted)

Figure 10. Smart Manufacturing: The Global Impact in 2020

In this study, the scope of the smart manufacturing sector is limited to the European countries, with strong focus on central Europe Electrical energy particularly in discrete manufacturing is one of the most important energy forms. Electricity is directly used for driving electric motors of production equipment but is also used for generating other secondary energy forms like heat, compressed air and hydraulic pressure. Fossil fuels are mainly used for the powering of mobile equipment while natural gas is the primary energy form used for building and process heating [4].

Talking about energy efficiency and the role of ICT in this sector, the GeSI Smart 2020 reports [5] identified an overall energy saving potentials of approx. 25% mainly referring to the fields 'smart motor systems' and 'industrial process automation'. This potential is comparable to other EU sources e.g. [6] and 'action plan for Energy efficiency [7].

5.1.2 Framework

For applying the adapted LCA methodology (as described in chapter 3) on the manufacturing sector, this research work focuses on the Life Cycle of production systems, which can be subdivided into the three main parts:

- the product, as the item which is produced,
- the processes, which includes all actions (e.g machining, assembling, handling or transportation to produce the item directly and organisational or supporting actions like production planning or scheduling),
- and resources, which addresses all objects being required to produce the item (e.g. machines, jigs and tools, facilities and human resources)

All three parts are bound by a common material and information flow. The material input includes not only raw materials or semi finished products but also energy flows. Therefore, achieving energy efficiency in manufacturing requires the holistic optimization of all 3 parts of a production system.

In industrial context, a production system can be analysed on different levels. A classification is shown in Figure 11 and splits the production system into five different stages:

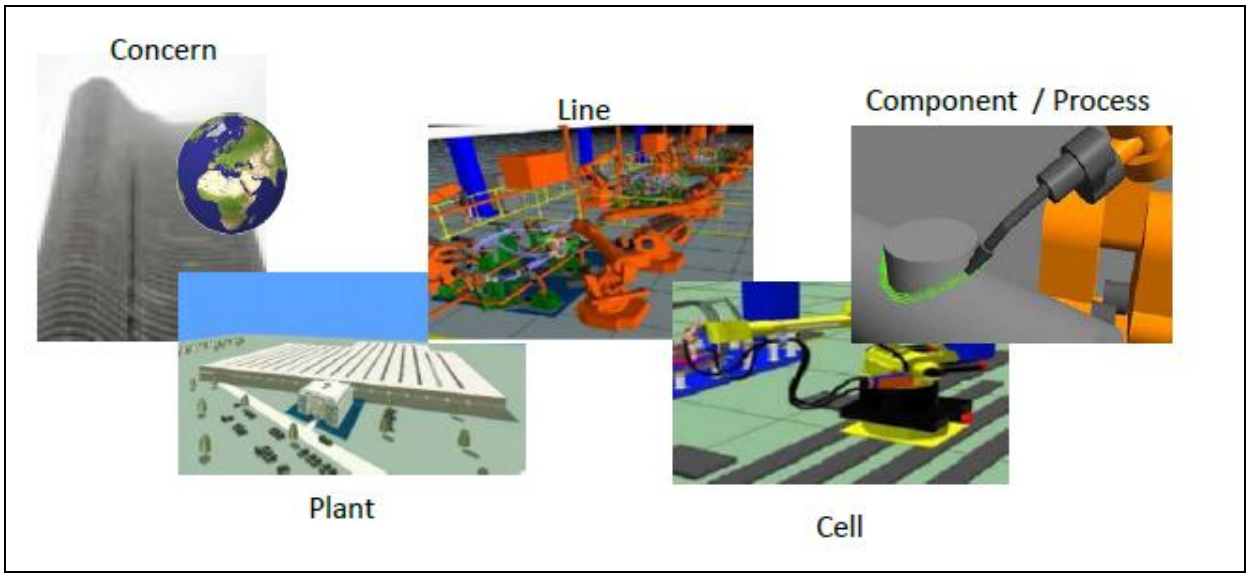


Figure 11. levels of a production systems

- The Concern or production network level is the highest level. Investigating energy efficiency on this level includes the analyses of the implication of markets (e.g. business or energy markets), product families or process in global production networks (e.g. logistic in supply chains). ICT are central to market information and transactional flows.
- The Company or manufacturing plant level represents a single factory within the production network. Especially the energy efficiency of industrial buildings is in the focus of this level, but also the efficient configuration of a factory layout. ICT has a paramount role to play in the design and operational phase of such an entity in terms of quality control, performance and energy efficiency.
- The Production line is a set of different machines or workplaces within a factory. Following a sequence of individual production steps within the production line creates value to a product. Therefore in this level organizational aspects (e.g. scheduling or process planning and control) are in scope. ICT can be utilised in a way that takes account of broader criterion than traditional manufacturing by including energy efficiency and suitable logic to scheduled workflow decision making.
- The Level workplace or production cell is focusing on the single machines or production equipment, which includes the intelligent control and monitoring of machines. ICT is essential here in terms of traditional sense and control functions in machines. However ICT could also include context aware adaptation of work cells based on user preferences and agreed energy SLA (service level agreements).
- Components or technological processes level represent the lowest level. Research regarding energy efficiency addresses optimisation of crucial components of a machine like electrical drives as well as the investigation of energy consumption of individual manufacturing process steps.

From a timeline point of view, the scope of the manufacturing sector is to be distinguished in the life cycle phase of design and materialisation/construction, which is followed by the use/operation of the production system to manufacture products. As the production system is the focus of this analysis, only energy efficiencies of the production system are taken into account. The holistic assessment of the life cycle phases of the resulting products are out of scope although obviously the linkage between the type of products and the production system are obvious and would need to be fully understood. For example, the production of a ferric car could be more efficient than an aluminium car when the production system is analysed, whereas it would definitely be less energy efficient in product life, due to its higher weight. This limitation is necessary in this analysis, to reduce the major complexity of the overall topic. But as the above example demonstrates one could develop energy efficient manufacturing process that did not make sense from an overall product perspective. So while our focus is the production system it is not a focus that can sit in isolation from the products produced.

One could also burden shift in terms of pushing energy intensive operations to sub-component manufactures claiming one's own process was energy efficient. That is why the interface to pre-design phase of the life cycle of the sectors is necessary in order to ensure embodied energy of sub components or materials are understood and considered. Furthermore the production system includes a complex web of stakeholder types with different perspectives that must be considered.

Table 6 summarises important actors in this sector, who all have individual impacts and interests on energy efficiency in the manufacturing sector. Again ICT plays an important role in assisting the interaction of those actors and in understanding the needs of product users.

Table 6. Actors in smart manufacturing

Group	Actors in the group
Companies	• Manufacturer of production systems • operators of production systems
Individuals	• Production system designers • Manufacturing Process designer • Product developer • Production system and equipment manufacturers • Production system operators • Marketing • Managers
Further interest groups	• Government • Public and Customers

5.1.3 ICT in Manufacturing

As can be seen from the previous section manufacturing has become almost impossible without the assistance of ICT mainly since numerical control and computing machines have been introduced. Nowadays, only few exceptions in the handcraft sector are known, where product development and production are carried out without any ICT. However it is also worth noting that sustainability and energy efficiency have rarely been included as 'defining criterion' in ICT implementation.

In general, the digital value chain begins with the Virtual Product Creation processes (VPC). IT solutions that are used comprise systems for authoring, process management, analysis and data management. Each of these groups clusters different IT solutions for the various phases of the VPC. The concept phase, which is assisted by ICT for Requirement Management, is followed by the design phase. The design phase is primarily supported by Computer Aided Design. CAD systems offer wide functionalities for modelling products in 3D. Specific tools for validating the product behaviour are summarized to Computer Aided Engineering (CAE) technologies. Traditionally these tools examine certain aspects (e.g. fluid dynamics, crash analysis) separately using different methods (e.g. Multi Body Simulation (MBS)), Finite Element Method (FEM) or Computational Fluid Dynamics (CFD) analysis) [8]. ICT has a unique opportunity to impact on sustainability and energy efficient throughout the life cycle of the production system by guiding eco design or re-design and incremental optimisation.

All required information and data during the development phase are managed in Product Data Management Systems (PDM). [9] . Nowadays Product Lifecycle Management (PLM) systems support the integration of other IT solutions used throughout the whole product lifecycle, not only the product development phase.

The current digital development state of a products structure and geometry is represented and visualized by a Digital Mock-Up (DMU), which displaces increasingly the Physical Mock-Up e.g. in design reviews or for validation in areas such as packaging, assembly or usability and the dematerialisation effect here of ICT is apparent. Current research aims for a Functional Mock-Up (FMU) that represents not only the product geometry but also the complete product behaviour comprehensively [9].

In parallel to product designing, production planning starts, this includes the designing of physical components of a production system (facilities, machines, tools etc.) as well as all processes which are carried out by the production system. In both cases, Computer Aided Process Planning (CAPP), computer aided manufacturing (CAM) and the Digital Factory come into play as they lead over to the production phase. (in our framework the usage phase of a production system). Traditionally CAM focus on the automatic generation of programs for numerical controlled machines (NC) developed from models of parts generated in CAD software. Again the impact of ICT in terms of energy efficiency is apparent as traditional physical energy intensive tasks now develop through virtualised digital iteration.

The 'Digital Factory' is defined as: "[…] the generic term for a comprehensive network of digital models, methods and tools – including simulation and 3D-visualisation – integrated by a continuous data management system." It aims the "[…] the holistic planning, evaluation and ongoing improvement of all the main structures, processes and resources of the real factory in conjunction with the product" [12] . The Digital Factory involves the use of a wide range of specialized tools for planning and validating different manufacturing processes (similar to product design e.g. CFD or FEM).

The Digital Factory covers not only the designing of manufacturing process but also different planning domains like logistics (material flow simulation) or layout design of production systems. However as yet, a fully integrated planning and validation of complete production systems and manufacturing process chains has not been achieved [8] and ICT has a role to play here in aiding that process.

The production phase itself is mainly assisted by ICT in terms of automation, status and process monitoring as well as controlling and scheduling of production tasks. ICT for automation and control of manufacturing processes includes methods and technologies on different manufacturing levels (Figure 11). On the machine level, tools are controlled with programmable logic controllers (PLC), which are responsible for controlling single machine tasks on the lowest level. Machine data and operating data which can be acquired by means of Supervisory Control and Data Acquisition (SCADA) systems for example, are processed by Manufacturing Execution Systems (MES) and used for controlling purposes. Production planning and control systems (PPC) assist the management and scheduling of the overall production processes. Resource and financial controlling in manufacturing is carried out with the assistance of Enterprise Resource Planning (ERP) systems. In many cases PPC functionalities are integrated in modules of a company's ERP system.

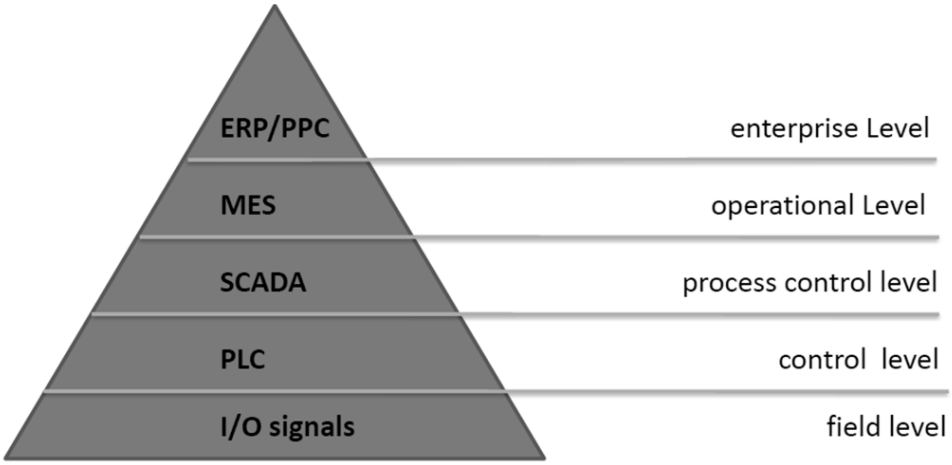


Figure 12. level of industrial automation

So in summary and as illustrated by figure 13, ICT is pervasive within manufacturing at all levels and as such is in a distinct position to enable energy efficient design and operation throughout.

5.2 Evaluation of RTD topics

ICT effects energy efficiency on multifarious ways. The overall goal in the manufacturing sector is to reduce energy consumption by optimising the life-cycle of production systems in a holistic view. ICT enables the optimisation of energy efficiency in all life cycle phases and at all levels of a production system, but mainly in the fields of planning and operation and control. A study by Fraunhofer Germany [7] identifies a potential of up to 30% of energy reduction by using ICT technologies. What follows are current RTDs of the European research landscape aligned to the REViSITE Taxonomy [3].

5.2.1 Specification and design ICT's

Design conceptualisation

Requirement engineering for production system design with stand alone requirement management tools or integrated into PLM Tools support the specification phase of products or production systems. Requirements modelling and the general RFLP (Requirement, Functional, Logical, Physical) approach is used in systems engineering to develop complex systems. Manufacturing requirements especially related energy efficiency can easily be documented and provided to product designers or production system planners and their fulfilment measured and tracked by program managers.

Energy Dependency Analysis in pre-design stage supported by software services (currently in development) helps designers in a very early stage of pre-design to select manufacturing technologies/ methods, parts, equipment and materials for meeting specs for energy efficiency [24] .

Decision tools for the conceptual design of production networks should assist mangers in the definition of internal and external supply chains and also in the selection of in-house production or the purchase of vendor parts. Currently energy is only indirectly covered within the transportation cost. However new solutions should explicit indicate the energy required for the transportation of products in global production networks.

Detailed design

Advanced computer aided engineering (CAE). The concept phase is followed by design and simulation or verification of the product / production system and its behaviour, which is supported by various CAx tools like Computer Aided Design (CAD) for modelling the geometry, Computer Aided Manufacturing (CAM) or Computer Aided Process Planning (CAPP) to plan and verify the manufacturing of parts. Underlying IT-technology is PDM which provides the data base for CAE applications. In terms of energy efficiency new functionalities or services for these tools are under investigation to support the holistic development of energy efficient products and manufacturing processes. The "Green-PLM" approach supports to design products in a more environmentally friendly manner by analyzing and evaluating the energy efficiency and environmental impact throughout the life cycle of a product [11]. Green PLM can be summarized as: "product conception processes that help to minimize the product's impact on the environment throughout its entire lifecycle". This is

essential since the European Union estimates that more than 80 percent of a product's environmental impact is determined in the product conception phase.

Green-PLM considers not only the use of materials and their environmental impacts, but also the use of energy required for manufacturing, logistic and recycling [10]. Some approaches include organizational concepts, collaborative planning methods, optimization of logistic processes and production resources, as well as production planning and capacity management in OEM-supplier networks and also in non-hierarchical company networks. The PLM concept is the enabler for a holistic development of energy efficient products and processes, providing the information base of ecological product related data over the whole lifecycle.

Green PLM technology can be extended for information management purposes with a focus not only on products but also on energy efficient factories. Lifecycle data from former product families will help to evaluate the life cycle impact and costs of new developed products within the design process.

Modelling

Reverse Engineering for manufacturing facilities is necessary for legacy industrial plants, since they are mainly documented in 2D blueprints and have very likely been overhauled several times without updating all blueprints consistently. Therefore creating 3D digital models representing the current state of the facility with data captured by 3D laser scanners is the first step to optimize energy efficiency of Brownfield manufacturing sites. Up to date models of factory buildings are also the basis for retrofitting planning and advanced simulation like thermal simulations.

Virtual Prototyping supported by Virtual Reality (VR) tools, Digital Mockups (DMU) or Smart Hybrid Prototyping (SHP) for product development can help to reduce physical mock-ups and optimise products or production systems for different life cycle stages and under various aspects (e.g. weight optimisation, reduction of material usage, optimization for disassembly and recycling). The use of virtual prototypes instead of physical prototypes does also have direct impact on energy efficiency since the best approach for energy efficiency is avoiding energy consumption for material extraction and manufacturing.

Current academics projects start to use Virtual Reality (VR) for a better and intuitive visualisation of complex energy flows within a machine combining 3D models of the machine with 3D Sanky Diagrams [13] .

Performance estimation

Life Cycle Analysis for manufacturing equipment. Energy consumption is one main aspect of LCAs. The holistic assessment of all life cycle phases is essential especially for long living products like production equipment [14] . LCA is supported by various Software applications. However applying LCA for the designing or optimisation of machines and tool is not yet state of the art.

Modelling embodied energy during manufacturing phase of a product Reliable energy consumption data are essential for LCA. Especially for the manufacturing phase a detailed breakdown of required energy is not available. New approaches are currently developed for modelling of energy consumptions of process chains in manufacturing [15] [16] . This helps to define the amount of energy being required to produce a single part or product and reduces estimation and simplifications in LCA studies.

Simulation

Simulation of energy usage and flows in machine and tool development. Especially in terms of energy efficiency the development of methodologies and concepts to model, simulate and analyze energy flows and losses throughout the whole machine, both for the design of new machines, and the analysis of existing machines (while considering possible improvements) is required. This methodologies need to be embedded in existing ICT tools for design, modelling and verification [17] . Enhancing them with the ability to model and simulate energy flows as well, allows the designer to balance and optimize machine performance and energy efficiency in the same simulation environment and integrates efficiency considerations in the design process.

Simulation of energy consumption on individual levels of the production system. Energy consumption starts to be focused more and more in modelling a production system since integrating energy consumption characteristics in planning phase can lead to huge efficiency improvements for future production systems[18] . However in most cases the overall energy consumption of a production system can only be estimated roughly before the beginning of production. Current research activities regarding energy consumption simulation only focus on individual levels of a production system: However an integrated model taking into account all levels and their dependencies does not exist due to its enormous complexity.

- Simulation of required energy on Process level is limited to very little individual processes for instance using NC-CAM simulation for cutting process.
- Simulation of energy consumptions of manufacturing process chains. Currently software tools are developed, which support manufacturing process designers in planning of process chains and the evaluation of planning alternatives[19] . However these tools are non standard yet and specified for individual manufacturing methods.
- Simulation on line or factory level bases on material flow simulation, using average energy consumption profiles of individual machines or processes [20] .

Integration of production simulation and thermal building simulation tools supports designers for a holistic assessment and dynamic simulation of complex energy systems as factories. Using detailed data of production simulation (e.g. usage profiles of certain machines) helps to provide better input (for instance heat absorption of production equipment) for thermal simulations and the dimensioning of HVAC systems [21] .

Specification & product / component selection

Rapid Manufacturing (RM) allows parts of completely arbitrary 3-dimensional geometries to be directly fabricated from a digital model. RM is basically described as layer-by-layer building technology. “The technique uses additive processes to deliver finished goods directly from digital data, which eliminates all tooling. As RM technology further develops, the layer-based approach of RM may be combined with subtractive (machining) operations or replaced by additive processes that use a multi-axis approach instead of a layered process” [23] .

5.2.2 Materialisation

‘Decision support and visualisation’, ‘management and control’ and ‘real-time communication’, These sub-categories focus on ICTs that are essentially common to the materialisation/construction/engineering of any physical entity regardless of context and are as such non-sector specific. The Smart building section talks to this in more detail as materialisation/construction is a significant element of a building life cycle.

5.2.3 Automation & operational decision support ICTs

Automated monitoring & control

Optimizing CNC programs is able to cut down energy consumption while still keeping the performance of the machine tool unchanged. Algorithms for optimised cutting paths as well as dynamic feed and tool speeds are just one approach. A second approach is the dynamic control of auxiliary units (e.g. hydraulic pumps or cooling and lubrication systems) aligned with the manufacturing process.

"Selective actuation of support systems of machine tools, like cooling system, chip removal or exhaust units, and an intelligent determination of the actuation level of such systems" [27] is another approach which also does not affect machine tool functionality in a negative way.

Power supply modulation and selective switch-offs are another ICT enabled approach, which are based on intelligent system status observations [28] .

Intelligent controlled motor drives can improve energy efficiency in different ways:

- Energy efficient controlled electrical drives may save up to 50% of energy during partial load using variable speed drives [27] . and energy optimized control technologies.
- Intelligent control of compressed air technologies has huge potential for energy savings, since "about 10% of industrial energy consumption is attributed to the use of compressed air" [28] .
- Reprogramming existing equipment and equipping ancient production systems with state-of-the-art control units is another possibility of moving Brownfield manufacturing sites closer to energy efficient production processes [22] .

Non-intrusive load monitoring (NILM) Is an inference or deducing technology that analyses consumption behaviour of individual machines best on a signature or profile. NILM can be particular effective where physical metering is an issue or where cost prohibits deployment. It is essentially a smart virtual metering technology.

Context-aware sensoring technology can be used to automatically adapt 'smart spaces' to suit the user. Given a manufacturing context a work cell might automatically adjust light levels, work bench or station to suit the ergonomic requirements of the user. Monitors or workstations could go into a power save mode when sensing non-occupancy etc. this could use cell-phone or embedded chip within company identification badges & integrated with wireless networks for real time decision support regarding personnel & aggregated energy profiling.

Control for adaptability. Autonomously adapting control systems may help to adequately react on fluctuations during the manufacturing process, changes of process parameters and disturbance variables. The aim is to increase reliability, efficiency, sustainability, flexibility and productivity of manufacturing processes. All these criteria have direct or indirect effects on energy efficiency. Expectations of ICT in this context are to enable "truly integrated mechatronic knowledge-based control systems with embedded intelligence and cognitive abilities" [26] . This includes functionalities like:

- Self learning techniques
- Easy plug-and-play interfaces
- Service-oriented control architectures
- MES integrated simulations
- Modelling production processes of high complexity including adaptive and scalable intelligent tools

Operational decision support & visualisation

Energy consumption monitoring and the provision of energy consumption information to decide on all levels in manufacturing are vital to assist decisions towards energy and cost savings. Visualizations, e.g. in MES, PPC or ERP, are developed to be recognised and taken into account appropriately in nowadays' information overload. The provision of data is supported by a very wide field of ICTs like data mining technologies as well as Online Analytical Processing (OLAP). Combinations of awareness and decision support methods and technologies with intelligent control systems can largely improve energy efficiency by operating manufacturing sites in a flexible and smart manner.

ICT assisted development and provision of EPIs (Energy Performance Indicators) at management and operational level. Individual EPIs have to be developed and implemented in organizations and sub-divisions. CO2 emission permits have already shown the right direction, as those are included in industries accounting models and KPIs in MES or ERP systems. The superior objectives of EPIs are to create awareness and to include considerations on energy consumption into every single decision process.

Quality of service

Integrated Process automation addresses a wide range of optimization loops between NC control and PLC systems by SCADA as well as the integration to MES & ERP for optimizing the overall manufacturing process using shop floor integration standard (e.g. ISA 95, OPC Unified Architecture, OAGIS or MTConnect). Besides enhanced quality and reduced production times, energy efficiency is another positive outcome.

Zero waste production is the first goal to achieve, since outage is a waste of energy. The avoidance of defective parts will increase efficiency as "less material has to be exhausted, transported, transformed, and disposed" [26] . Process stability is the "key parameter" to "achieve the required product quality and quantity in an (energy) efficient way" [26] . Intelligent automation and control systems and Statistical process Control (SPC) can help to control process quality in-line and reduce scrap.

Condition based maintenance and service activities help to reduce non-optimal production runs. Embedded Information devices "facilitate users to provide details and information about the use " of the production system. The detection of abnormal plant behaviour is essential since abnormal behaviour often results in excessive energy consumption and may lead to a large chain of further inefficiencies in down-stream manufacturing processes. A system of sensors is required as well as an IT infrastructure for the optimization of maintenance cycles. Standard "Enterprise Asset Management (EAM) systems typically focuses on proactive maintenance and monitoring strategies" By "integrating OEE (Overall Equipment Effectiveness) to energy consumption analysis equipment and asset performance can be improved and the scheduling of maintenance, needed upgrades, replacements, design changes or purchasing can be supported." [25] .

Advanced Asset Monitoring and Management addresses several topics like asset reliability, performance, risk and safety, as well as asset requirements from a financial and from a technical point of view. Product Lifecycle Management (PLM) technologies allow the management of all kinds of assets during their entire product life. Therefore, it is a key technology for predictive maintenance concepts, life cycle sustainability and all connected models, methods and tools. From an operational point of view, advanced asset monitoring and management supports effective decision making to reduce maintenance efforts, improve the efficiency of maintenance activities and improve the overall production system's productivity and performance. Energy efficiency stands to benefit from all of these improvements. Ontology and according reasoner technologies are used to improve asset monitoring and

management regarding predictability and transparency of maintenance repair and overhaul (MRO) activities.

Wired/Wireless sensor networks

Analysis of energy-relevant parameters on process level by means of sensor-based ICT-infrastructure and Complex Event Processing (CEP) can support identifying energy consumption patterns of individual processes on line and assist in using undiscovered energy efficiency potentials.

Smart meters networks for machines and production equipment have the ability to remotely monitor production systems on plant level in real-time. This can be done using wireless networks, for example. Real-time data gathering, remote monitoring, ad hoc analysis and decision support are the expected outcomes which promise to have a large influence on energy efficiency in manufacturing [29] .

Sensor based intra logistic systems (E-Kanaban system) are used to trigger the movement of materials (e.g. using RFID) within a manufacturing or production facility. Additionally service based ICTs optimize the internal material flows and reduce inventory

5.2.4 Resource and Process management ICT's

Inter-enterprise coordination

Advanced scheduling algorithms in MES & ERP systems can have several positive impacts on energy efficiency in manufacturing:

- Reduction of still-stand times with high base load power consumptions. Since base load energy consumption of production systems usually is around three quarters of overall energy consumption [27] .
- Reduction of re-tooling and re-arrangement reduces energy intensive start-up and shut-down processes and consumption during still-stand.
- Reduced re-configuration outage
- Scheduling of energy intensive tasks when the lowest economic and ecological effects are to be expected has positive effects on overall energy consumption characteristics and on gross energy consumption as well. Avoiding macroeconomic energy consumption peak loads, preventing of high cooling requirements in warm hours and seasons and taking further environmental variabilities into account are possible approaches [31] .
- Reduced inventory can also assist to save energy since storage room which needs to be heated or even cooled can be levelled down and logistics efforts can be reduced.

Supply Chain Management (SCM) for optimizing logistics in production networks and for intra-logistics can help to improve transparency for the supply chain collaborators. This enables stakeholders to head for global optima and does not force them to optimize according to locally available information, only. The aim is to increase the overall efficiency of the value chain which has direct influence on energy efficiency. Appropriate SCM systems increase the ability to evaluate and improve the overall supply chain. Underlying IT technologies are Advanced Planning Systems (APS) including interfaces to PDM and ERP systems as well as Radio Frequency Identification (RFID) for the identification of goods and statuses in logistics processes.

Process integration

Real-time alert communications are used to provide latest information on abnormal plant behaviour and increased energy consumption. Underlying IT-technologies are messaging

services, applications for mobile devices like PDA, tablets and smart phones as well as web based communications. Web-based ad-hoc collaboration in product development. Collaborative Engineering is supported by methods and tools for instant communications with shared models and simulations between distributed partners in global value creation networks.

Knowledge sharing

Energy efficient knowledge provision in design phase (Eco design guidelines or "eco-knowledge repository")**.** Eco design mainly refers to an ecologically optimized usage phase of products. Nevertheless the manufacturing phase (e.g. energy consumption in manufacturing processes) becomes more and more important for a holistic eco design. Also the eco design of machines and tools (in this case it is a product itself rather than a resource) is essential for energy efficiency in manufacturing. In addition to well established tools for the design phase (like CAD etc), the role of ICT in this case is mainly assisting the designer with knowledge provision for new design concepts. Currently ecodesign guidelines for machine tool builders and best practice reference specifications for future generations of machine tools are under investigation [32] **.**

Energy efficiency labels for machines like today's common refrigerator or light energy labels are currently not available for production equipment. However a database with energy consumption data currently is under development which can be used to implement a labelling system in future.

Database listing the energy consumption of manufacturing processes. Unlike the material production phase, manufacturing processes are currently poorly documented in terms of energy usage. Current research activities aim to analyse systematically conventional as well as new process technologies (such as such as electro-chemical and laser based processes) in terms of energy usage and CO2 emissions and to provide reliable data in an online database.

Tools for Energy Auditing are designed to assist professional consultants and cover main functionalities with data collection forms, report templates and checklists for data gathering as well as integrated calculation methods and analysis tools [25] .

5.2.5 Technical Integration ICT's

Technical integration & interoperability

Integration of energy consumption data into ERP systems allows the integration of ecological objectives besides classical objectives (e.g. cost, time quality) in planning of production [33] .

Integrated development and simulation of product and manufacturing processes have potential for increased energy efficiency in manufacturing[34] . The products can be designed for efficient manufacturing processes, whereas the constraints of the machine tools are taken into account in an early stage. ICT is an enabler to this kind of development. Due to the complex interdependencies between product design and manufacturing processes planning as well as the current production an integration of ERP and PLM is essential.

5.2.6 Trading / transactional management ICT's

District energy management

Energy Management Systems are used for managing, monitoring and reducing energy consumption of complex systems [35] . Energy management software enables the integrated planning, monitoring, control and optimization of the energy usage at plant level. Main scope of these systems is the identification of energy loses and the prevention of load peaks. Even

though there is a wide range of functionalities of Energy Management software, the use of energy management is still not standard in industries.

Facility energy management

Integration of building energy management and manufacturing energy management. Apart from the independent energy management of production machines and processes other subsystems of the factory building such as heating, lighting and compressed air subsystems need to be integrated into a holistic energy management system. In recent research activities interdependencies of production equipment and technical building services are taken into account to derive proposing measures and find global optima.

Citizen (personnel) energy management

Holistic energy efficiency controlling for production sites goes beyond facility boarders. It aims a holistic optimization of production (including traditional factors as production time, production rate and quality as well as energy efficiency). It also takes the raising dynamic of the energy market into account due to growing number of deterministic energy sources such as wind turbines. This includes for instance aspects such as shifting workloads of (secondary) processes to avoid energy demand peaks or benefit from temporarily decreasing energy costs.

5.3 Summary of current research activities

Energy Efficiency is very significant and more and more important research topic within the manufacturing sector. Therefore many European and national founded projects address the improvement of EE on various levels of a production system. Often projects work technically on process level or machine level, using ICT as an enabler for the optimization of specific components of tooling and machines or for the development of more energy efficient manufacturing processes. But also organizational aspects as well as the holistic optimization enabled by modern ICT are in scope.

During the last years various research projects have been set up 11.2 describes the research targets of promising projects with a special focus on ICT. Not only currently running projects but also recently finished projects have been taken into account for identifying the current state of the art in research, how EE can benefit from the use of ICT in the manufacturing sector. The following matrix aligns the projects with the REViSITE taxonomy. In fact these tables make no claim to be completed as research landscape in this field is very variable and increasing, but it covers the main research fields and tendencies in the European world of academia.

Table 7. Alignment of manufacturing research projects with REViSITE Taxonomy

acronym	Specification & Design ICT'S	Design conceptualisation	Detailed Design	Modelling	Simulation	Performance estimation	Specification & Product / component Selection	Automation & operational decision support ICT'S	Automated monitoring & controll	Quality of Service	Operational decision support & visualisation	Wired/Wireless sensor networks	Materialisation ICT'S	Decision support & Visualisation	Management & controll	Real-time communication	Resource & Process management ICT'S	Inter-enterprise coordination	Process integration	Knowledge Sharing	Technical Integration ICT'S	Technical integration & interoperability	Trading / transactional management ICT'S	Facility energy management	District energy management	Citizen (personal) energy management
AMI-MOSES								●	●		●	●					●	●			●	●	●	●		
ATKINS	●		●	●	●		●																			
BEAT	●		●	●		●											●		●	●						
CO2PE!	●			●		●	●										●			●						
DEMI	●	●		●	●								●	●			●			●						
E-Klic								●			●	●	●		●		●	●	●		●	●				
EnEffAH	●		●		●			●	●																	
EnEffCo	●			●	●			●	●			●					●		●		●	●	●	●	●	
EnHiPro								●	●		●						●	●	●	●	●	●	●	●		
ENOPA	●				●		●														●	●				
e-SimPro	●		●	●	●		●																			
ESTOMAD	●		●	●	●		●																			
ExtREMe								●	●		●								●		●	●	●	●		
FoFdation								●	●	●			●		●		●	●			●	●				
KAP								●	●	●	●	●					●	●	●		●	●				
MAXIEM	●	●	●			●											●			●						
NCplus								●	●			●														
Plant Cockpit								●	●	●	●						●	●	●		●	●	●	●		
ProGRess	●	●	●	●	●	●																				
QCOALA								●	●	●		●									●	●				
ReVista								●	●	●			●	●			●		●		●	●				
S-SCAM-S	●	●	●				●	●				●														
UES	●		●	●				●	●	●		●					●	●	●		●	●				
ZuPrEff	●			●				●	●			●					●		●							

6 ICT DEVELOPMENTS IN SMART BUILDINGS

6.1 Characteristics of the Building & Construction Sector

The construction sector plays undoubtedly an important role in every nation economy in Europe. In the European Union (EU27) the construction industry generated a total production of 1305 billion € and employed 13.2 million persons. This represents 10% of the gross domestic product (GDP) and 7.3% of the total employment. Directly or indirectly some 26 million workers in the EU are depending on the construction sector.

The sector is not only economical significant but environmental and socially also. Buildings are responsible for 40 % of total EU Energy consumption and 1/3 of GHG emissions during their construction and operation stages. More than 50% of all materials extracted from the earth are transformed into construction materials and products.

The construction sector has been typically characterized by many small enterprises and high labour intensity, being also highly dependent on public regulations and public investments.

It is well understood that the usage of buildings together with industry relating to buildings represent the largest source of CO2 emissions within the European Union. As such the European Construction Technology Platform (ECTP) has identified Energy Efficiency in Buildings has a prime area of focus in combating climate change.

In order to address this strategic topic, the construction model must evolve towards a new multidisciplinary approach which will empower the scope and impact of future developments, improving cooperation with ICT, Energy and other sectors.

6.1.1 Energy profile

The energy consumption of houses and buildings taking into account the whole life cycle is responsible for 40% of total EU energy consumption and is the main contributor to greenhouse gas (GHG) emissions (about 36% of the EU's total CO2 emissions and for about half of the CO2 emissions which are not covered by the Emission Trading System).

From 1997 to 2008 households and services (primarily buildings) accounted for 56% of total electrical consumption within the EU27.

Therefore, the sector has a crucial role to play in achieving environmental sustainability. Environmental issues that the sector faces on a daily basis include: reducing greenhouse gas, mitigating existing polluted areas, enhancing energy efficiency and conserving natural resources such as greenfield spaces, water, energy and balanced ecosystems. When it comes to the vital issue of energy, construction has an important role to play in reducing its use and finding alternative sources of generation. Smart design can also impact on energy efficiency in the usage phase.

As shown in figure below, the majority of energy consumption in households is due to space heating [36] . The situation in the service sector is similar, although the share of lighting and appliances is higher due to greater utilization of ICT in equipment.

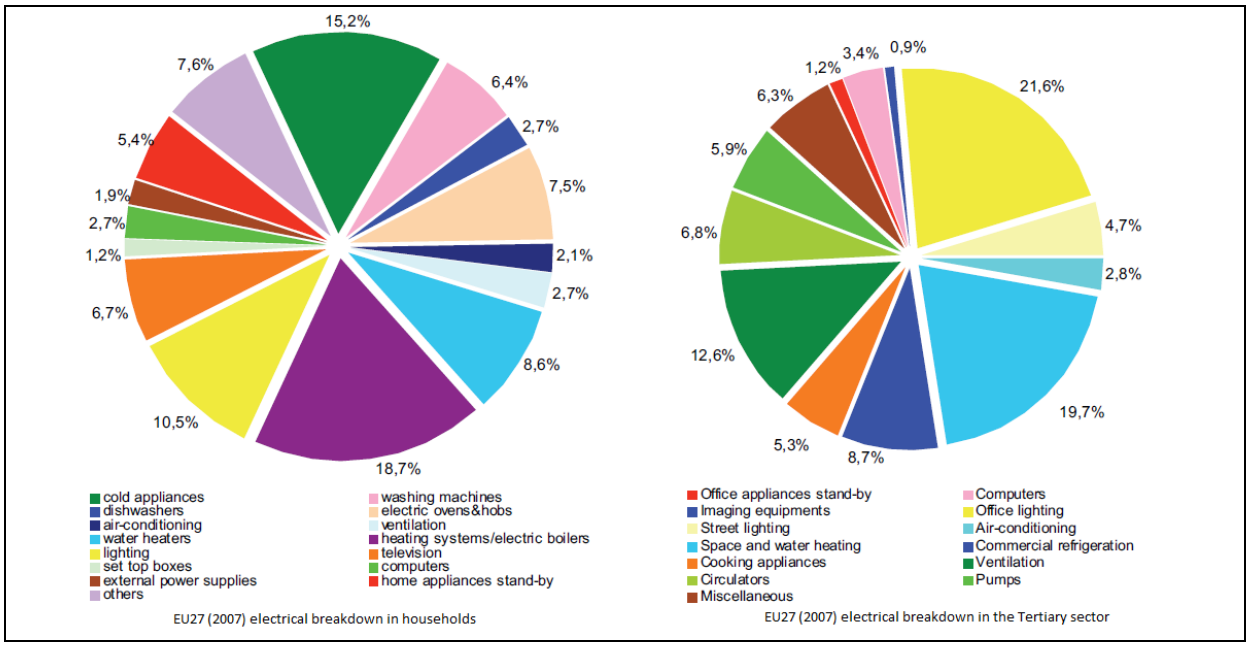


Figure 13. Breakdown of energy consumption in households [37]

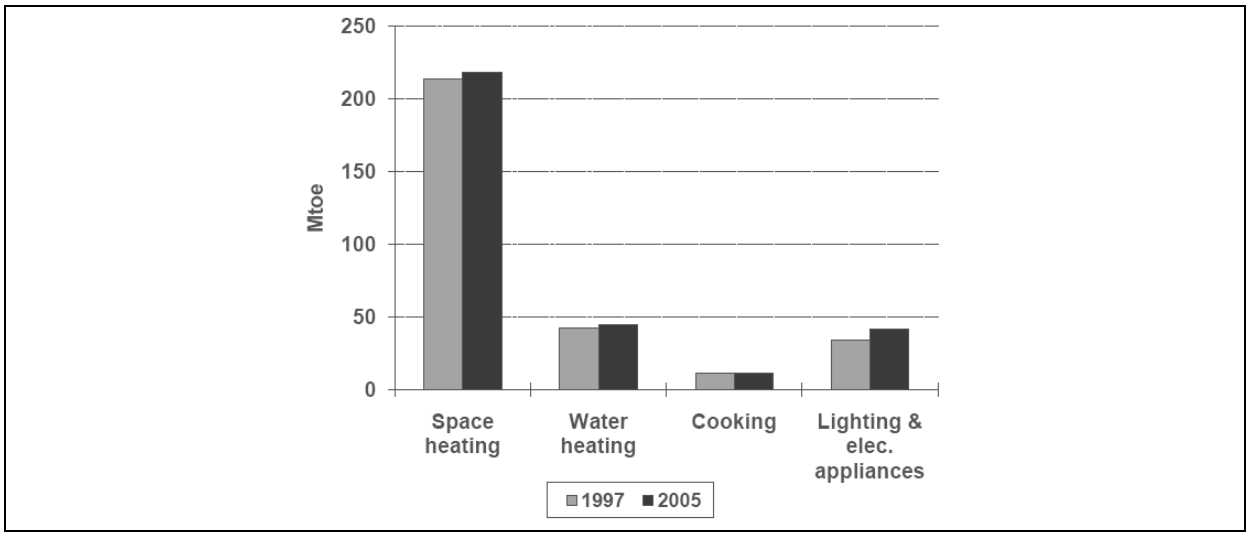


Figure 14. Household energy consumption by end-use in the EU-27 [38]

The reduction of energy consumption in buildings can clearly make a significant contribution to achieving the targets mentioned in the *Green Paper on Energy Efficiency [40]* . The buildings sector provides many cost-efficient opportunities for action, while at the same time contributing to the welfare of EU citizens, through a number of benefits, such as reduced energy needs, reduced import dependency and impact on climate, reduced energy bills, an increase in jobs and the encouragement of local development.

In a broader aspect, a study of the whole life-cycle of buildings (estimated around 50 years) shows that, even if the most important part of the total energy consumption occurs during the operation phase of a building, other phases like construction, productions of materials, renovation or demolition should not be discarded as they can also provide some opportunities for energy savings.

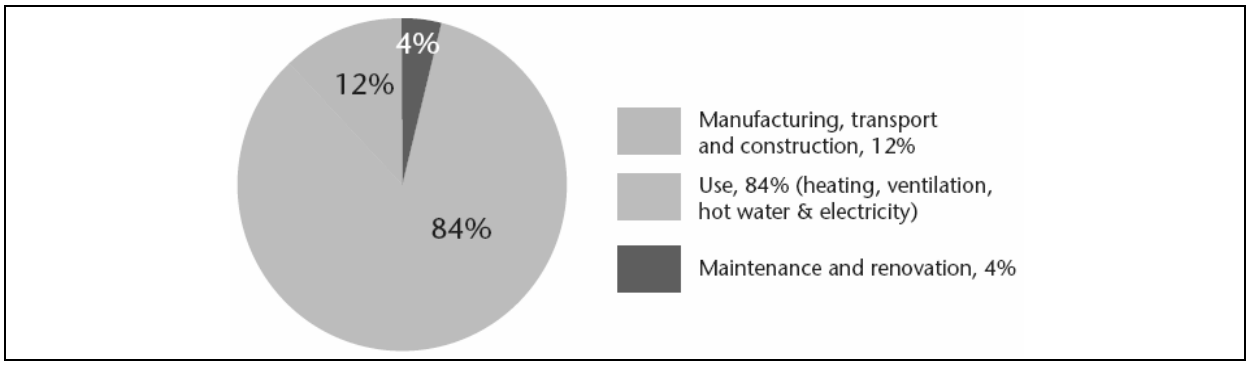


Figure 15. Energy use in a building's life-cycle [39]

Currently the energy performance of buildings is mainly driven by regulations. The prevailing market practice is driven by initial investment cost with little attention to life cycle costs. The decisions that influence energy consumption are mainly made in the design stage and also in (repeated) renovations. Altogether, many stakeholders, parallel processes and life cycle stages are involved.

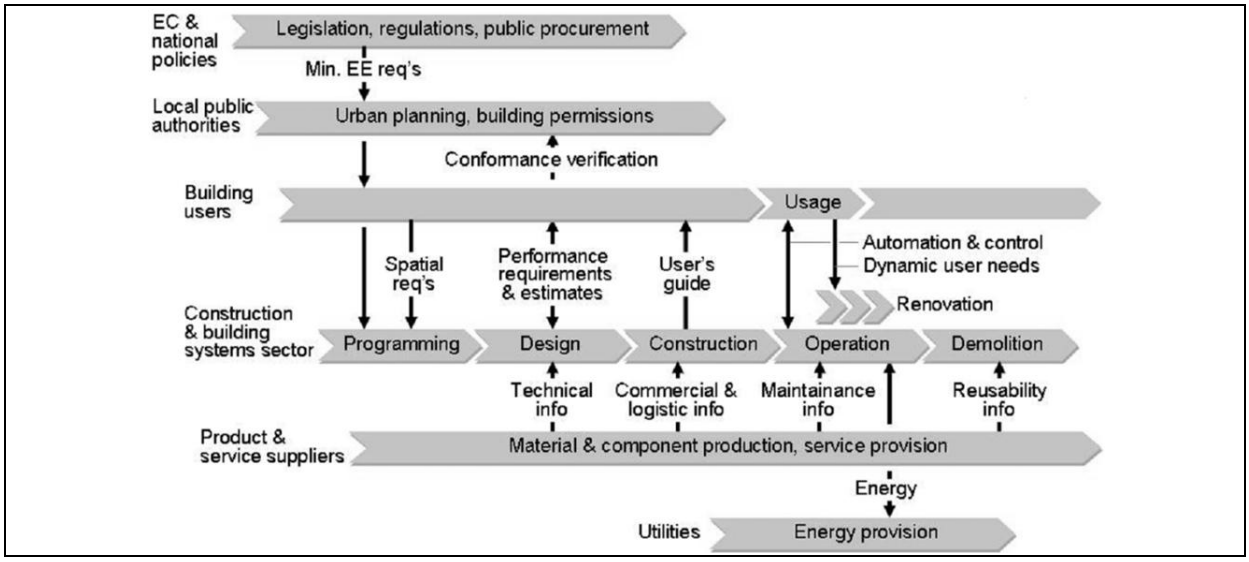


Figure 16. Context of Energy Use in Building [39]

6.1.2 Framework

According to the European Union Directive on the Energy Performance of Buildings [42] , more than 40% of Energy consumption in Europe is due to heating and lighting operations in buildings. Moreover, buildings are the largest source of CO2 emissions in the EU15 (including their electric power consumption), and their total energy consumption has been rising since 1990.

The majority of energy consumption is due to space and water heating, although the share of consumption of lighting and appliances is rising over time (this situation is similar within the service sector although the share of lighting and appliance consumption is higher than in households due to greater utilisation of ICT equipment).

Buildings can be considered as energy-intensive systems through their whole life-cycle, being particularly important figures the ones related to the building operation phase which account for 85% of the total energy consumption.

Concerns (and therefore solutions) on Energy Efficiency (EE) exist throughout the whole construction product life cycle. In each stage of the product life cycle one can overlook solutions and approaches that positively contribute to more EE buildings.

Roughly one can consider three main phases in the construction product life cycle, namely the design phase (early and detailed design and engineering), the realisation phase (construction itself) and the support phase (maintenance, renovation, etc). Throughout each of the phases of the product life cycle, several considerations in respect to EE of buildings could be set, namely:

Design Phase: At design phase the focus on EE should be on realising the best efficient design considering the many variables to be potentially taken into account (health and comfort performance, building costs, whole life costs, etc).

For a designer and engineer (D&E), and from the EE (and also Sustainability) viewpoint, the need is to have comprehensive (account the many variables at stake) and enhanced (with enriched knowledge) EE analysis and simulation services in order to optimize (e.g. by testing alternate design solutions, changing materials, trialling distinct scenarios, etc.) the overall design towards a more suitable design, that presents the optimal EE levels while considering the many competing dimensions under concern.

Realisation Phase: At realisation, the first aspect is the procurement activities, and the need for the establishment of a Sustainable Procurement process, evolving from the typical price and quality criteria to account in the case the EE of purchased materials. Another aspect that is of major importance for the authorities (and therefore for construction stakeholders) is the conformance assessment of a building in view of existing codes and regulations for EE, enabling e.g. the establishment of rankings that would set distinct taxation levels given the level of efficiency, or to adapt building codes and regulations for EE to the specific characteristics and properties of given locations or applications.

Support Phase: From the support phase view point, one can distinguish from two kinds of processes that greatly impact on EE of buildings – Operation and Renovation. From an operation perspective, there is much that the so-called smart buildings can perform to support a more efficient operation, namely by the supervision using networked ambient intelligence and control of building devices and systems to maintain comfort and operative levels while being more energy efficient. Considering Renovation, the important aspect is on how to support the reformation of existing buildings towards being more EE performing thus towards sustainable modernisation and renovation of buildings. Taking into account the targets agreed for 2020 by the European Council in 2007, reducing the energy consumption in buildings is an unavoidable issue to approach in order to fulfil these challenges as stated in the Set Plan (European Strategic Energy Technology Plan). In order to achieve this ambition, one of the most important aims that the European Commission points to in its Communications "Addressing the challenge of EE through Information and Communication Technologies" [43] and "Mobilising Information and Communication Technologies to facilitate the transition to an energy-efficient, low-carbon economy" [43] is the use of ICT among other technologies.

6.1.3 ICT in Building

A recent national report on climate change [44] identified the "diffused sectors", such as transport and buildings, as the main contributors to Greenhouse Gas Emissions in the coming

years. The reduction of energy consumption through the use of ICT as key enabler technology is expected to be about 15% in the medium term, to 2020.

The report estimates contributions to that reduction figure from different technologies and policies emphasizing that ICT tools for the improvement of EE in buildings at a design phase and smart building management systems could have the biggest impact. For that purpose, the R&D targeting the EE in future smart buildings is to be developed around the following fundamental pillars:

"Intelligent" objects: these objects must have embedded electronic chips, as well as the appropriate resources (including potential operating systems or platform such as J2ME) to achieve local computing and interact with the outside, therefore being able to manage appropriate protocol(s) so as to acquire and supply information.

Communications**:** these must allow sensors, actuators, indeed all intelligent objects to communicate among them and with services over the network. They have to be based on protocols that are standardised and open.

"Smart Building Management Systems (BMS) / Energy Control Management Systems (ECMS)" relying on embedded intelligent objects and communications, they are to be new systems characterised not only by improved features (e.g. optimising the equation EE/duration/cost), but being able to communicate by embedding appropriate tags (RFID, etc.), and to improve global monitoring of complex assembling of products and equipments in the built environment. They have to potentially allow dynamic control & (re-) configuration of devices (based on strategies), through new algorithms and architectures for any configuration of smart devices (i.e. any set of such devices being inter-connected) to be able to dynamically evolve according to the environment or change in a choice of a global strategy. Ultimately, networks of such BMC/ECMS are to be the foundations of self-configuring home & building systems for EE, based on architectures where Component-based in-house systems learn from their own use and user behaviour, and are able to adapt to new situations, locating and incorporating new functionality as required, including the potential use of pattern recognition to identify and prioritise key issues to be addressed, and to identify relevant information.

6.2 Evaluation of RTD topics

6.2.1 Specification & Design ICTs

Design Conceptualisation

Despite the fact that this step (prior to the detailed design) is the most important one regarding the impact on the Energy Efficiency behaviour of the project, there is almost no application on the market and very few research is done in that area. Some in-house tools are used by architects or consultants that allow capturing client requirements or express functional requirements that can be turned later on into building layout information and sent to CAD tools for detailed design. They are designed for experts, with limited flexibility and lacking interoperability concerning models and design cultures. Special purpose tools need to be used for energy related issues as they are not covered by mainstream tools.

Detailed Design

General purpose CAD tools are provided by major software companies. Most tools address mainly detailed design, while only few support other design phases. Mature collaboration and concurrent engineering tools for the one-of-a-kind buildings are missing and especially, collaboration platforms should be developed to support concurrent engineering between various stakeholders involved in design and planning. Vertically integrated life cycle design is

still missing due to the lack of sufficiently powerful data models, inadequate interoperability and fragmented design cultures across various disciplines. Guidelines for integrated design are needed to encourage the use of available new technologies and adoption of new ways of working (Information Delivery Manual (IDM)).

Modelling

Building Information Modelling (BIM) has become the key technology for representing data about products within the Architecture, Engineering and Construction (AEC) and Facility Management (FM) industries for design, energy simulations and performance estimation. It's use also in building automation & control is emerging. Ideally BIM consolidates available product data from different sources to provide high quality and up-to-date information about buildings. Thus it has the potential to act as a single point of information that can be used by various applications avoiding time consuming, error-prone and costly re-entering of data. The current use of BIM is mainly for file based data exchange while data sharing using model servers in under early development. The existing data models still miss most concepts needed for EE analyses. Due to limited scope of existing models and lack of supporting tools, expertise on BIM and laborious efforts are often needed to achieve interoperability. REVISITE envisages relatime enregy consumptions data could be integrated into an augumented BIM system.

Performance estimation

ICT tools for performance estimation consist of numerous distinct tools targeting cost estimation, life cycle assessment, simulation of energy usage and indoor conditions, and visualisation of these analyses for decision support. These tools are mostly based on local standards and simple static methods, leading to just basic approximation. Many tools are expensive, laborious to use and require special expertise. The estimation results can vary essentially depending on the used tools. This reduced their reliability and use as conformance criteria in contracts and regulations. The consequence is over- or under-dimensioned building service equipment i.e. increased whole life energy cost or excessive initial investment cost. Research topics in this area are:

- Definition of building energy performance indicators and methods to assess them using available information from various ICT based systems.
- New tools and collaborative platforms must be developed to obtain interoperability and integration among stakeholders for EE buildings design, construction and management.
- A European-wide database of possible technical interventions and their effect in real buildings can also support the cost- and energy effective retrofitting of buildings. Such an ICT system will establish a link between theoretical modelling (from fundamental research and simulation) and experimentations on real buildings

Simulation

ICT tools for simulation consist of numerous distinct tools targeting cost estimation, life cycle assessment, simulation of energy usage and indoor conditions, and visualisation of these analyses for decision support. These tools are mostly based on local standards and simple static methods, leading to just basic approximation. The estimation results can vary essentially depending on the used tools. This reduced their reliability and use as conformance criteria in contracts and regulations. The consequence is over- or under-dimensioned building service equipment i.e. increased whole life energy cost or excessive initial investment cost. Poor integration of BIM-CAD tools, insufficient interoperability between all tools forming the chain of performance estimation, and the lack of appropriate data flows transporting the

required semantic information, lead to a situation where the likely future performance of the building under design is hard to evaluate, especially in the early planning and design phases. Gaps in current practices are not only due to technological barriers such as insufficient ICT means. Already available tools are often not used because of lacking incentives to make additional efforts and to adopt enhanced responsibilities.

Specification & product / component selection

There are limited tools in this space. There are some initiatives to bind sustainable information to construction materials and products in order allowing selection of existing products and component according to sustainable requirements (or Energy Efficiency requirements). An Environmental Product Declaration database exists and this has been done in conjunction with the Sustainable Building Alliance (SBA).

6.2.2 Materialisation

ICTs in this phase are all primarily special cases of the same theme, which essentially involves the management and control of the physical act of materialisation/construction. ICTs in the main focus on timing, costs and contracts. Energy Efficiency and sustainability in general, is an emerging concern. Construction activities account for about 5% of energy used, including construction related transport [45] while construction and demolition waste account for about 22% of all waste [46] . While transport is outside the scope of this review it cannot be ignored that the impact of ICT in this phase will be primarily realised in the logistic arena or waste industry.

‘Decision support and visualisation’, ‘management and control’ and ‘real-time communication’ ICTs are therefore primarily logistical and project management technologies and while as stated the prime energy efficiency gain sits outside the building sector as defined here there will be knock on on-site energy savings that stem from well planned and executed construction tasks.

6.2.3 Automation & operational decision support ICTs

Automated monitoring & control

The existing Smart Meters enable real-time electricity consumption reporting and visualization as well as bidirectional communication with the Smart Grid. Concerning instrumentation in general, many sensors are available to monitor the building conditions or usage from an EE point of view. The most commonly used are for water, electricity, or gas metering. Temperature, wind, humidity, air quality, brightness and luminosity sensors are also available. But depending on the envisaged application, specific sensors with given accuracy are required, that are not still available or at least affordable for a large scale deployment (e.g. convective heat flux sensor). Thus, progress has to be made to develop new kinds of sensors when necessary and, even more important, to decrease costs of manufacturing of the existing range of sensors. In order to optimize workload of gas pipelines and/or of pipelines for district heating, dynamic prices not only for electricity but also for heat / cold / domestic gas will be introduced. This requires, from a technological standpoint, generalized smart meters able to measure, record and visualize all kinds of energy consumption.

For buildings, it exists already automation and control algorithms that include for some of them even functionalities for predictive maintenance. But they are, for the large majorities of cases

- Independent for each building dimension: heating, light, ventilation, air conditioning, micro-generation and corresponding storage systems…
- Hard-coded in the device: it is not possible to update or to modify them by a central control instance

In order to make the next step, it is first of all necessary to develop concrete control strategies that link all building dimensions (Heating, Ventilation and Air Conditioning (HVAC), lighting, energy production and storage…) between them and provide a holistic EE approach at level of the whole building.

To implement such strategies, even when the systems come from different manufacturers, it is necessary to lay in a conceptual way the foundations for more interoperability by, for example, defining modular and scalable system architecture for monitoring, diagnosis and control tools and their interaction and interfaces. We need moreover a commonly shared model that clearly defines roles (one for each kind of device) to which belongs a given set of APIs / services (SOA approach). This kind of work will guarantee that new devices that will emerge in the coming years, like innovative energy-efficient lighting systems or multi-functional dynamic glazing, can be integrated without further problems in the existing algorithms.

The next generation of automation and control algorithms should also take user activities and building usage into account. Weather forecast is also an important element and should be considered for predictive (and not only reactive) control.

Finally, these algorithms must not only manage the building's energy but also the components of the BMS, like for example filters of HVAC devices, in order to provide predictive maintenance functionalities, important for overall ROI considerations, especially in a professional context.

Operational decision support & visualisation

Visualisation of energy use: This topic needs to be further continued, especially through multidisciplinary pilot projects (involving experts in mobility, user interfaces, sociologists, designers, etc.) so as to work on energy efficiency incentives and adequate energy visualisation presentations.

Behavioural change by real-time pricing: New technologies for energy metering and local energy generation will considerably change the customer relationship with the energy providers. The implied change on regulation and business models offer new perspectives and need to be accompanied by new adapted ICT infrastructures.

To improve energy management of buildings, the most detailed level of information is required. Current buildings are often equipped with monitoring systems offering basic indicators (e.g. global consumption at building level), and they lack decision support functionalities. The main envisaged ways of progress on this topic are to increase information granularity, and to add features for benchmarking, decision support, and optimization. In order to progress in this domain the following topics should be tackled:

- Benchmarking tools to assess theoretical models towards data from real operations;
- Establishment of a performance track record database, including accurate building specifications;

- Communities for sharing and ranking energy information;
- Data security privacy;
- Decision-support tools for energy trade between buildings/parts of buildings;
- Energy efficient buildings certification.

There are some running projects in that area, but there is still a need for further experimentation to analyze the actual impact on energy reduction. Further work related to information presentation and content is also needed.

- User motivation and incentives: Small scale research projects are needed for a classification of incentives & triggers per stakeholders in different contexts (e.g. residential, office, etc.).
- Interfaces for energy display: There is also a need to define the most appropriate way to present the energy information. One of the axis of the research is to fine-tune the metrics and units (e.g. kWh versus Euros) used in traditional interfaces (e.g. web based), as well as the information delivery process (e.g. information push). A second aspect is to prototype innovative interfaces and display for energy visualisation; experts in design, ubiquitous yet unobtrusive interfaces, and mobility aspects should all together create the specifications for more intuitive and natural energy displays for buildings.
- Energy awareness impact on user behavior.
- Model-based knowledge management: Impact models explain causal dependencies, mechanisms and potential impacts of ICT on energy efficiency. Parametric knowledge of building energy efficiency related attributes is embedded and managed through building, neighbourhood, and eventually city information models.

Quality of service:

In the HVAC or lighting domain, self-diagnosis systems, which can even use other sensors than those required for the control functionality, already exist for some building equipments. Gas sensors can for example detect a gas leak in a boiler system or production of CO resulting from incomplete combustion. The functioning of sensors themselves can be monitored to a certain extent. Sensors can control the load of their battery and send a warning in case of low level. Communication protocols also include features to detect errors in the data frame sent by sensors. Progress has to be made in the monitoring of the building components which are most important for EE. We need such sensors even for some “passive” building components (does the wall / door / window fulfil its mission as a wall / door / window?) and for the building functions like HVAC, µ-generation of electricity, in order to react quickly in case of malfunction and prevent energy waste. For maintenance relevant devices, this kind of sensors also provide precious information to be used for predictive maintenance scenarios.

Wired/Wireless sensor networks:

The first priority is to develop transmission protocols that satisfy the specific ICT4EEB requirements in terms of reliability, security, privacy, data consistency, and transmission rate for wired (all kinds, including PLC) and wireless transmissions. However sensor networks can have different usages, for example a WSNcould be the starting point to perform an assessment of the building performances. It could also be used to provide more information on user behaviour or static componenets in the context of energy consumption optimisation in Buildings

6.2.4 Resource & Process management ICTs

Inter-enterprise coordination

In Construction Management, one important aspect regarding Inter-enterprise coordination is the Construction planning. There are some specific tools regarding that kind of planning but not a lot a research has been done in that area.

Process integration

Current processes integration is mainly based on digital files that are shared by the different stakeholders that take part in the definition, realization and use of the building. Most of the time, these files are "flat files", without semantic value. They require a human expertise to be understood and treated. At the same time, workflows are manually managed, been the email the main tool to support the interaction among the stakeholders. In order to move towards a better process integration (like server based workflows, which integrates multiple collaboration mechanism, as multimedia documents sharing and live editing, comments annotation…) the main topics are the following:

- Adaptive user interfaces that are able of automatically adapt the user interface of the collaboration environment to the characteristics of the current terminal and to the capabilities, access rights and current context of the user.
- System security: Protection against threats and attacks, as Denial of Service and Intrusion detection, privacy of the members of the community, identity management and trust in service based systems.
- Model Management tools: Multiple actors take place in the building design, execution and operation of a building, but everyone has a specific role that defines what he is allowed to see and edit. Model management tools need to make possible the interaction among this large and dynamic group of stakeholders during the building life cycle and support multimedia contents.
- Integration of synchronous and asynchronous collaboration tools. Although many collaboration tools exist (email, file servers, blogs, social networks, document sharing and life editing …), there is no link among them. All this tools should be integrated in order to share the same configuration data and easily tracing the evolution of the building.
- Natural and multimedia user interface. Natural interfaces mimic typical human-to-human patterns of interaction such as speech, gestures, facial expressions and body motion. Current user interfaces are good for desktop environments, but building sector activities are characterized by the mobility, what makes the use of the keyboard, mouse and conventional screens very uncomfortable.
- Intelligent and multimedia search engines. The large amount of information in multiple formats (text, plans, virtual reality models, photographs, video,…) which is in permanent evolution requires the development of new search engines that are able of recognize the current context of the user of the system and satisfy his information demand with the most accurate data.
- Integration of digital and real worlds. Some technologies, as Distributed Virtual Reality and Augmented Reality, could make possible the integration of the digital information (installations design, simulation results …) with the real world (physic building, stakeholders …).
- Dynamic formalization, management and interaction of business processes implemented through services: This necessitates the transition from business processes to IT applications: modelling of functional and non-functional properties, modelling of mediators to support negotiation; supporting round-trip management of business

processes, supported by simulation of end-to-end business processes based on a multi-model approach.

Knowledge sharing:

There is a real lack of efficient solutions to retrieve existing knowledge. There are limited if at all any mechanisms for the capture, structuring, and propagation of knowledge not only across organisations, but within organisations themselves. At best, some basic file/document management systems exist. There is limited support for interactive training, simulation, etc… The following topics should be explored:

- Education, e- & m-learning: Tools that support and enable continuous learning on energy efficiency solutions and practices within buildings.
- Community forums: These support people in sharing both good and bad experiences with different energy efficiency solutions and practices.
- Catalogues: Intelligent digital catalogues of building products/services. They should contain substantial product/service information (much more than simple geometry) in parametric form.
- Semantic knowledge services and toolkits: Meta repositories (that will provide definitions of, and relationships, and mappings between different energy efficiency related information repositories, knowledge sources and ontologies) and semantic knowledge services and toolkits will be able to modify / adjust / enhance user's queries so as to retrieve the required information from the relevant sources (taking into account, the implicit context of the query).
- Template solutions: Reusable knowledge templates i.e. object with built-in configuration rules and constraints.
- Knowledge platforms: Platforms and services dedicated to energy efficiency knowledge sharing in inter-organisational and inter-community environments

6.2.5 Technical integration ICTs

Technical integration & interoperability

Within a building or a buildings neighbourhood, a wide variety of different technologies, from different vendors and companies, are coexisting. Information exchanged through these technologies is heterogeneous. It doesn't have the same meaning from one system to the other and data are defined regarding each particular technology. Another problem is the lack of a common standardized infrastructure and middleware in order to facilitate System integration. An envisaged way of progress towards a better integration is the definition of a Service Oriented Architecture platform able to communicate with the devices installed in a building (or neighbourhood of buildings). This platform requires the definition of some middleware components behaving like gateways or bridges between it and the multiple installed devices. Finally, and after the global infrastructure has been initialized, the most difficult effort is to define a common vocabulary amongst all the system(s) components, in order to be able to reuse the solution as a generic pattern, in many buildings, ideally working with many kinds of pluggable devices.

Currently, a lot of ICT tools are used along the building life cycle (design and simulation tools, management tools, control and monitoring systems, energy trading systems,…). However, there is a lack of interoperability among them. Although standards exists, there are too much and fully independent standards. The main short term RTD priority is the definition of a common BIM for energy efficiency in buildings, bridging the gap between the building design and the building operation tools. Once a common data model for energy efficiency in buildings is available, the next objective should be development of a unified open

communication standard for monitoring and basic control operation that allows feeding this data model with real time data and their exploitation. This monitoring and control protocol should support also the management of dynamic building components (for example, active windows, shading devices …), in such a way that their energy efficiency parameter in the BIM are automatically updated when their energy performances are changed. Then the next step would be the integration with standards from other domains.

Regarding also communication protocols (Wireless and wired protocols), there are still mainly under development. They need to be harmonised and required still an important standardisation work ((NFC - Near Field Communication, Bluetooth, WiFi, RFID, ZigBee, Z-Wave, en Ocean, PLC, etc.). These technical solutions aim at establishing and managing communication between objects.

6.2.6 Trading / transactional management ICTs

There are very few current realisations in that domain even if this will become crucial point for the next generation of buildings. Buildings are already connected to Smart grids as nodes and thus need now to communicate with the neighbourhood and the grid. The different needs in term of communication / transaction needs are listed according to three different levels, District / (installed) Facilities / Occupants.

District energy management:

With the increasing installation of Renewable Energy Systems on District Level in form of micro-generation devices small-scale producers can provide energy to other customer(s) via the local network (distribution grid), i.e. network operator takes energy from a small-scale producer and distributes it to other end users. The network operator could also use the overcapacity and build reserve capacity connected to the network. Therefore, the establishment of District Energy Management Systems (DEM) is required to achieve coincident demand-supply capacities for electricity or thermal energy (i.e., steam, heating, or cooling) during the most of the year. District Energy Management Systems assist the operators of DEM to distribute the energy to the network of buildings and other large facilities (e.g. hospitals, hotels, apartment blocks etc., where significantly constant energy demands exist). The DEM-operator must ensure that necessary information, e.g. who lives where, which areas are most suitable for integration is compiled, considering building types, user profiles, existing energy supply and network topology, etc

The following topics need to be explored

- Demand Response Capabilities: The operator should provide access to all technological as well as economical data and information of the DEM system. The breakdown for the total energy cost (e.g. heat, electricity, power) must be transparent.
- Performance Analysis and Evaluation: Major difficulties in planning DEM systems are poor information bases characterising the energy demand of the network potentially leading to the use of wrong parameters. In this case the usage of properly developed simulation techniques and complementing tools will provide innovative findings enabling optimal planning and control strategies for DEM systems. Interest in the availability of these tools is being encouraged by new national and international policies associated with reducing carbon emissions from the built environment.
- Load Balancing: The energy co-generation units are often integrated in BMS. They are often used in BMS where an easy access to energy sources (solar, geothermal) is

available and if there is a constant demand for energy during the most of the year. Data characterising the energy-production costs and capacity of the co-generation units should be provided to the DEM-operator. The supply side can accurately be planned and if there is less demand - the output of the energy-production unit can be adjusted or the excessive energy can be sold to utilities.

Facility energy management:

It is essential that the currently existing Building Management Systems (BMS) can easily exchange information with other technical systems and with the different user groups, such as tenants, owners, network operators, etc. In other words, the BMS must be enabled to understand the "context" in which a building is operated. The context is specified by user preferences, energy tariffs, and energy services offered (e.g. maintenance offers & requests). This means that the BMS installed must be capable to effectively represent in real-time the current situation, create awareness about energy consumed and predict future demand/overflow of energy. Systems supporting these functionalities could be named as Intelligent Building Management System (iBMS). Today there are three main short term challenges to be addressed by the research community related to iBMSs development:

- To integrate Building Automation Systems (BAS) with the Internet and enterprise applications;
- To solve the incompatibilities for the integration of BAS among products of different vendors;
- To find a common platform for all the different systems, architectures, protocols and devices to make streamlined integration in an iBMS (e.g. pro-active public display systems, advanced home/room/area automation systems, smart security/access control systems, fire-protection systems, lighting systems, car park management systems, etc.) .

This requires the incorporation of different embedded control technologies for:

- Embedded Sensing, automation & control;
- Real-Time Self Assessment;
- Integrated System Platforms;
- Decision Support Algorithms;
- Secure, Ubiquitous Communication;

Citizen energy management

- User motivation and incentives: Small scale research projects are needed for a classification of incentives & triggers per stakeholders in different contexts (e.g. residential, office, etc.). This research should be conducted through interviews of selected representatives and using panelist methods. The main expected outcome is the best content or package of information needed per stakeholder for energy-efficiency awareness and stimulation.
- Integrated energy visualization tools: Cross-sectors research projects should be launched to create a new generation of integrated energy visualization tools that encompass energy consumed in a comprehensive way (home, travel, office, etc…). These new tools would allow proactive (simulation) and reactive (real-time analysis) functionalities for a comprehensive evaluation of individual carbon footprints, showing the balance between the different consumption uses.

6.3 Summary of current research activities

Climate change, growing demand for energy and depleting fossil-based resources are emerging as a huge challenge for our society. Every link in the energy supply chain, from energy generation and distribution to energy consumption, must be optimized and the construction sector has a major role to play in optimising this chain. Modern Information and Communication Technologies can help us to achieve this goal. Various research projects have been set up, exploring different areas. A selection of these initiatives aligned to the REViSITE taxonomy is provided in the following table. A description of the projects can be found in appendices 11.3.

Table 8. Alignment of building research projects with REViSITE Taxonomy

acronym	Specification & Design ICT'S	Design conceptualisation	Detailed Design	Modelling	Simulation	Performance estimation	Specification & Product / component	Automation & operational decision	Automated monitoring & controll	Quality of Service	Operational decision support &	Wired/Wireless sensor networks	Materialisation ICT'S	Decision support & Visualisation	Management & controll	Real-time communication	ICT'S	Inter-enterprise coordination	Process integration	Knowledge Sharing	Technical Integration ICT'S	Technical integration & interoperability	ICT'S	Facility energy management	District energy management	Citizen (personal) energy management
ADDRESS								●									●									
AIM								●	●				●		●											
Be Aware								●				●	●		●						●	●	●			●
BeyWatch								●	●		●												●		●	●
Building Controls Virtual Test Bed	●																				●					
BuildWise	●						●	●			●	●	●		●						●	●				
CITYNET	●			●	●			●				●					●		●		●	●				
DEHEMS								●	●		●												●			●
DEMOHOUSE	●			●							●															
DigiHome								●	●	●		●	●		●		●		●				●			●
E-ARCHI	●																						●			
eDIANA								●	●		●	●									●	●				
e-retrofit kit	●																				●					
FM Comfort/FM Ware	●							●	●				●													
GINSENG								●																		
GreenerBuildings								●	●		●	●	●								●	●				
HOMES								●	●	●	●	●	●	●			●			●						
HOSPILOT								●	●		●															
I3CON	●			●				●			●	●					●		●		●	●	●	●		●

InPro				●	●	●											●		●	●	●	●				
Intelligent Building Agents								●	●				●													
IntUBE	●			●	●	●		●	●														●		●	●
IRON																	●									
ITOBO	●	●		●				●	●		●	●									●	●				
NEMBES								●	●				●			●										
OPEN meter								●															●			
POBICOS								●															●			
SafetyBIM	●	●		●													●		●							
SemSorGrid4Env								●				●	●	●												
SensoByg								●	●			●	●	●												
SIMUENER								●	●				●													
SmartHouse / SmartGrid	●			●	●																●	●	●	●	●	●
SmartSpace	●			●	●			●			●	●	●			●										

7 ICT DEVELOPMENTS IN SMART LIGHTING

7.1 Characteristics of smart lighting

Lighting is one of the most widely used energy component in domestic as well as industry settings. The key developments in lighting have been towards new lighting technologies that enable energy efficiency. However, ICT developments in making the use of existing and new lighting technology smartly are still novice and present ample opportunities for further R&D projects. We focus on this topic of ICT-led controlling of lighting as part of this report.

7.1.1 Smart lighting

The total lighting energy used depends in addition of the used equipment (lamps, ballasts and luminaires) also on the lighting design and the room itself. The room has an effect on the final lighting outcome since part of the light comes to the working desk through reflections. Ultimate example of this is indirect lighting in which all of the light is reflected through ceiling and walls to horizontal surfaces.

Reducing the wattage of installed lighting system represents only one part of the energy saving opportunity; another part is to minimize the use of those loads using right control system. Lighting control system strategy can be based on predicted occupancy control, real occupancy control, constant illuminance control or daylight harvesting control.

Baaijens showed that energy consumption can be reduced by 44 % in office rooms by occupancy and daylight sensors [48] . Pertola estimated the savings through utilization of daylight to be about 50 % annually and further 10 % savings of cooling electricity [47] .

Lighting control systems can easily be associated with building management systems (BMS). This facilitates the smart integration of the lighting control systems with other technical equipment (e.g. HVAC and blinds). Three levels of integration can be distinguished for indoor lighting control:

- The first level takes into account the artificial lighting alone
- The second level takes into account artificial lighting and its control by external information such as daylighting, occupancy, etc.
- The third level takes into account artificial lighting and deals with artificial lighting plus external interaction with external elements such as HVAC systems and blinds.

7.1.2 Lighting sector energy usage profile

Lighting is a large and rapidly growing source of energy demand and greenhouse gas emissions. In 2005 grid-based electric lighting consumed was 2 650 TWh worldwide, about 19 % of the total global electricity consumption [49] . Global lighting electricity use is distributed approximately 28 % to the residential sector, 48 % to the service sector, 16 % to the industrial sector, and 8 % to street and other lighting. For the industrialized countries national lighting electricity use ranges from 5 % to 15 %, while in developing countries the value can be more than 86 % of the total electricity use [50] .The percentage of the electricity used for lighting in European buildings is 50 % in offices, 20-30 % in hospitals, 15 % in factories, 10-15 % in schools and 10 % in residential buildings [51] .

Directive [52] of the European Parliament and of the Council of July 6th 2005 establishes a framework for the setting of ecodesign requirements for energy-using products. A recast of the directive was adopted on 21 October 2009 [53] . The implementing measures have been

published in form of Commission Regulations (Commission Regulation (EC) No 244/2009 and 245/2009) [58] , [59] . Regulations will gradually phase out incandescent bulbs starting in 2009 and finishing at the end of 2012, give limits for the efficiency of ballasts and stand-by losses and set limits for the efficacy of discharge lamps.

In different studies lighting has been found to be a cost-effective way to reduce CO2 emissions. The Intergovernmental Panel on Climate Change for non-residential build-ings concluded that energy efficient lighting is one of the measures with the largest potential and also providing the cheapest mitigation options. Among all the measures that have potential for CO2 reduction in buildings, energy efficient lighting comes first largest in developing countries, second largest in countries with their economies in transition, and third largest in the industrialized countries [54] .

Life cycle:

The European Lamp Companies Federation has published environmental impact assessment of lamps on their webpage. According to that 90 % of the energy is consumed during the operation. In other phases, energy is consumed as follows: resource 4 %, production 5 % and transport 3 %, and disposal releases 2 % [55]

Preliminary data of Osram on LEDs life cycle assessment show that only 2 % of total energy consumed by LED based lamps is used in their production [56] .

In the life cycle analysis of light sources the environmental impacts are assessed in raw material production, manufacturing, distribution, use / consumption and disposal through fifteen environmental indicators. One of the indicators is the Global Warming Potential (GWP), which is measured in kilograms of carbon dioxide (CO2) equivalents. In the use phase the GWP indicator is measured by the power consumption. In the following the percentage is the GWP impact of the use calculated over the total GWP impact for different light source systems [57] .

- integrally ballasted LED lamp, 93,3 %
- dedicated LED luminaire system, 97,3 %
- ceramic metal halide luminaire system, 98,7 %
- T5 luminaire system, 97,7 %
- integrally ballasted compact fluorescent lamp, 97,7 %
- general service incandescent lamp, 99,7 %.

7.2 Evaluation of RTD topics

Future lighting can be more than illumination, intelligent lighting system can respond for instance to people's sociological, psychological and biological needs. Coloured LEDs or white LEDs with different colour temperature enable the adjustment of the colour of the light according to daylight or the activities of the room or for instance the use of light for effects. The colour and the spectrum of light is assumed to have an effect for instance on the alertness of the user. The major trend in lighting is the use of LEDs, others being energy-efficiency, digitalization.

7.2.1 Specification & design ICT's

Design conceptualisation

The aim of an optimum lighting design is to achieve certain appearances and, at the same time, to fulfil the fundamental physiological and psychological visual requirements and to

ultimately put the whole thing into effect in an energy efficient manner. Lighting design defines the installed power. The power and energy of lighting can be affected also by the control of lighting. The more complex the application is the more modelling and simulation is needed.

In the conceptualisation phase 2D-programs can be used to visualize luminaires and lights. In these programs the light has to be drawn or copied from picture. Two dimensional pictures do not allow the rotation of the picture. Vector graphics can be scaled without to decrease the quality of the picture. 2D programs are, for instance, Photoshop, CorelDraw, Micrografx Designer, Autosketch, ClasrisWorks and Paintshop.

Detailed Design

Several lighting design programmes are available which can calculate illuminances and luminances of the surfaces. Results can be presented as figures, curves or coloured surfaces. Examples of these programmes are DiaLux, Relux, Autodesk, Lightscape, Desktop Radiance, Lumen designer. Two common formats for luminous intensity distribution curves are EULUMDAT and IES. The IES and EULUMDAT are internationally accepted data formats used to describe the light distribution of luminaires. They can be used in numerous lighting design, calculation and simulation programs. IES is originally the format adopted by the IESNA (Illuminating Engineering Society of North America). EULUMDAT is the European counterpart of the IES.

3D programs are, for instance, Vector Works, Autocad, 3Dstudio MAX, Lightscape, 3DStudioVIZ, Compucad, Starda, Rhinoceros, LightWorks Picturemaker.

Modelling

Some lighting design programmes, but not all, can use layouts done with CAD-programmes (DXF/DWG formats). For the modelling 2D or 3D grapics can be imported and there exists also libraries for the texture and surface materials. Of course, they use luminaire libraries. CAD programs are, for instance Autocad, Archicad, Microstation. AutoCAD's file format is DWG (drawing). Data interoperability between AutoCAD and other programs is possible with DXF file format (Drawing Interchange Format of Drawing Exchange Format).

Performance estimation

Lighting design programmes give the relevant photometric values, like illuminance, luminance and glare, and based on the chosen luminaires, installed power (W) and power per area (W/m^2 or W/m^2, 100 x). They often lack the financial estimation. For the energy calculation, info is needed of the operating hours.

Some lighting manufacturers have created their own programs, web-based or downloadable for performance calculations. They can be used to calculate energy consumption, costs, efficiency and/or quality.

Life cycle cost analysis has to be performed for the economic evaluation of different lighting solutions. It means that all cost categories, including initial and variable costs, must be considered over the lifetime of the whole lighting installation. Initial costs are e.g. the cost of the lighting design, lighting equipment, wiring and control devices, and the labour for the installation of the system. Variable costs may include the replacement of the burnt-out lamps (relamping), cleaning, energy, the replacement of other parts (reflectors, lenses, louvers, ballasts, etc.) or any other costs that are incurred. The energy costs of a lighting installation during its whole life cycle are often the largest part of the whole costs.

Simulation

More advanced lighting systems can be controlled by daylighting and presence sensors. With the daylight use the lights are often dimmed down, but not switched off entirely, whereas with presence sensors lights are turned off after a certain delay. With the two variables, daylight and human behaviour, simulation is needed to estimate the energy consumption. The building structure enables further usage of daylight, but at the same time, it can cause undesirable effects, like glare.

Specification & product / component selection

Built-in libraries can have different surface materials and also common office products like chairs and tables. Luminaires can be more integrated in the programme, so that list of luminaires used in the design are available and the list also updates, if luminaire is switched to another luminaire.

7.2.2 Materialisation ICT's

In terms of materialisation we see no specific ICTs for lighting beyond standard ICTs for decision support and visualisation with perhaps some specific ICT devices for real-time sensoring during lighting infrastructure deployment. There may be some specific ICTs for on street lighting (grids)

Management & control

In the materialisation phase of lighting system the first step consists of collecting the performance targets of the lighting system and defining the criteria to assess these performances. It should be verified that the system enables proper operation and maintenance through functional performance testing.

7.2.3 Automation & operational decision support ICTs

Automated monitoring and control

Different control strategies can be utilised with lighting systems like Predicted occupancy control (time scheduling, dusk or dawn control), Real occupancy control, Constance illuminance control, Daylight harvesting.

All the strategies described above can be applied in almost any building. They can be stand alone systems or part of a fully interoperable lighting management system. In case of implemented building management system, the management of the lighting system can be combined with heating, ventilation, air conditioning, security, etc. This type of integrated management system will allow sharing of actuators and sensors.

Operational decision support & visualisation

The building operator should understand the system and optimise its operation (fault detections, maintenance, etc.) The facility manager should understand the performance indicators of the dashboard (energy consumption, running cost, pay back time, etc.) The occupants should understand the control strategies (predicted occupancy control strategy, real occupancy control strategy, constant illuminance control strategy, daylight harvesting control strategy, etc.) and how to use the control system to optimize his/hers visual comfort with an eco friendly behaviour (e.g. remote control, dimmer, task lighting, etc.)

The above mentioned decision steps can be supported with visualisation tools in different steps.

Quality of service

The main issue for the success of integrated solutions in buildings is to define the appropriate communication protocol and the media for the information transfer. BACnet, KNX and LonWorks are building communication protocols. They are capable of integrating HVAC, lighting, fire safety, security functions.

However, DALI (Digital Addressable Lighting Interface) and wireless low power technologies have a certain future regarding lighting control. DALI has been established worldwide as the standard for digital lighting control. It is an open non-proprietary standard that makes genuine freely addressable lighting control a reality (individual, group, and all together). DALI seems to be much easier to install, extremely versatile and much more cost-effective than any lighting control systems already on the market, despite its greater functionality.

Wireless networks or power line communication system (PLC) seem very attractive as they are flexible and less expensive to install. However these solutions have limitations when the lighting system is very large (in buildings over 10.000 m^2) due to signal attenuation, electromagnetic compatibility disturbance, etc.

Wired / Wireless sensor networks

Wireless technologies (low consumption or battery less) may present a new solution to bring the installation cost down and to ensure energy efficiency. Over the past 10 years many new RF solutions have been developed. It is expected that soon a reliable, robust, easy-to-install and secure wireless network technology for connecting devices in buildings will gain market acceptance and substantial shares of new and retrofit installations. ZigBee and Zwave (wireless network protocols) are heading in this direction. Nevertheless they are still not well defined on a semantic point of view. Moreover it does not exist efficient tools to design, install, commission and troubleshoot this kind of technologies.

7.2.4 Resource & Process management ICT's

Inter-enterprise coordination

Contract & supply network management, process planning & scheduling, procurement, Intra-logistics, elements of ERP systems etc

Process integration

Lighting as part of building process should be integrated in other building service systems in all phases; design, materialization and usage.

Knowledge sharing

In commissioning process knowledge is shared during lighting system life cycle. Commissioning is done for the number of different reasons: clarifying building system performance requirements set by the owner, auditing different judgments and actions by the commissioning related parties in order to realize the performance, writing necessary and sufficient documentation, and verifying that the system enables proper operation and maintenance through functional performance testing. Commissioning should be applied through the whole life cycle of the building.

Even if not proper commissioning plan is done, the principles of commissioning could be taken into account.

7.2.5 Technical Integration ICT's

Technical integration & interoperability

BACnet (ISO 14684-5), KNX (ISO 14543) and LONtalk (EN 14908) are standardised building automation systems. In addition there are several not-standardised protocols, which are however largely used. These are, for instance Zigbee, X10, Modbus, Lonworks and Z-wave.

DALI is a digital communication protocol designed specifically for lighting systems. DALI is effective for scene selection and for getting feedback regarding faulty light sources. This makes it very useful to use together with building automation systems where remote supervising and service reports are required. All actuators, controllers and sensors are connected to one single control cable. A DALI-system consists of load interfaces (electronic ballasts), control panels (push buttons), sensors (occupancy sensor) and control interfaces (controller) and gateways (1-10V converter).

7.2.6 Trading / transactional management ICT's

District, Facility and Citizen (personal) energy management

The percentage of the electricity used for lighting in European buildings is 50 % in offices, 20-30 % in hospitals, 15 % in factories, 10-15 % in schools and 10 % in residential buildings. And since lighting is easy and quick to control, it could be used as a resource for energy demand management.

This would need a pre-defined protocol. For instance some lighting loads could be dimmed 20 % without effect on safety, productivity or health.

If citizens are more aware of the relationships between lighting and emissions on energy production, they could be more positive on the "central-operated" lighting loads reduction.

7.3 Summary of current research activities

More than 100 European lighting related RTD projects were identified. However, most of them focus(ed) on topics like light emission technologies (Solid State Lighting), bulbs, luminaires, photonics and related manufacturing methods.

The objective of REViSITE is to identify potentially common RTD topics across several industry sectors, notably Smart Grids, Smart Manufacturing, Smart Buildings and Smart Lighting. Therefore only such projects were selected for closer analysis that address **lighting control**. As a rule "old" projects, that were completed before 2009, were excluded except in a couple of cases where such projects seemed especially relevant. Table 5 shows shortlisted projects regarding ICT development in smart lighting aligned with the REViSITE Taxonomy. A description of the projects is provided in Appendices 11.4. .

The overall conclusion is that very few European RTD projects address lighting control. Therefore some already completed projects have also been included.

Table 9. Alignment of lighting research projects with REViSITE Taxonomy

acronym	Specification & Design ICT'S	Design conceptualisation	Detailed Design	Modelling	Simulation	Performance estimation	Specification & Product / component Selection	Automation & operational decision support ICT'S	Automated monitoring & controll	Quality of Service	Operational decision support & visualisation	Wired/Wireless sensor networks	Materialisation ICT'S	Decision support & Visualisation	Management & controll	Real-time communication	Resource & Process management ICT'S	Inter-enterprise coordination	Process integration	Knowledge Sharing	Technical Integration ICT'S	Technical integration & interoperability	Trading / transactional management ICT'S	Facility energy management	District energy management	Citizen (personal) energy management
CLEAR-UP						●	●		●															●		
EFFICIENT LIGHTING																										
ENRGYSAFE			●		●				●											●						
GREENERBUILDINGS					●				●											●						
HOSPILOT		●				●			●		●	●								●		●		●		
I3CON									●		●	●										●				
IEA- ECBS		●				●														●		●				
IEA - 4E						●														●						
IEA -SHC									●													●				
LITES			●		●		●		●			●										●				
OLED100.EU				●								●										●				
POWERMANSWITCH			●				●		●																	
SEEMPUBS									●	●												●		●		
SMARTCODE		●							●										●			●		●	●	
SSL4EU		●	●				●		●																	

8 LINKS BETWEEN THE 4 SECTORS

Subsequent to the detailed sector centric review of the previous chapters, the following section identifies and focuses on commonalities as well as gaps between the four sectors. This process will inform the impact assessment model/framework and synthesis of deliverable D2.3 and roadmap development of WP3.

Each sector begins with a description of the most important links, as they see them, to the other sectors. Each sector then attempts to describe the linkages aligned to the SMARTT taxonomy, so as to aid cross-comparison. The premise is to identify where sectors can benefit from the knowledge of other sectors or where joint research activities are required to promote ICT enabled Energy Efficiency.

A final consolidated synthesis attempts to identify -

- Possible synergies whereby a sector can benefit from adopting the ICT4EE technologies deployed in another.
- Homogenous RTDs/ICTs where technologies are essentially context independent and where practice sharing might prove the best opportunity for energy efficient improvement.
- Sector specific gabs and improvement opportunities.

8.1 Smart Grids

Smart Grids will allow optimised generation of electricity in small scale distributed energy resources, including CHP, Wind Farms and large scale “traditional” generators such as large coal or gas fired or nuclear power plants. While the main emphasis in this section is the electrical grid, other energy grids are in scope, for example district heating grids, heat re-use etc

Main issues in optimising are the boundary conditions set by the physical transmission and distribution grids, the electricity consumption, and the economical conditions set by the electricity market.

In the following section we will discuss the links between ICTs in Smart Grids and the other three sectors, Buildings, Manufacturing and Lighting. The focus will be on the benefits Smart Grids can derive from the other sectors, and vice-versa, especially in the field of ICT enabled energy efficiency.

Links to Smart Buildings, Manufacturing & lighting:

As one will read in the sections that follow Smart Grids are unsurprisingly at the heart of the ‘smart sustainable society’ vision. From a grids perspective, the most significant linkages can be found in terms of monitoring and control and can be thought of in terms of several hierarchical control loops:

- On the lowest level, households and small industries, energy consumption may be optimised based on contractual conditions, on tariffs, market conditions, and energy balances.
- On Neighbourhood level, the control loops of a relatively large number of households are coordinated and aggregated. Nett energy balances should be negotiated with higher level

control loops, and larger industries are monitored and controlled within the limitations that the energy market imposes.

- On Regional level, all neighbourhood level control loops are monitored and coordinated. Nett regional energy balance should be negotiated with higher level control loops. Relatively large energy generators may be controlled within the limitations that the energy market imposes.
- National level and European level monitoring and coordination similar to the regional level, but operate on a larger scale. Obviously there are several supporting functions required: besides the monitoring and control systems, and market systems, there are simulation systems to do real-time analysis and to calculate offline scenarios to e.g. assess feasibility of new installations or techniques.

In short, at its simplest the smart grid vision will be an augmentation of the existing that will include fixed actors, in essence the built environment (manufacturing and lighting being special cases), and mobile actors, in essence electrical transport. But integrated in a way that enables those actors to operate as both consumers and producers of power i.e. prosumers. These, bi-directional and multi-directional relationships is what drives the level of complexity currently acting as a barrier to the wide-scale implementation of the smart grid vision. It is impossible to think how that vision can be achieved without the permeating use of ICT.

What follows attempts to identify the key intersections between the various actors and the ICTs central to the management of those cross-sectorial relationships. The SMARTT taxonomy is used to structure the categorisation and sharing process amongst the different sectors/partners.

8.1.1 Specification & design ICT's

Smart Grid specification and design requires basic boundary conditions or models from the other sectors, including but not limited to geographical location and spread, energy consumption and production characteristics, and economical parameters such as cost of energy production and cost of delayed or avoided consumption.

At this stage, during the design of Smart Grids, and during the design of upgrades to Smart Grids, mainly information is required from other sectors. This information would typically be across all sectors although the scale of energy exchange would vary. It includes energy demand patterns, or estimated energy patterns and where applicable energy generation patterns and is required for the development of optimisation models, simulation models and control algorithms.

The interface descriptions, to interface between the Grids control systems and the manufacturing control systems, would typically include the technical communication interface, but also the commercial market related aspects, and technical limitations.

8.1.2 Materialisation ICT's

During the materialisation of Smart Grids, very few specific ICT based systems are required, besides the regular systems providing logistic support, basic technical support and elementary test facilities. These systems are all well known and not specific to any of the sectors.

8.1.3 Automation & operational decision support ICTs

The daily operations of Smart Grids require the installation of smart meters in buildings, manufacturing sites, and (aggregated) lighting. Smart Meters are here understood to be the energy exchange meters that have the capability of transmitting energy consumption on a

regular basis. Any logic, including control logic, business logic, and monitoring, is usually done in higher level systems.

The monitoring and control systems are then to be integrated: Smart Grid control systems on each level are to be connected and integrated with home automation systems, building automation systems, ERP or production control systems.

Additional functions to be supplied are (e.g.)

- decision support systems to allow end users (home owners, manufacturers, etc) to make informed decisions on their energy exchange
- methodology to actually verify the effects of Smart Grid processes
- reporting facilities to report on the consumption or production of individual machines

Additional ICT systems should support a new market structure. The development of a market structure that supports relatively small scale and intermittent generation capacity, and that supports Demand Side Management, is being researched in several projects. However the support of this in series of market support systems may be an issue.

8.1.4 Resource & Process management ICT's

The hierarchical structure of Smart Grid components, from the single national control structure for high voltage transport grids through several regional distribution grids and further to great numbers of industries and households, results in enormous amounts of raw measured data. Data aggregation, data storage and data mining techniques are most relevant in this respect.

The exchange of forecast and planning data, as well as the exchange of measured data, is mostly time critical so as to allow real time control. Data definitions and functional specifications of data exchange, data aggregation and data storage should typically be prepared as joint activity over all sectors.

8.1.5 Technical Integration ICT's

In all sectors sensors (Smart Meters, see above) and control instruments need to be installed. The installation of metering equipment will benefit all sectors, in that detailed reports on energy consumption will made available. Local controls should allow the facility (house, building, factory etc) to optimise based on economical (market) factors, on energetical (efficiency) factors or other. Additionally, based on contracts, there could be an option to let the energy supplier, or new players like ESCO's, control the facility. Data abstraction, storage and processing require technical integration standards and protocols to be defined, this is made all the more challenging given a distributed grid that touches different sectors. Nevertheless it is imperative.

8.1.6 Trading / transactional management ICT's

The market structure (see above) will need changing to accommodate intermittent generation capacity, and DSM. There may also be a requirement, or a need, to calculate regional or local price differences to take grid congestion or insufficient local generation capacity into account.

Market interfaces, as well as related decision support, risk management, and financial interfaces need to be integrated into local control systems of e.g. manufacturing plants and buildings.

Recently during discussions in the ICT4EE High Level Event 2010 it was pointed out that there is a clear need for DSOs, RetailCos, ESCOs to balance between aggregated virtual

power plants and energy users. Such balance would have its effects on energy production and consumption, and on market conditions. Obviously energy production, energy consumption and energy market conditions interact and are not independent.

8.2 Smart Manufacturing

Smart manufacturing and products will cross boundaries impacting on many sectors some of which, for example logistics, are not the direct focus of REViSITE. Nevertheless the pervasiveness of ICT within manufacturing as outlined in section 5 and its importance for sustainable operations is unquestionable.

As legislation and consumer demand move towards increased accountability and transparency regarding embodied energy/carbon of products and as energy prices increase, the need for manufactures to efficiently manage the energy intensity of their operations becomes increasingly apparent.

What follows discusses the important role ICT plays and will play in delivering future energy efficient smart manufacturing facilities through intelligent integration with the other 3 projects sectors.

Links to smart grids:

From a provider perspective Smart Manufacturing has an obvious role to play in producing the meters, appliances, transformers and other components that constitute smart grid systems. The design, manufacture and usage of those elements should consider energy intensity and efforts should be made to reduce the embodied energy/carbon of such components. There is an onus on manufacturing and grid operators to collaborate on the echo design of such products with special emphasis on the usage phase of same. The role of ICT in design will be crucial here.

Manufacturing sites are major consumers of energy. Understanding the impact of manufacturing schedules on energy supply and demand will be crucial. Automated monitoring and control that incorporates energy efficiency logic will be paramount in delivering sustainable smart manufacturing. The individual energy consumption of production equipment, sensors, control units and networking technologies have to be understood and considered in delivering sustainable operation at machine and plant level. In short, energy management at the micro has implications at the macro grid level and that needs to be understood.

Within the distributed vision of the smart grid buildings have a unique role to play as prosumers of energy. Manufacturing can be considered a special case of buildings as the sheer volume of energy consumption involved will be crucial to the management of distributed smart grids. Manufacturing facilities also have the potential to operate as middle scale energy producers and to act as storage to the grid via thermal, compressed air and pumped energy storage for example.

Under distributed grid scenarios manufacturing facilities could act as power generators to the grid and the on-site solar and wind capability and patterns need to be integrated with the wider grid. This might not deliver energy efficiency but it would positively impact on carbon intensity of the Manufacturing sector and impact energy efficiency of the grid.

Links to Smart Buildings:

Buildings and the manufacture of building materials/products is the largest contributor to energy consumption and related CO2e within the EU. Manufacturing has an important role to

play in reducing the embodied energy of building materials and sub-components that go into the construction and retro-fit of buildings. Also one must consider that, manufacturing facilities themselves are housed within built environments.

To that point, a significant proportion of energy consumed in manufacturing systems is attributable to supporting infrastructure (HVAC & Lighting etc) in factory buildings. In fact within service environments the energy footprint of the building essentially constitutes the energy intensity of the product/service offering.

There is considerable cross-over opportunity in terms of holistic echo-design ICTs in the planning phase of production systems and the buildings that house those systems. While in the usage phase automation, operational decision support and control ICTs should prove particularly synergetic. In the usage/operational phase there is also opportunity for reduced maintenance or a move to predictive maintenance models that may deliver energy gains through optimal operation.

There are other connections that go beyond the scope of REViSITE for example there is considerable opportunity in ensuring effective sustainable operation in terms of water usage, waste and heat-reuse and these initiatives may result in secondary energy savings say in pumping energy for example. While effective production scheduling might positively impact on energy in the logistical sector.

The connection between manufacturing facilities and the built environment is apparent. With the number of organisations that actively seek building certification testimony to the competitive advantage efficient buildings hold or are destined to hold in the market place of manufactured products.

Links to Smart Lighting:

At a very obvious level manufacturing has a connection in being the producer of lighting products. Solid state lighting is an integral part of the built environments energy strategy and as discussed above there is strong connection between buildings and manufacturing in terms of energy efficient operations. At a very basic level the intelligent control of lighting in manufacturing facilities especially round-the-clock operations will have considerable impact on the energy consumption of manufacturing systems especially when one considers support infrastructure.

At a machine level but perhaps beyond the scope of REViSITE the use of photonics in terms of optical control and lasers has had considerable impact on manufacturing and the energy efficiency of same. In an extension of digital-mock-up prototypes can be created directly from the CAD through the use of laser irradiation. When viewed from this perspective the use of light as a tool in manufacturing processes is quite pervasive from the use of laser welding in automotive production to more complicate photolithography in semi-conductor manufacturing.

However, in the context of ICT4EE the connection between manufacturing and lighting is essentially limited to ‘eco-design’ and ‘automated control’, or ‘decision support’ regarding control, of lighting.

8.2.1 Specification & design ICT’s

The usage of design tools (e.g. CAD) is very similar across sectors. However there are sector specific tools as well as methods which may be applicable and useful in the other sector. It would be important therefore to get a more ‘hands-on’ understanding of the design practices

of same in order to transfer energy efficient best practice. Dissemination of best practice through eco-design journals and other media and forum should be encouraged.

ICTs that support the specification process such as material databases with 'energy-properties' information are to a degree currently utilised. An extension and integration of such databases is one possible area for cross-collaboration. Embodied energy characteristics form the manufacturing sector could be coupled with in the field measurement data from the building or lighting sector, all of which could aid the task of echo-design or operational phase decisions.

Since concurrent engineering is well established in the designing of mechanical products and production systems other sectors (e.g. building sector) could easily benefit from these methods and technologies. Also the PLM concept with underlying technologies such as PDM-systems may help to reduce the identified weaknesses in a vertical integrated lifecycle design. Additionally the adoption of approaches from mechatronic product development may be helpful to support design activities of various disciplines.

Advanced Virtual Reality and Digital Mock-up ICTs used in the product design domain can be utilised to verify a building's design in an early stages, however it is recognised that ICT technology in this space in buildings is already at a sophisticated level, whereby the building is effectively treated as a product.

Sensors, control units and networking technologies although utilised in the usage phase have to be incorporated in the design phase of machine tools and plants in order to build a smart sustainable sensor network that underpins the manufacturing production system.

Simulation ICTs can prove useful in many contexts and phases. For example in interaction with the grid sector, simulation of existing or future energy demand of a production system could be linked to market simulation regarding energy pricing thus informing future strategies. It provides useful insights and provides planning data for both energy providers and manufacturers tasked with improving energy consumption and efficiency as part of the overall design process.

Simulation in terms of embodied energy of a product could be used to represent life cycle energy more realistically. Such simulation could be used to optimise production processes in theory while assessing implications for products. Realistic simulation of waste heat of production equipment will helps to dimension HVAC systems precisely and to investigate heat re-use opportunities in usage phase. Such simulation is akin to the augmented building vision for BIM's.

8.2.2 Materialisation ICT's

Onsite decision support tools or visualisation tools used within the building sector including standard project management or material integrity technologies could be utilised in the manufacturing of 'mega' structures/products (ships, plane construction etc.) Manufacturing in this sense is akin to on-site construction. ICT could aid in ensuring energy efficient manufacture of such structures in an extension of existing real-time project management tools and practices. From a manufacturing perspective materialisation ICTs are in essence context independent and such ICTs are a possible area for cross-sector collaboration regarding tools and practices.

8.2.3 Automation & operational decision support ICTs

Automation and operational decision support and by association control is perhaps the most promising area in terms of generic applicability. For example, there exists a strong link between manufacturing and buildings in terms of integrated control of manufacturing equipment and HVAC. ICT control might ensure service level agreements (SLAs) whereby ventilation or air-conditioning of a factory is dynamically aligned to machine operation. As stated previously context aware ICTs could be used to spin-up down work cells (lights out, or warm down scenarios) or building environments based on user requirements, such technology could be used to manage the trade-off between user preferences and energy efficiency. This topic is a burgeoning area of research and one which addresses various aspects like holistic controlling strategies as well as interoperability and standards.

Smart meter systems so crucial to the smart grid will be produced and used in manufacturing facilities. Individual energy profiles and inference technologies will be crucial in efficiently controlling in-house processes and in controlling the interaction between the facility and its environment via the grid. Effectively smart sensing, integration, interoperability and processing of information, is another area of ICT that is affectively context independent and standard setting in this space needs to be accelerated if not by standards bodies then by best practice proliferation.

In interaction with the lightning sector 'Lights out' scenarios for fully automated production lines with occupancy control for maintenance activity is a simple example of building level energy abatement opportunities. Context aware ICTs could be used for smart control of 'manned work cell' environments in balancing the trade-off between ergonomics, illumination preferences etc with energy usage of the cell.

8.2.4 Resource & Process management ICT's

The manufacturing view is that in the main ICTs in this space are context independent. The efficient use of resources in horizontal processes is of universal appeal. The general consensus would suggest that productivity gains can quiet easily be translated into energy efficiencies but that joint-up thinking and incentive is required and ICTs have a paramount role to play with that regard.

Business process improvement methodologies and supporting ICTs could be utilised in this space also. Sector practices around ERP systems would need closer study to ascertain cross-sectorial leveraging; closer study would also be required to ensure energy efficiency resulted from performance related efficiency through the supply chain.

It is often the case that from an energy perspective another sector is the beneficiary of changed practices and technology, for example process scheduling efficiencies in manufacturing may result in energy savings in the transport sector. ICT can play a part in ensuring a holistic view is taken and credit given where one sector makes changes that result in indirect energy savings in another. It is often the case now that businesses do not compete but rather supply chains or networks compete, this needs to be extended to energy efficiency whereby a life cycle approach to energy consumption and efficiency is taken. The role of policy will be crucial here in incentivising such approaches while ICT will be paramount in ensuring effective, transparent accountability in measuring and reporting on same.

Knowledge sharing repositories should be leveraged extensively in sharing best practices. Virtual collaboration technologies could be utilised and practise shared in order to reduce unnecessary corporate travel, this is a good example of ICT impact on a sector outside the

direct scope of REViSITE and a reason for reviewing collaboration with other initiatives in the transport and logistics space.

Other valuable common ICTs in this space are collaboration technologies. Group-work tools, electronic conferencing, distributed and virtual team systems for process management and information sharing platforms etc

8.2.5 Technical Integration ICT's

Central to the ICT4EE conversation is the subject of interoperability both technical and semantic. Future 'Smart' visions are based on the premise that there is an integrated flow of information that permeates through all sectors and levels of abstraction.

Middleware, inference and prediction algorithms, complex event processing (CEP), communication protocols etc would all play into this space. Again to a degree these enabling ICTs are context independent and agreement on standards is crucial. Whether those standards are realised through traditional models or via more organic methods is open to debate.

An obvious example of value-add integration is that of ERP, EMS and BMS systems that would allow for a holistic management of enterprise energy consumption. Another example is the potential integration of BIM (buildings) and PLM (Digital Factory) ICTs including data regarding energy consumption. This would prove particularly useful in delivering efficient operational designs and decision support throughout the respective life cycles. As BIM technologies are new and mainly file and data-base approaches manufacturing learning's with regard to PLM may prove useful at this stage of development.

As state above automation and operational support ICTs and the technical integration of same will be crucial as holistic energy management of factories needs to consider production equipment as well as technical building services (HAVC, Lighting etc) SCADA and security systems should also be integrated, allowing for truly holistic management that can balance voice of the business and the voice of the environment.

8.2.6 Trading / transactional management ICT's

Innovative trading and transactional ICTs and algorithms will be paramount especially to SME's who are more likely exposed to short-term energy pricing. Real-time and asynchronous communication is crucial to a distributed prosumer based smart grid. As such, technical integration and standards will be central to ensuring the effective and efficient flow of information that will in turn result in the effective and efficient flow of energy.

From district to enterprise to machine level ICTs will be paramount to the efficient and effective management and control of the manufacturing/grid relationship. Real time data exchange between energy providers, markets and factory operational systems (MES, ERP etc) and energy management systems will be vital. Benefit at the grid level comes from effective and efficient load balancing and peak shaving. The manufacturing enterprise may avail of off-peak pricing, more energy efficient operations and possible revenue streams via energy storage and production. Integration of real-time pricing and energy demand data into the forecast and planning aspects of manufacturing ERP systems should yield considerable benefit both economic and environmental. Emerging 'cloud computing' models and open standards may proof particularly advantageous in this space.

At a simplistic level manufacturing facilities will be just another type of 'actor' in a distributed system that will include other commercial buildings, residential buildings, automobiles and even citizens.

8.3 Smart Buildings

There has been a clear statement from the ECTP that the generalisation of "Positive-Energy Smart Buildings" is a key issue that could be achieved by exploring not only Construction RTD topics but also by exploring cross sector topics that may influence the whole Building life cycle. Within REViSITE the other sectors concerned with this achievement are the manufacturing sector, the Electric grids sector and the Lighting sector.

From an ICT / Interoperability point of view, the Construction sector has started to move towards new ways of working. Most of the time, this new way of working is summarised by the acronym "BIM" (**B**uilding **I**nformation **M**odel or **M**odelling).

The notion of BIM is often understood as a synonym for 3D models. But it is more than that, BIM is a building design methodology characterized by the creation and use of coordinated, internally consistent computable information about a building project. BIM makes a reliable digital representation of a building that can be exploited in many views like construction planning, performance predictions, and cost estimations. Different actors (architects, engineers, builders, operators, etc.) of the same project can cooperate to the same model and enrich it of their particular data. This approach, model based, ease the development and integration of multiple services and therefore the development of new innovative business applications (distributed energy production for renewable energy management, storage and peak erasing, enhanced diagnostic and renovation of existing buildings and infrastructures and simulations to assess variants of environmental performance of buildings, tools for dynamic building evaluation at run-time, and allowing optimisation based on multi-dimensions / multi-criteria constraints, etc..). Of course BIM is increasingly used through-out the life cycle of the construction project.

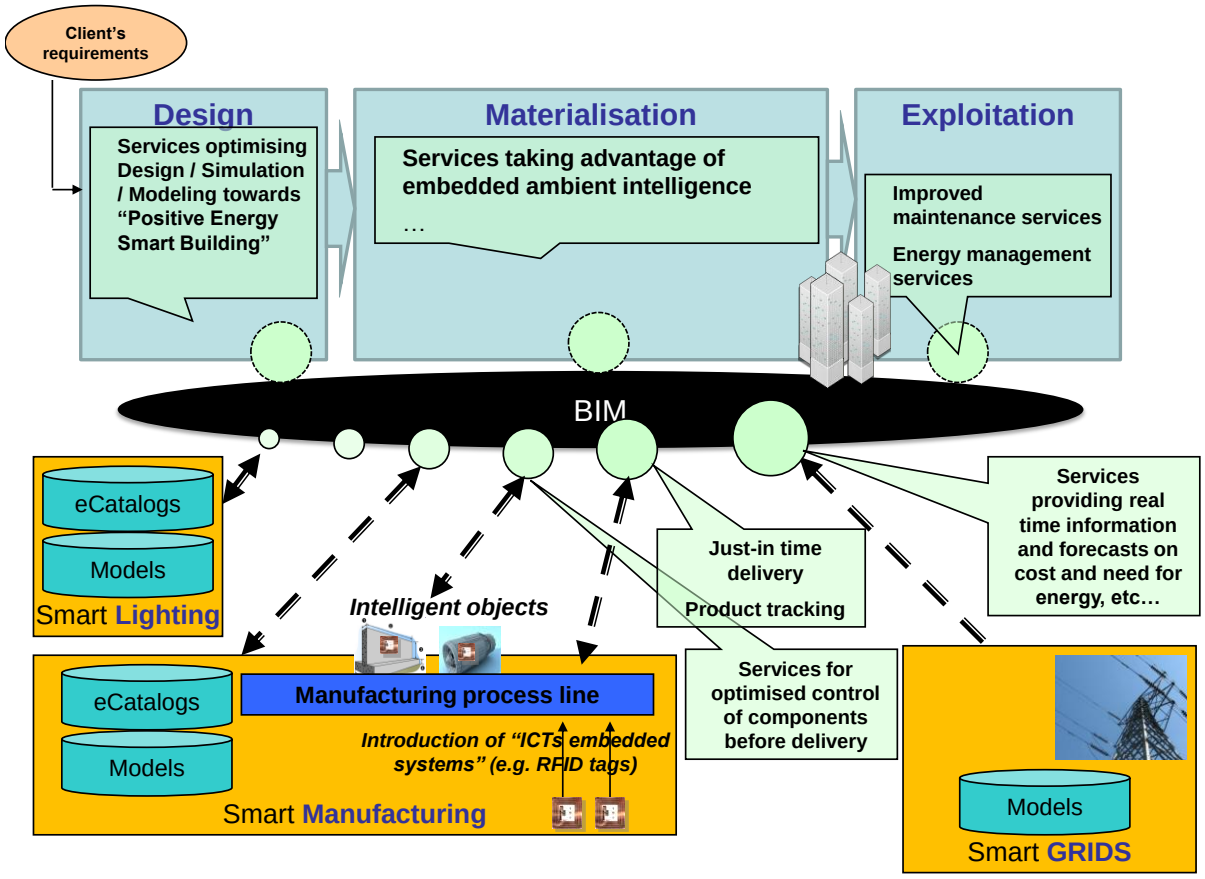


Figure 17. BIM based services & possible interfaces with Lighting, Manufacturing & Grids

Figure 17 illustrates how connections / synergies can be developed from a Construction perspective towards the 3 other sectors and during the different life stages of a Construction project, followed by a narrative description detailing linkages to other sectors, utilising the SMARTT taxonomy.

Links to Smart Manufacturing:

The interaction with the Manufacturing sector can be seen from 2 different perspectives. The first perspective sees the building as a housing or host for a production system and its interconnection as part of a production system (see chapter 8.2). The second perspective is the manufacturing of construction elements which requires very high production temperatures that can only be reached today by the burning of fossil fuels (i.e.: cement, steel, glass). In this case the smart manufacturing offers high potential as an enabler in terms of sustainability and especially in energy efficiency of a building by addressing embodied energy.

Intelligent industrialised production processes in the Construction sector largely involve a complex supply chain – improvement from Smart Manufacturing considering Construction supply chain constraints will have impact in terms of reduction of CO2 emissions. This should lead to the development of tools allowing "flexible manufacturing", standards for supply chain integration and then to the emergence of a fully integrated production process (customised product along with service integration, information management, etc.)

If we set aside the important implications design has on future operations we can say the usage phase (incl. Maintenance and renovation) represent the most important phase in terms of energy consumption of a building. The Manufacturing of intelligent objects with embedded ICT systems in Construction products / elements will facilitate effective and efficient

operations. These "smart products" will include software tools for tracking, logistics, diagnostics, monitoring and control and with encompass modular integration capabilities allowing for "holistic optimisation".

Links to Smart Grids:

As state above 80% of energy consumption of a building occurs is during the "exploitation" i.e. usage/operational phase, corresponding to the normal use or occupancy of same. Therefore, there is during this life cycle stage an important potential to improve the energy profile of the building.

Future buildings will be positive-energy buildings, there is a need to integrate them into the energy grid as potential active nodes (supply of energy) and to develop as well ICT-based NMS (Neighbourhood Management Systems) taking into account these new generators.

The other link to establish is the interaction between the energy grid and the consumer by the development of specific devices (Home energy controlling internet system and interactive home devices) and services (pricing policies, adaptive forecast, etc…) in order to help consumers to manage is Home Energy Consumption according to the information sent by the Smart Grid. The use of smart metering, decision support and visualisation ICTs coupled with embedded control ICTs, throughout the control loop levels as described in section 8.1, will be paramount. Without the effective flow of information there will not in turn be the efficient flow of energy between buildings and the grid.

Links to Lighting & Photonic:

It is considered that about 12% of energy consumption in buildings is due to lighting. This figure increases in the non-residential building sector. The smart integration of new lighting technology (high performance technology) and devices (e.g. intelligent LED solutions) in Smart Buildings could contribute to significant reductions in that 12%. To facilitate such integration, links have to be developed between both sectors (Construction & Lightning) to provide enriched models of new and efficient lightning devices in order to take into account these new systems since the design phase of a building and also specific packaging have to be proposed in order to facilitate the replacement of existing systems or devices by new energy efficient ones.

From an ICT / Interoperability point of view, the Construction sector has started to move towards new ways of working. Most of the time, this new way of working is summarised by the acronym "BIM" (**B**uilding **I**nformation **M**odel or **M**odelling).

8.3.1 Specification & design ICT's

The design phase is highly important given decision will be taken that will profile the energy consumption of the building for the rest of its life cycle. At this stage, it is crucial to be able to perform analysis based on the digital representation of the building. The better the model is, the more accurate the results of these a priori analyses will be. Therefore the needs for shared models (geometry, materials, HVAC systems, lighting systems, embedded energy, etc.) and communication buses or interoperability among sectorial solutions (i.e PLM/PDM based on Smart Manufacturing side) are of high importance.

8.3.2 Materialisation ICT's

The materialisation phase in construction has a limited impact regarding the energy consumption of the building life cycle. Energy Efficiency is still an emerging concern. However, Processes in the Construction sector largely involve a complex supply chain. Therefore improvement in the Manufacturing and construction relationship considering supply chain constraints will have impact in terms of reduction of CO2 emissions. This should lead to the development of tools allowing "flexible manufacturing", of standards for supply chain integration and then to the emergence of a fully integrated design and production process (customised product along with service integration, information management, etc.). Standard project management ICTs that indirectly save energy due to just-in-time material supply etc could be utilised in other sectors, although it is recognised this is a common area of focus within manufacturing supply chains already.

8.3.3 Automation & operational decision support ICTs

From an energy efficiency perspective, the exploitation of a Building is an important phase. For instance, it is considered that about 12% of energy consumption in buildings is due to lighting. This figure increases in the non-residential building sector. Strong interactions have to be developed for the smart integration of new lighting technology (high performance technology) and devices (e.g. intelligent LED solutions) in Smart Buildings as well as systems for the integrated manufacturing (e.g Intelligent objects with embedded sensors). The literature would suggest the use of HEMS devices could save as much as 19% through behavioural change although it is more likely that this level of saving would be achieved when decision support and visualisation was also coupled with automated actuation and control. The use of sensors, wired and wireless networks, smart metering and control as well as decision support and visualisation is effectively a universally applicable area of focus, with smart metering being central to the smart grid vision.

8.3.4 Resource & Process management ICT's

The level of interdependency involved in achieving the smart society vision is such that collaboration between Grids, the manufacturing and the built environment is paramount in order to achieve better energy management of the system as a whole:

Grid need to provide new energy contract, better accuracy about information on the planning of electricity generation, based on short term and long term consumption forecasts (taking into account new buildings as potential energy generators) , as well as planning of maintenance in grids and equipment;

Manufacturing needs to develop "Advanced scheduling algorithms in MES & ERP" and when the construction sector is concern, taking these constraints into the construction process.

Construction needs to develop gateways between process integration solutions form the manufacturing sector (general use of RFID for instance).

And all sectors can benefit from standard collaboration and process management ICTs such as virtual/distributed team work tools, teleconferencing systems, information sharing and workflow management systems.

8.3.5 Technical Integration ICT's

BIM interoperability relies at the technical stage on standards that provide the necessary pillars for an efficient interoperability. Bridges have to be developed from Construction/BIM standards towards Lighting/Grid/Manufacturing standards. Middleware, data abstraction, inference and data mining-processing technologies will be central, while the role of standards both technical and semantic of same cannot be over-emphasised

8.3.6 Trading / transactional management ICT's

The integration of Buildings as active nodes in the energy Grid will become a reality. To achieve such vision, links have to be established with the existing technologies in use in the smart grid domain (MMS / DMS /EMS). The various implications and use cases from a building perspective have been adequately expressed in section 8.2 and 8.2.6

8.4 Smart Lighting

Links to Smart Grids:

Lighting interacts with smart grids via intelligent lighting control which is typically an integral part of building (energy) management systems. In this sense lighting is not essentially different from other building services. With the emerging new light emission technologies (SSL), also outdoor lighting will become more flexibly controllable, whereby new control systems will be needed. Lighting can respond to load reduction requests from the grid e.g. via partial dimming.

Links to Smart Manufacturing:

As the producer of lighting devices the manufacturing industry needs to provide information regarding embedded energy, performance, inter-connectivity and usage & maintenance instructions. This requirement is widely applicable to all manufactured products.

Proper design of luminaires can significantly improve the lighting efficacy (~proportion of light from the bulbs actually emitted by the luminaire) and reduce the amount of waste heat that would potentially need to be cooled.

As the user of lighting in its production facilities the manufacturing sector needs to operate lighting similarly as in buildings.

Links to Smart Buildings:

In buildings lighting needs to be controlled in a holistic way together with other subsystems, mainly HVAC. Lighting control exploits information from sensors (e.g. user presence, daylight) and security / access control systems.

8.4.1 Specification & design ICT's

Information about smart grid services influences selection of the lighting control system concept. The detail design of lighting control system needs to be adopted to the transactional protocol with the grid.

Generic requirement management tools, product libraries and some CAD tools are adoptable to all sectors for the design stage. PLM/PDM technologies from the manufacturing sector are potential to the building (incl. lighting) sector for enabling a smoother transition from document-based to model-based (BIM) approaches.

Advanced model-based CAD tools and intelligent product libraries, including semantic data, are applicable to all sectors. These need to be enhanced with sector-specific data related to energy efficiency and performance. At the same time, there is a need for convergence of standards for semantic data in order to enable cross-sectorial communications.

Holistic building simulation is needed to estimate energy consumption. Key aspects for lighting are user presence and daylight availability. Analysis of lighting may lead to more optimal design of the building layout.

8.4.2 Materialisation ICT's

Similarly as for buildings, tools are needed to visualise the status of building process during construction, including its subsystems (such as lighting), components, and work in progress. Visualisations can be e.g. 3D/4D/VR models derived from BIM, bar charts, flow-line schedules etc. A construction specific aspect is to the support allocation of working space for different teams inside the building that is being built.

Lighting control is integrated with the building management system. Tools and methods are needed for performance testing of the lighting system, under different interactions with the smart grid, and validation of conformance to requirements and design specifications.

No lighting-specific needs for real-time communication are identified.

8.4.3 Automation & operational decision support ICTs

The control of lighting system needs to be integrated with other building subsystems, all supporting responses to smart grid signals. Similarly, in manufacturing environments the control of lighting needs to be integrated with the production system. New system architectures of all smart systems are anticipated in order to enable industrialisation via modular composition and re-configuration of systems reducing the need for custom design and re-design.

Operators and users (of e.g. buildings) need interfaces that integrate information of various systems (e.g. grid, HVAC, lighting). In order to support decision making these should make use of consistent performance indicators and labelling across different sectors and subsystems.

System integration and quality of service need to be improved by harmonisation of different communication protocols, bridges/gateways between them, secure communications for external services (via Internet), common WSN infrastructure, communication between emitting devices & measurement collectors and back office systems.

8.4.4 Resource & Process management ICT's

ICTs for inter-enterprise coordination and process integration are similar as in construction and many other sectors: management of business relations, communication, information flows and collaboration between stake-holders, planning & monitoring work in progress, status of deliveries and on-site assembly etc. Examples of useful ICTs are: collaboration and groupwork support tools, electronic conferencing, distributed systems, work flow management systems, information sharing platforms etc.

Knowledge sharing and industrialisation can also be supported by similar tools as in other sectors such as product libraries including data about embedded energy and the performance of components.

In construction (including lighting) there is a need to increase the semantic level of data (BIM), make it openly available to different enterprises, while improving IPR protection. A

possible development into this direction could be to provide "intelligent" object libraries with embedded but protected / encrypted knowledge + certification.

8.4.5 Technical Integration ICT's

The obvious need to harmonise and standardise automation and energy trading protocols applies to all sectors. In construction (including lighting) there is a need to improve the "BIM-compliance" of ICTs for all life cycle stages and to enhance current BIM definitions with EE related data. On the other side, there is a parallel need for more flexibility between different levels of semantic richness such as "graphics-based" (mainstream CAD) and "model-based" (BIM) approaches. This could be achieved by adopting elements of PDM/PLM technologies from manufacturing.

8.4.6 Trading / transactional management ICT's

Also in this area lighting can be regarded as part of integrated systems for buildings or production facilities with no lighting-specific requirements.

9 CONCLUSIONS

This report has reviewed ICT developments and potential energy efficiency impacts in the four focus sectors: Smart Grids; Smart Manufacturing; Smart Buildings; and Smart Lighting. An overview of the state-of-the-art in each sector has been developed by domain experts within the REViSITE consortium supported by the REViSITE Expert Group, a dynamic panel of ICT for energy efficiency experts drawn from industry and academia. The ICT developments of each sector are structured according to the REViSITE SMARTT taxonomy developed previously by the consortium and described in Deliverable 2.1. Once completed, the domain experts reviewed all the sector overviews and developed a synthesis across all four sectors. In particular this focussed on the synergies, homogenous RTDs/ICTs and gaps between their sector of expertise and the other sectors under investigation. What follows attempts to synthesis the main themes.

9.1 Conclusions on the synthesis of ICT developments across the four sectors

ICT for assessment

REViSITE has found it particularly useful to think in terms of the life cycles phases of the target sectors. Doing so provides a recognisable backbone to common assessment. Life cycle analysis is an ICT supported process and the principle means of accurately understanding the impact of ICTs at a product level. However it is an in-depth, specific, direct impact analysis. The REViSITE study identified no commonly recognised means for quantifying the energy impact of an ICT on the system in which it is deployed i.e. in considering enabling impacts.

When dealing with enabling impacts and where direct measurement is not possible current practice utilises qualitative assessment and the REViSITE approach offer one means for such assessment. Such approaches need to act as foundations for what is perhaps the most obvious RTD topic, the development of ICTs for quantitative impact assessment. Such developments would offer valued guidance for decision makers from consumers to policy makers.

ICT for Design

Design ICTs are pivotal and much like in the case of buildings decisions made at the design stage have profound implications for energy efficiency of all other life cycle phases within all the sectors. CAD applications and augmentations are prevalent across the sectors. There may be synergies here in terms of technologies such as BIM or PLM, which seek to build holistic information systems, databases and applications around the basic visualisation of the physical in order to make decisions right through the life cycle phases.

There needs to be greater learning based feedback mechanisms back into the design process of both products and processes. The use of ICT will be pivotal here with operational visualisation, inference technology and automated control all playing a role in terms of building energy intelligence back into the design process.

ICT for automated monitoring/control and operational decision support

Within REViSITE we have identified the need for actors to Sense, Understand, Decide and Act in energy conscious ways. Wired and wireless sensor ICTS offer significant potential in aiding the first step of that learning process, 'sensing'. Such ICTs should be utilised in the monitoring of energy consumption from district level down to individual home and citizen level. In terms of 'understanding' HEMs, BMS and FMS systems are particularly relevant also, as are decision support and visualisation ICTs. However technology cannot 'go-it-alone' here and decision support and visualisation ICTs should be based on cognitive work analysis (CWA) and other behavioural sciences practices that ensure the value of ICT is appropriately channelled.

In an extension of the 'understanding' step and moving towards 'deciding and acting' intelligent energy based algorithms, smart controlled actuation and control is pivotal to maximising potential energy efficiencies by automating those behavioural elements and choices that can be taken outside the human decision loop. At a residential and communal level, an emerging RTD trend that may significantly augment traditional automation and control is 'context aware' technologies. Such ICTs can intelligently control traditional energy intensive infrastructure and devices based on personalised preferences, ensuring an optimal 'sweet spot' is maintained that balances the consumer preference and collective sustainability goals.

ICT for trading

An extension of the smart monitoring and control theme is the intelligent management of the economic transactions and trading that will underpin future distributed flow of energy resources. The European vision is for a 'smart sustainable society' that includes the economic, environmental and social sustainability of its citizens. Inclusive growth at the macro level will rely on the intelligent trading management of existing, new and yet to be conceived business models and this must be balanced with the responsible, optimal and sustainable utilisation of energy resources. ICT will again be central to the information network and the sophisticated management and security of energy information from the macro to the citizen level. Key enablers like cloud computing (private, public and hybrid models), service orientated architectures and automated service level agreements will again be pivotal. While again, context aware ICTs can offer possible individualised augmentations to automated transactional models.

ICT for interoperability

A horizontal and central theme through-out the sectors and the life cycle phases of the sectors, is technical and semantic integration, standards and protocols. Technical integration will be essential in realising the EU vision but also poses significant challenges in integrating the various formats, protocols and standards involved in delivering on that collective sustainable vision. ICTs like middleware, gateways, complex event processing, automated decision engines/algorithms and service orientated architectures are particularly significant in delivering the intelligent 'back-office' infrastructure that that in-itself supports the realisation of smart energy grids. In essence to achieve a smart grid we need to deliver an integrated smart information network and the general purpose technology that is the 'Internet' will play a crucial role.

9.2 Conclusions on ICT themes for energy efficiency

A number of themes and gaps have been identified as being critical to energy efficiency in the four sectors:

- Technical Interoperability & standards
- The importance of design 4 EE in all sectors
- The gap in clearly defined metrics or indeed methods for quantitative assessment.
- The difficulty in substantiating the casual connection between RTD themes
- The usefulness of the REViSITE SMARTT taxonomy and approach in terms of a common framework from which to guide more quantitative analysis
- The importance of data visualisation and decision support particularly in the 'usage' phase of each sector
- The links between such data visualisation and cognitive and behavioural science

9.3 Recommendations for Task T2.3 – Impact assessment model for ICT for energy efficiency

Section 9.1 looked to a synthesis of the common ICT4EE trends and potential synergies identified in the target sectors. Deliverable D2.3, which follows this deliverable, will aim to analyse, in more depth, those themes and associated ICT/RTDs identified within the D2.2 review. ICT/RTDs deemed to offer the most potential for positive impact on energy efficiency/consumption will be further qualitative assessed will utilising an adapted Capability Maturity Model/framework to quantify the qualitative assessment. In doing so it is envisaged REViSITE will identify clear trajectories for RTD roadmap development by gaining greater understanding into the impact of various ICTs and the causal relationship through the sector life cycle phases.

9.4 Implications for Task 3.1 - Vision for multi-disciplinary ICT-enabled Energy Efficiency

The findings from this deliverable provide us with solid foundation to set up the vision for multi-disciplinary ICT based energy efficiency which will be developed within D3.1. The analysis of the sector specific ICTs and RTDs in this deliverable will be cross checked with the sector specific visions elaborated in part 1 of D3.1. Similarly, the concluded cross sectoral ICT themes identified from this deliverable will be used as an additional validation mechanism for the vision for cross sectoral ICT-enabled energy efficiency to ensure that the developed vision is in line with the latest trends in ICT uptake

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11 APPENDICES

11.1 Research projects in Smart Grids sector

Acronym	Title	Description
ADDRESS	Active Distribution network with full integration of Demand and distributed energy RESourceS	ADDRESS researches, develops and deploys technologies and processes to increase usage of distributed generation and renewable energy resources. The project aims to develop new innovative architecture for Active Distribution Networks (ADN) that is able to balance power generation and demand in real time. This allows network operators, consumers, retailers and stakeholders to benefit from the increased flexibility of the entire system. Innovative use of communications, automation and household technologies combine with new trading mechanisms and algorithms, providing ADN with low cost and reliable solutions. The secure and reliable operation of the distribution networks must also take into account distributed generation, energy storage systems and large customers connected at the MV level.
DLC+VIT4IP	Distribution Line Carrier: Verification, Integration and Test of PLC Technologies and IP Communication for Utilities	DLC+VIT4IP will develop, verify and test a high-speed narrow-band powerline communication infrastructure using the Internet Protocol (IP) which is capable of supporting existing and extending new and multiple communication applications. These shall include the existing power distribution network for novel services in smart electricity distribution networks such as demand side management, control of distributed generation and customer integration.
E-Price	-	The E-Price project focuses on the real-time power imbalance in the power net, which arises as a consequence of errors in the prediction of both production and demand. As this power imbalance will increase both in size and in frequency, presents arrangements to cope with this imbalance are no longer valid. They are neither reliable nor economic anymore. This project proposes an advanced ICT and control framework for ancillary services (reserve capacity) which allows a more intelligent solution by giving consumers and producers clear, real-time financial incentives to adapt their consumption/production according to the actual needs of the power system. This design is based on a distributed control structure, enabled by a fast ICT infrastructure and advanced control theory to reliably and economically deal with the necessary ancillary intelligent ICT and control.

Acronym	Title	Description
HiPerDNO	High Performance Computing Technologies for Smart Distribution Network Operation	Future electricity distribution networks with mass deployment of network equipment sensors and instrumentation, millions of smart meters, small-scale embedded generation, and responsive load will generate vast amounts of data requiring near to real-time analysis. So-called cloud and grid computing will enable scalable data mining, feature extraction, and near to real-time state estimation. These and other HPC tools and techniques have been recently developed to cost-effectively solve large scale computational challenges in areas such as genomics, biomedicine, particle physics and other major scientific and engineering fields that require similarly scalable communications, computation and data analysis. Based on such recent success it is the aim of this research project is to develop a new generation of distribution network management systems that exploit novel near to real-time HPC solutions with inherent security and intelligent communications for smart distribution network operation and management. Cost effective scalable HPC solutions will be developed and initially demonstrated for realistic distribution network data traffic and management scenarios via off-line field trials involving several distribution network owners and operators.
Inovgrid		The InovGrid project addresses the technical architecture that is being developed for the implementation of a fully active distribution network. It is based on a multi-level hierarchical architecture, capable of dealing both separately and in an integrated way with commercial and technical information, where the infrastructure includes several components from Central and SCADA system to Energy Boxes. The Inovgrid project is a step towards the smart grid paradigm, giving support to all new smart metering and commercial processes recently defined by Iberian energy regulators and allowing, at the same time, increases in operation flexibility and efficiency, grid reinforcement cost reduction, improvement of quality of service, and others, while keeping costs down. The project will in stages connect more than 6 million customers in Portugal, bringing benefits for all stakeholders and also contribute to changes in energy consumption behaviors in order to successfully address the energy efficiency European requirements, as stated in the European Service Directive and subsequent local countries initiatives.

Acronym	Title	Description
Integral		The INTEGRAL project aims to build and demonstrate an industry-quality reference solution for Decentralized Energy Resources (DERs) aggregation-level control and coordination, based on commonly available ICT components, standards, and platforms. To achieve this Integrated ICT-platform based Distributed Control (IIDC) solution, the project will take the following steps: 1. Define Integrated Distributed Control as a unified and overarching concept for coordination and control, not just of individual DER devices, but at the level of large scale DER/RES aggregations. 2. Show how this can be realized by common industrial, cost-effective and standardized, state-of-the-art ICT platform solutions. 3. Demonstrate its practical validity via three field demonstrations covering the full range of different operating conditions including normal operation, critical operation and emergency operation.
Integris		INTEGRIS project proposes the development of a novel and flexible ICT infrastructure based on a hybrid Power Line Communication-wireless integrated communications system able to completely and efficiently fulfil the communications requirements foreseen for the Smart Electricity Networks of the future. This includes encompassing applications such as monitoring, operation, customer integration, demand side management, voltage control, quality of service control, control of Distributed Energy Resources and asset management and can enable a variety of improved power system operations, some of which are to be implemented in field trials that must proof the validity of the developed ICT infrastructure. Focus is on interoperability of the PLC, Wireless Sensor Network and Radio Frequency Identification, technologies that together are able to achieve the indicated goal with reasonable cost. The system will require an adequate management system that is also an objective of the project. Such system will be based on beyond the state-of-the-art cognitive techniques to provide the system with the adequate flexibility, scalability, availability, security, enhanced system life-time and self healing properties as is necessary in complex and dynamic systems.
Miracle		The MIRACLE project's main goal is to develop a conceptual and infrastructural approach that allows energy distribution companies to efficiently manage higher amounts of renewable energy and balance supply and demand. Currently, most renewable energy sources (RES; e.g. windmills, solar panels) pose the challenge that the production depends on external factors, such as wind speed and direction, the amount of sunlight, etc. Hence, available power from RES can only be predicted but not planned, which makes it difficult for energy distributors to efficiently include RES into their daily schedules. As an unfortunate consequence, power from RES often has to be given away for free due to a lack of demand.

Acronym	Title	Description
Open Meter	-	the OPEN meter project will carry out the activities resulting in identifying and filling the knowledge gaps necessary to enable the relevant industries to agree, implement and embrace the new set of international standards specified. This is to be based on a completely open and public solution for AMI. The OPEN meter project will take advantage of the existing International and European standards, technologies and solutions, adapting them to the specific needs of AMI wherever possible, and carrying out the research and technological development activities where necessary. This will minimize the time needed for the adoption of the standards while ensuring the cost-effectiveness of the solution. As the OPEN meter Consortium comprises world-wide leading electricity, water, gas and heat meter manufacturers, alongside with some of the largest multi-utilities in Europe, the support of the majority of the relevant stakeholders in the area is ensured. Furthermore, the participation of CENELEC as a member of the Consortium guarantees the support for the dissemination and standardization activities that are necessary to make the OPEN meter the definite European set of smart metering standards.
Open Node	-	The OpenNode project will especially focus on inner parts of the distribution grid, namely the smart Secondary Substation Nodes (SSN) as substantial component to monitor and control the distribution grid status. Based on Information and Communication Technology (ICT) the three challenges will be addressed by a network of embedded devices – the SSNs – capable of communicate to each other and contribute to the efficient exploitation of the energy resources. OpenNode project will focus on research and development of (1) an open secondary substation node which is seen as an essential control component of the future smart distribution grid, (2) a Middleware to couple the SSN operation with the Utilities systems for grid and utility operation and (3) a modular communication architecture based on standardised communication protocols to grant the flexibility required by the stakeholder diversification and to cope with massively distributed embedded systems in the distribution grid. Developments will be guided by an initial analysis of requirements and definition of the overall architecture and interfaces together with the detailed description of the use cases leading to the technical demonstrations.

Acronym	Title	Description
Rempli	Real-time Energy Management via Powerlines and Internet	The overall goal of the REMPLI project is to design and implement a communication infrastructure for distributed data acquisition and remote control operations using the power grid as the communication medium. The primary target application is remote meter reading and SCADA (supervisory control and data acquisition) with high time resolution, where the meters can be energy, heat, gas, or water meters. Based on the availability of fine-grained energy consumption data at the end user's site, this benefit applies to both utilities and customers, since they gain more detailed information about how energy is consumed.
W2E	Web to Energy	The unbundling of the energy market requires new business models and new integrating technologies to optimize the economy of the whole value chain. To realize the Europe-wide electricity network of the future, a crucial ingredient is an open, universally accessible and standardized ICT communication infrastructure. All market participants shall be provided with required information without discrimination. The project WEB to Energy (W2E) aims to develop this open, universally accessible and standardized ICT communication infrastructure.
Smart House	Smart House	The SmartHouse/Smart grid project introduces a holistic concept for smart houses situated and intelligently managed within their broader environment. It develops intelligent networked ICT technology for collaborative technical-commercial aggregations of Smart Houses able to communicate, interact and negotiate with both customers and energy devices in the local energy grid so as to achieve maximum overall energy efficiency as a whole.

11.2 Research projects in Smart Manufacturing sector

Table 10. research projects in sector Smart Manufacturing

Acronym	Title	Description
ActionPlanT	European Forum for ICT in Factories of the Future	This analysis will consider technology and business trends as well as policy, environmental, and societal needs. The threefold objective of ActionPlanT is therefore to come up with an ICT-enabled manufacturing vision for use cases and services of the future using this analysis as a basis. Secondly, this vision would pave the way for a detailed roadmap which will prioritise and schedule most promising topics for the upcoming Framework Programme 8. Finally, within the scope of ActionPlanT, a concept for industrial learning will be developed, validated and extensively piloted via summer schools and workshops amongst stakeholders in industry, academia, and the relevant European Technology Platforms.
AMI-MOSES	Ambient-intelligent interactive monitoring system for energy use optimisation in manufacturing SMEs	The AmI-MoSES project will develop an (ambient) intelligent monitoring system for energy consumption, dedicated to manufacturing SMEs, to provide comprehensive information about the energy use, and knowledge-based support for improvements in energy efficiency.
ATKINS	ATKINS – Rapid Manufacturing a Low Carbon Footprint	The aim of ATKINS is to fundamentally migrate the design, manufacturing and distribution of goods and components away from the high energy-intensive methodologies that we use today to a more sustainable method of production, service and distribution to the consumer. This low-carbon design, manufacturing and service philosophy will be enabled by the unique characteristics of Rapid Manufacturing (RM).
BEAT	Ganzheitliche Bewertung der Energieeffizienz alternativer Technologieketten *Holistic evaluation of the energy efficiency of alternative technology chains*	The aim of the project BEAT is the development of a software tool that helps companies with the selection of the most efficient technology chain, considering the real energy and material flows of individual process steps recorded and assigned to their originators.
CO2PE!	Cooperative Effort on Process Emissions in Manufacturing	The project coordinats international efforts to document, analyse and improve the environmental footprint for a wide range of available and emerging manufacturing processes with respect to their direct and indirect emissions.
DEMI	Product and Process Design for AmI Supported Energy Efficient Manufacturing Installations	The aim of the project is to enhance existing product/process design systems with features that will enable engineers to collaboratively design energy efficient and ecologically optimal discrete manufacturing processes, and generate appropriate extended monitoring and decision making services to support manufacturing installations to ensure optimal ecological impact over the process life cycle.
E-Klic	E-Klic	The Project aims to study, design, develop and experiment an advanced ICT-based service to support Manufacturing SMES in achieving supply chain optimisation.

Acronym	Title	Description
EnEffAH	Energieeffizienz in der Produktion im Bereich Antriebs- und Handhabungstechnik *„Energy efficiency of drive- and handling technique in production "*	Project goal is to develop methods, tools and products in order to ensure an energy efficient automation. Pneumatic and electric drive technologies and the use of these technologies for handling and robotics will be considered.
EnEffCo	Energie-Effizienzcontrolling am Beispiel der Automobilindustrie *„Energy Efficiency Controlling the example of the automotive industry"*	The scientific objective of the project is the development of methods and tools that allow the optimized operation of existing production equipment through awareness of energy consumption during the operation phase. Additionally new options of the energy market, such as usage of functional storage will be taken into account to reduce energy consumption as well as energy costs.
EnHiPro	Energie- und Hilfsstoffoptimierte Produktion *Optimized usage of energy and auxiliary materials in production*	The project EnHiPro develops an approach and related methods / tools enabling cross-industry manufacturing SMEs to determine organizational and technical measures to increase efficiency and to
EniProd	Energy-efficient Product and Process Innovations in Production Engineering	The cluster of excellence "Energy-efficient Product and Process Innovations in Production Engineering" (eniPROD) aims at reducing the demand for energy as well as increasing the efficiency of resources in the manufacturing sector. Several projects within the cluster focus on the research complex "energy-efficient production" their fields of action are: 1-Virtual product development for energy-efficient products and processes 2-Active principles for intelligent production systems with poor energy demand 3-Design of highly integrative process chains with a poor energy demand 4-Energy-optimized and resource-saving materials and structures 5-Energy-efficient systems and processes in the logistics and factory planning
ENOPA	Energieeffizient durch optimierte Abstimmung von Produktion und TGA *„Energy-efficient due to optimized coordination of production and HVAG"*	ENOPA aims for energy efficiency through improved coordination of planning of production and technical building equipment. By integrating individual and sector specific simulation tools.
e-SimPro	Effiziente Produktionsmaschinen durch Simulation in der Entwicklung *"Efficient production machinery by simulation in the development phase"*	The e-Simpro developed a software tool for designing energy-efficient machinery and equipment and to develop energy-mechanical components and concepts.

Acronym	Title	Description
ESTOMAD	Energy Software Tools for Sustainable Machine Design	Design approaches for production machines,, have to evolve to approaches where resource efficiency is optimized .To do so, energy efficiency has to be taken into account as a key parameter in the design process. The main goal of the ESTOMAD project is to develop a methodology and related ICT tools to model, simulate, analyze and optimize energy flows and losses throughout the whole machine.
ExtREMe	Energy And Resource Efficiency In Manufacturing	Within the cooperative project ExtREMe, a holistic concept is developed - specifically focusing on SMES - to continuously identify and plan organisational and technical measures to improve energy and resource efficiency in manufacturing and to assess the realisable impact.
FoFdation	The Foundation for the Smart Factory of the Future	The project will establish a universal manufacturing information system based on a data exchange standard that allows disparate entities and their associated devices of a manufacturing system to share data seamlessly in a common format.
KAP	Knowledge, Awareness and Prediction of Man, Machine, Material and Method in Manufacturing	The KAP project will deliver energy management standards and a technology framework for next-generation, sustainable manufacturing.
MAXIEM	Maximierung der Energieeffizienz von Werkzeugmaschinen *„Maximizing the energy efficiency of machine tools"*	MAXIEM is german national funded project. The projects aim is to increase the energy efficiency of cutting tools. The focus is on demonstrating potential savings through the configuration of a prototype machine integrating the most efficient components and optimization of control of the components.
NCplus	Effiziente Steuerung von Werkzeugmaschinen *"Efficient control of machine tools"*	The overall objective of the project is the improvement of the energy efficiency of machine tools by focusing on energy consumption as one criterion for optimisation of different subsystems as cooling system, main spindel, axel drives. An intelligent overall energy management system for NC machines which controls the peripheral components, will be developed as well.
PlantCockpit	1.3.1 Production Logistics and Sustainability Cockpit	PLANTCockpit will focus on defining standard interfaces and a reference model for integrating the most prominent manufacturing processes.
ProGRess	Gestaltung ressourceneffizienter Prozessketten am Beispiel Aluminiumdruckguss *„Designing of efficient process chains in aluminum's casting"*	Aluminum casting is one of the most energy-intensive processes of metal processing. Goal of the German founded research project ProGRess is to increase the energy efficiency and utilization of resources in the entire process of die-cast aluminum up to 15%. Therefore the energy and material flows of the sub-processes melting, casting, heat treatment and machining are individual analyzed and optimized by using simulations. Secondly a simulation study of the entire process helps to identify further potentials.
QCOALA	Quality Control of Aluminium Laser-welded Assemblies	QCOALA is focused on energy-efficient, environmental-friendly and agile manufacturing, through the feed-back of in-line-monitoring and inspection information into the production line, allowing process control, continuous quality improvement and waste reduction.

Acronym	Title	Description
ReVista	Ressourcen- und verfügbarkeits-orientierte Instandhaltungs-strategien *„Resource availability and maintenance oriented strategies"*	The project Revista develops holistic strategies for the maintenance and repair of production equipment concentrating on a resource and availability oriented approach. An expert system ("self learning Sensors") is developed to analyze the wear of components as a function of process parameters. This system will improve forecasts of availability and defects and therefore extend the life of components and increase energy efficiency. Furthermore the consumption of the machine and its auxiliary units is stored in a database as a function of tool wear and the process parameters. Thus enables a forecast of the energy demand and a set up energy-efficient operating points. A software tool is processing this information, so maintenance strategy can be evaluated.
S-SCAM-S	Sustainable And Safe Components For Advanced Manufacturing Systems	S-SCAM-S is aiming at applied research to reach a new generation of components (materials, sensors, control units and mechatronics) for Manufacturing Integrated Production Systems, contributing, as an important catalyst, to radical industrial innovation.
UES	Ubiquitous Oriented Embedded Systems For Globally Distributed Factories Of Manufacturing Enterprises	Ues Delivers The Next Generation Of Methods And Means For Development And Production Of Hi-Tech Products In Modern Manufacturing Enterprises. A Synergetic Result Comes From The Domains Of A) Management And Control Architecture, B) Distributed Systems Of Ict, C) Ubiquitous Oriented Embedded Systems.
ZuPrEff	Effiziente Temperaturregelung in der Kunststoff-verarbeitung "*Efficient temperature control in plastics processing"*	The project ZuPrEFF aims to improve the energy efficiency of the injection molding process, concentrating on the machinery, tools and temperature control system. The interconnected control of all subsystems and the realisation of a energy monitoring is in the main focus of the project.

11.3 Research projects in Smart Building sector

Table 11. research projects in sector Smart Buildings

Acronym	Title	Description
AIM	A novel architecture for modelling, virtualising and managing the energy consumption of household appliances	"A novel architecture for modelling, virtualising and managing the energy consumption of household appliances". AIM's main objective is to foster a harmonised technology for profiling and managing the energy consumption of appliances at home. AIM will introduce energy monitoring and management mechanisms in the home network and will provide a proper service creation environment to serve virtualisation of energy consumption, with the final aim of offering users a number of standalone and operator services
Be Aware	Boosting energy awareness with adaptive real-time environments	BeAware studies how ubiquitous information can turn energy consumers into active players by developing: (1) An open and capillary infrastructure sensing wirelessly energy consumption at appliance level in the home; (2) Ambient and mobile interaction to integrate energy use profiles into users' everyday life; (3) Value added service platforms and models where consumers can act on ubiquitous energy information and energy producers and other stakeholders gain new business opportunities.
BeyWatch	Building Energy Watcher	"Building Energy Watcher" aims to design, develop and evaluate an innovative, energy-aware and user-centric solution, able to provide intelligent energy monitoring/control and power demand balancing at home/building & neighbourhood level. The system will interconnect legacy professional/ consumer electronic devices with a new generation of energy-aware white-goods, where multilevel hierarchic metering, control, and scheduling will be applied, based on power demand, network conditions and personal preferences.
BuildWise	BUILDING a SUSTAINABLE FUTURE	The objective of this project is to specify, design, and validate a data management technology platform that will support integrated energy & environmental management in buildings utilising a combination of wireless sensor network technologies, an integrated data model and data mining methods and technologies. In collaboration with Tyndall Institute and Cork Institute of Technology
CITYNET	CITYNET	The research project aims to establish an innovative internet based online tool for planning, managing and operating urban quarters with low energy consumption and high renewable energy fraction in order to reduce up to 30% of state of the art quarters' CO2-emissions. A major research focus of the network will be the analysis, optimization, standardization and benchmarking of existing and planned buildings and energy efficient power plants. This system will provide internet online monitoring, simulation and visualization using Geographical Information System (GIS) software as the front end.

DEMOHOUSE	DESIGN AND MANAGEMENT OPTIONS FOR IMPROVING THE ENERGY PERFORMANCE OF HOUSING	DEMOHOUSE is focused on improving sustainable renovation of the existing housing stock in Europe. DEMOHOUSE project aims to develop minimum standards for energy-efficient and sustainable renovation of dwellings. A recently developed Decision Support Tool provides simple guidelines to help energy-efficient and sustainable renovation of dwellings. DST is a tool, containing simple guidelines to help energy-efficient and sustainable renovation of dwellings.
Digi Home	Digi Home	The main objective of the project is to design and implement Digihome pilot facility at VTT – a prototype house of digital home and mobile services for field tests. Digihome demonstrator will be used to field test and develop the research results created at VTT on home networks, intelligent equipments, and home services.
E-ARCHI	E-ARCHI	The Virtual Campus E-ARCHI is an EU funded project and is an operational tool to be developed by the project partnership aiming at the creation of a collaborative post Master's and Doctorate educational virtual EE environment.
eDIANA	Embedded Systems for Energy Efficient Buildings	eDIANA (Embedded Systems for Energy Efficient Buildings) addresses the need of achieving energy efficiency in buildings through innovative solutions based on embedded systems. The main goal of eDIANA is to enable sustainable urban life through rationalisation in the use of resources while increasing comfort in urban environments by means of embedded intelligence and integration technologies.
e-retrofit kit	e-retrofit kit	This international project is developed under Austrian sub-program "Building of Tomorrow"; Aim - development of an internet based tool that enables social housing companies to identify buildings that are well suitable for passive house retrofit, target group - social housing companies. Actualization of tool after test and evaluation in case-studies will be done.
FM Comfort/ FM Ware	FM Comfort/ FM Ware	"Building of Tomorrow" sub-program. "Software for optimizing the use of energy and other resources in the virtual house". The main aim is to develop a software system called FM Comfort/FM Ware, which is able to represent a model of a complete description of a building. This computer based description should be suitable for visualizing, technical modelling and analyzing of the building infrastructure and the influence and behaviour of the inhabitants. (cf. [36])
GreenerBuildings	GreenerBuildings	GreenerBuildings aims to realise an integrated solution that addresses the challenge of energy-aware adaptation from basic (energy harvesting) sensors and actuators, up to an embedded software for coordinating thousands of smart objects with the goals of energy saving and user support. GreenerBuildings will investigate how buildings can dynamically adapt their operations according to actual use, aiming at substantial energy savings.
HOMES	Optimized Conditions for Homes and	HOMES – "Optimized Conditions for Homes and Buildings, Controlling Energy and Services". Its purpose:

	Buildings, Controlling Energy and Services	to adapt the electrical distribution and control systems in buildings in order to optimize energy management. Its ambition: to reduce buildings' energy consumption by 20%.
HOSPILOT	Intelligent Energy Efficiency Control in Hospitals	“Intelligent Energy Efficiency Control in Hospitals” The project should begin in February 09, focusing on ICT for Energy savings in hospitals, with large scale pilots in 3 hospitals across Europe.
I3CON	Industrialised, Integrated, Intelligent Construction	I3CON will enable the transformation towards a sustainable European construction industry delivering Industrially produced, Integrated processes and Intelligent building systems using distributed control systems with embedded sensors, wireless connections, ambient user interfaces, autonomous controllers, smart business services, and lifecycle solutions. This project involving 26 partners from 14 countries across Europe.
IntUBE	Intelligent use of buildings' energy information	IntUBE will develop tools for measuring and analysing building energy profiles based on user comfort needs. These will offer efficient solutions for better use and management of energy use within buildings over their lifecycles. Intelligent Building Management Systems, Neighbourhood Management Systems, Business Models will be developed to support efficient energy distribution across groups of buildings. The results of IntUBE are expected to enhance not only the comfort levels of buildings users, but also reduce overall energy costs through better energy efficiency.
IRON	Integral Resource Optimization Network	IRON (Integral Resource Optimization Network) is a fundamental study in the field of “coordination of distributed energy resources”. The objective of this project consisted in paving the way for a stable, distributed automated network for the optimization of electric energy as a resource. (cf. [41])
ITOBO		ITOBO develops an anticipated (smart) building that operates on an energy-efficient and user-friendly basis while reducing its maintenance costs, including: Hardware Design Wireless Systems integration and network protocol development Constraint-based Decision Support N-dimensional Information Modelling Facilities Management with access to sophisticated built infrastructure and co-operation with standardisation bodies.
NEMBES	NETWORKED EMBEDDED SYSTEMS	NEMBES is an inter-institutional and multi-disciplinary research programme that will investigate a "whole system" approach to the design of networked embedded systems, marrying expertise in hardware, software and networking with the design and management of built environments.
Power-Matcher	Power-Matcher	“PowerMatcher” is a new coordination system which can match the demand and supply of electricity more efficiently. Devices connected to the network will be

		equipped with intelligent software that can automatically respond to fluctuations in demand and supply of electricity. This will support the accommodation of more sustainable energy sources without complications in the grid. Additionally, it reduces the need for traditional (e.g. gas-fired) central power plants to be kept in reserve in order to cope with the fluctuations in (sustainable) electricity supply.
SafetyBIM	Building Information Model promoting safety in the construction site process	The main objective of the Safety BIM research project is to encourage and develop utilization of BIM technology in construction planning and management - from viewpoint of occupational safety. In the project, potential of BIM in safety management has been studied, 3D site planning objects has been collected and created, and 3D building site modelling and visualization tests has been carried out.
SensoByg	SensoByg	The purpose of SensoByg is to develop and demonstrate inexpensive and reliable monitoring systems for buildings and other large constructions established by means of embedded wireless sensor technology and intelligent decision-supporting tools. Focus centres on the monitoring of moisture and temperature based on wireless sensors. Moisture and temperature control offers the greatest potential, while the embedding of sensors in concrete and wireless transfers in structures with much metal pose great challenges
SIMUENER		SIMUENER will develop a building energy management system that will integrate intelligent predictive strategies of the building behaviour into the control system.
SmartHouse / SmartGrid	SmartHouse/SmartGrid	The SmartHouse/SmartGrid project introduces a holistic concept for smart houses situated and intelligently managed within their broader environment. It develops intelligent networked ICT technology for collaborative technical-commercial aggregations of Smart Houses able to communicate, interact and negotiate with both customers and energy devices in the local energy grid so as to achieve maximum overall energy efficiency as a whole.
SmartSpace	Sensor Networks and Data-Driven Modelling in Underground Infrastructure Management	The research project is focusing on the new ICT tools as a supporting part of the life-cycle technology by developing new methods for measurement, modelling, simulation, visualization and analyzing, and connecting those with wireless transmission systems. In addition, the program aims at creating new real-time sensor network -based monitoring systems to support the maintenance of the infrastructure.

11.4 Research projects in Smart Lighting sector

Table 12 research projects in Smart Lighting

Acronym	Title	Description
CLEAR-UP	Clean buildings along with resource efficiency enhancement using appropriate materials and technology	Clear-up presents a holistic approach to the reducing operational energy use in buildings. By development and novel use of nano-materials it aims to increase energy performance in heating, ventilation, air conditioning (HVAC) and lighting systems, and to improve indoor air quality using catalytic purification.
EFFICIENT LIGHTING	Efficient Lightning for the 21st Century	The development of significantly more efficient light sources for use in general lighting and other industrial applications has the potential to reduce substantially electric power consumption. The main objective of the proposed action, at both the basic breakthrough and the pre-competitive research levels, is to seek new concepts and materials for the lighting industry which avoid any known environmentally harmful substances through the study of the feasibility of high efficacy, novel, light source technologies.
ENRGYSAFE	The development of a new low cost retrofittable wireless and self-powered building control system for improving energy efficiency employee comfort and fire safety in commercial buildings	Objective: Although Intelligent Building Controls IBC can improve the energy efficiency of commercial buildings they only have a few per cent penetration of the market. There are major barriers to adoption of these technologies such as high installation costs and the fact that the controls are fixed once installed and therefore are not adaptive to the changing needs of a commercial building. Moreover, today's systems do not provide optimal energy efficiency control and do not provide the ability to control the HV AC and lighting conditions for individual comfort zones to optimise the working conditions for employees.
GREENERBUILDINGS	An ubiquitous embedded systems framework for energy-aware buildings using activity and context knowledge	Making efficient use of energy in buildings is a paramount challenge to conserve energy and reduce greenhouse effects. Greener Buildings will investigate how buildings can dynamically adapt their operations according to actual use, aiming at substantial energy savings. People spend a great deal of time in buildings, may these be offices, hospitals or commercial buildings. While active indoor, people desire to have comforting lighting and microclimate conditions that adapt to their activity and wishes.
HOSPILOT	Intelligent Energy Efficiency Control in Hospitals	The concern of European society for the well being of its residents and the sustainability of the environment has led to the consciousness that energy savings need to be at the top of the political agenda. Until recently, the focus of energy reduction has been on schools and offices. Hospitals, however, also use large amounts of energy.

Acronym	Title	Description
I3CON	Industrialised, Integrated, Intelligent Construction	The vision behind I3CON is to enable the transformation towards a European construction industry delivering Industrially produced, Integrated and Intelligent building systems that provide high performance spaces to building-users. I3CON's objective-driven approach: a new approach for industrialised production of building components with integrated services and intelligence will be created. These building components will be multifunctional, efficient, sustainable, reusable, interoperable and user friendly.
IEA- ECBS	ECBCS Energy conservation in buildings and community systems	The goal of IEA ECBCS Annex 45 was to identify and to accelerate the widespread use of appropriate energy efficient high-quality lighting technologies and their integration with other building systems, making them the preferred choice of lighting designers, owners and users. The aim was to assess and document the technical performance of the existing promising, but largely under-utilized, innovative lighting technologies, as well as future lighting technologies. These novel lighting system concepts have to meet the functional, aesthetic, and comfort requirements of building occupants. The guidebook mostly concerns the lighting of offices and schools. The energy efficiency of lighting installations can be improved with the choice of efficient lamps, luminaires, and electronic ballasts with low losses, lighting design, the control of light, the usage of daylight, and the usage of highly efficient LED-based lighting systems.
IEA - 4E	Efficient electrical end-use equipment (4E)	Project aims to provide an international platform to collaborate on rating performance of LED based lighting systems for the highest possible energy efficiency and satisfaction of the users. It is expected to bring together manufacturers, laboratories, energy agencies and customer organisations.
IEA -SHC	Solar heating and cooling programme (SHC)	In order to ensure that daylit buildings will become the preferred option in this millennium, it is necessary to optimise energy savings by taking into account the integration of daylighting, control systems and occupant response and transferring this new research to design professionals and industry. Currently only a small fraction of daylighting possibilities is being captured in buildings and many are beset with problems.

Acronym	Title	Description
LITES	Led-based intelligent street lighting for energy saving.	The main objective of the LITES project is to prove in real life experimentation that intelligent street lighting using solid-state lights LED drastically reduces energy consumption. The lighting service delivered is compliant with road classes CE2-CE5, S- and A- according to the standard of EN13201. That means that our device can be installed in secondary street, commercial access, allotment, pedestrian way, cycle track. It is compliant with ll electric standards for luminaires general requirements and tests as well. The core element of the solution is the dimming of the lamp depending on the environment; a set of embedded sensors measure ambient light, temperature, current, and detect motion. Output data of sensors is then processed by the embedded intelligence allowing optimum regulation of light levels. The members within the consortium have been carefully selected to cover the entire value-chain of the project and the standardisation as well.
OLED100.EU	Organic LED lighting in European dimensions.	The overall goal of OLED100.eu is to develop all the necessary technologies forming the basis for efficient OLED applications for the general lighting industry in Europe. Organic light-emitting diodes are promising candidates to substitute conventional light sources. They provide potential for power-efficient large area light sources with revolutionary properties like thin, flat, transparent, color-tunable, and flexible. This grade of flexibility in terms of design and application make them highly appealing for consumers.
POWERMAN SWITCH	An Innovative Energy Consumption Management System Based on a Punctual Electrical Control Device	The objectives are related to the Rational Use of Energy. The amount of saved energy depends on the specific application. A pre analysis has been performed on lighting systems. Considering the actual not practicable possibility of controlling separately each consumption point of the electrical networks feeding street lighting (lamps) or commercial buildings (lamps, heaters, coolers), and also taking into account the future possibility of managing customised contracts with the energy supplier even for private and domestic use, we can state the following Project targets: Street lighting: reduction of total energy >50% (existing and new installations); Large commercial buildings: reduction of total energy used 50% long term, 30, 40% short term; Private houses: reduction of total energy used 10% short term, >20% long term; Reduction of maintenance costs: 80%.

Acronym	Title	Description
SEEMPUBS	Smart Energy Efficient Middleware for Public Spaces 1.3.2	SEEMPubS specifically addresses reduction in energy usage and CO2 footprint in existing Public buildings and Spaces without significant construction works, by an intelligent ICT-based service monitoring and managing the energy consumption. Special attention will be paid to historical buildings to avoid damage by extensive retrofitting. SEEMPubS will provide control of appliances to effortlessly optimise energy efficiency usage without compromising comfort or convenience and offering decision makers strategies and tools needed to plan energy saving measures. SEEMPubS will make use of the service-oriented middleware for embedded systems being developed in the Hydra project and use its huge potential to create services and applications across heterogeneous devices to develop an energy-aware platform.
SMARTCODE	Smart Control of Demand for Consumption and Supply to enable balanced, energy-positive buildings and neighbourhoods	Future buildings and neighbourhoods are expected to combine a manifold of Energy using Products (EuP) ranging from electrical lighting to HVAC with locally available renewable energies (e.g. solar, wind) and with locally available storages (e.g. car batteries). An intelligent management of energy in such a local grid would enable customers to participate in the energy market and even contribute to the stability of the power grid. The problem is that such an energy management requires fine grained infrastructure and expensive hardware. Today, this limits applicability of energy management to large consumers in the industrial and commercial sector.
SSL4EU	Solid State Lighting for Europe	The lighting industry worldwide faces a paradigm shift as a new era of lighting appears at the horizon: that is Solid State Lighting (SSL). Light emitting diodes (LEDs) based on inorganic semiconductors are mercury-free, have a long lifetime and instant on/off, can be colour tunable and most important: they will become the light source with the highest energy-efficiency in the near future. Thus, LEDs are able to outperform all existing light sources and reduce CO2 emissions significantly.

11.5 Smart Grid Conceptual Framework

Overview:

The conceptual model presented in this chapter supports planning and organization of the diverse, expanding collection of interconnected networks that will compose the Smart Grid. For this purpose, the NIST [1] adopted the approach of dividing the Smart Grid into seven domains, as described in the next table and shown graphically in the next figure.

The conceptual model consists of several domains, each of which contains many applications and actors that are connected by associations, through interfaces.

Domain	Actors in the Domain
Customers	The end users of electricity. May also generate, store, and manage the use of energy. Traditionally, three customer types are discussed, each with its own domain: residential, commercial, and industrial.
Markets	The operators and participants in electricity markets.
Service Providers	The organizations providing services to electrical customers and utilities.
Operations	The managers of the transport of electricity.
Bulk Generation	The generators of electricity in bulk quantities. May also store energy for later distribution.
Transmission	The carriers of bulk electricity over long distances. May also store and generate electricity.
Distribution	The distributors of electricity to and from customers. May also store and generate electricity.

- Actors may be devices, computer systems, or software programs and/or the organizations that own them. Actors have the capability to make decisions and exchange information with other actors through interfaces.
- Applications are the tasks performed by the actors within the domains. Some applications are performed by a single actor, others by several actors working together.
- Domains group actors to discover the commonalities that will define the interfaces. In general, actors in the same domain have similar objectives. Communications within the same domain may have similar characteristics and requirements. Domains may contain other domains.
- Associations are logical connections between actors that establish bilateral relationships. Actors interact with associated actors through interfaces. Associations are in Figure 3-1; the electrical associations between domains are shown as dashed lines and the communications associations are shown as solid lines.
- Interfaces represent the point of access between domains. Communications interfaces are at each end of the communication associations and represent the access point for information to enter and exit a domain (interfaces are logical).Interfaces show either electrical connections or communications connections. Each of these interfaces may be bi-directional. Communications interfaces represent an information exchange between two domains and the actors within; they do not represent physical connections. They represent logical connections in the Smart Grid information network interconnecting various domains

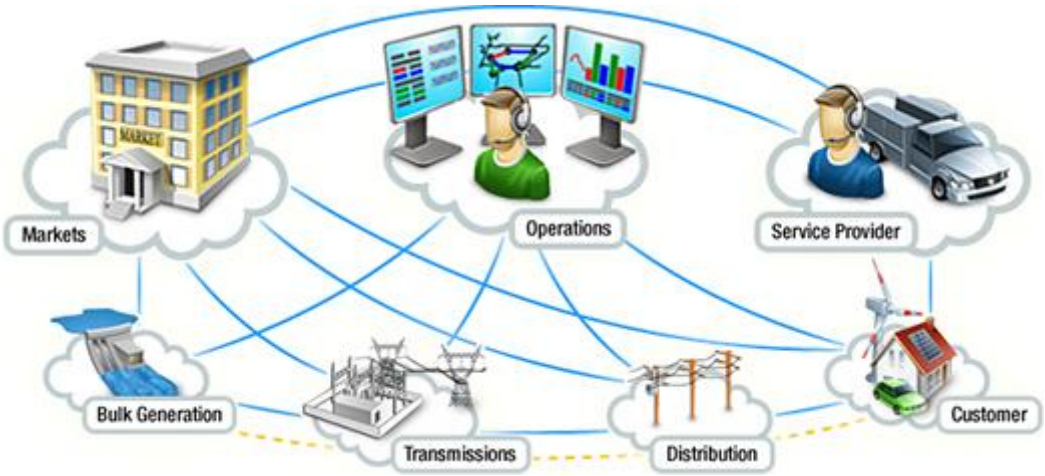

Figure 18 Framework Overview

The National Institute of Standards and Technology (NIST) Smart Grid Conceptual model provides a high level framework that defines seven important Smart Grid domains: Bulk Generation, Transmission, Distribution, Customers, Operations, Markets and Service Providers. It shows all the communications and energy/electricity flows connecting each domain and how they are interrelated one to another. In a more specific view, each domain is comprised of important Smart Grid elements connected to each other through two-way communications and energy/electricity paths, which are the basis of the future, intelligent and dynamic power electricity grid.

The NIST Smart Grid Conceptual model helps stakeholders to understand the building blocks of an end-to-end Smart Grid system from Generation to/from Customers and explores the interrelation between these Smart Grid segments.

At IEEE, the Smart Grid is seen as a large “System of Systems”, where each NIST Smart Grid domain is expanded into three Smart Grid foundational layers, which are the (i) Power and Energy Layer, the (ii) Communication Layer and the (iii) IT/Computer Layer. Layers (ii) and (iii) are enabling infrastructure platforms of the Power and Energy Layer that makes the grid “smarter”.

Bulk Generation:

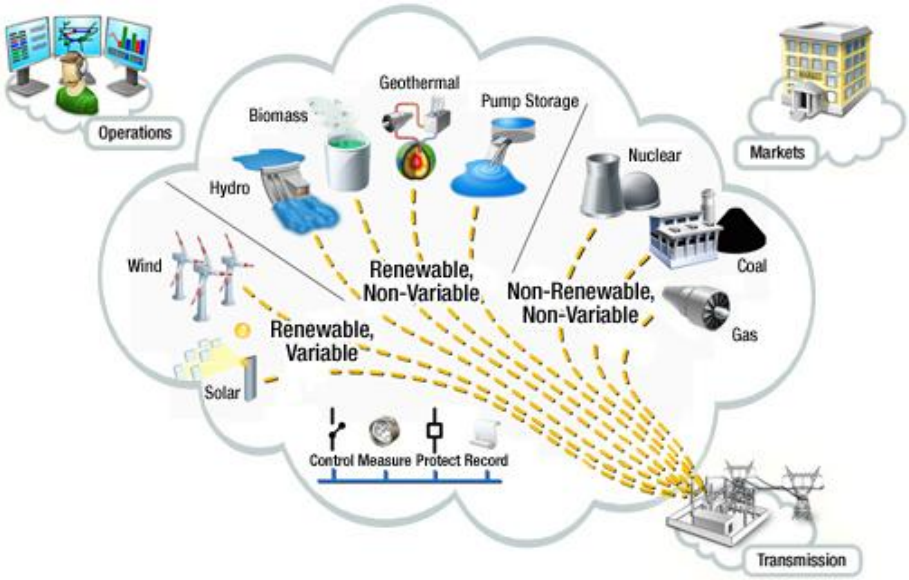

Figure 19 Bulk Generation Domain

The Bulk Generation Domain generates electricity from renewable and non renewable energy sources in bulk quantities. These sources can also be classified as renewable-variable sources, such as solar and wind; renewable non-variable such as hydro, biomass, geothermal and pump storage; or no renewable, non-variable, such as nuclear, coal and gas. It may also contains energy storage for later distribution.

Transmission:

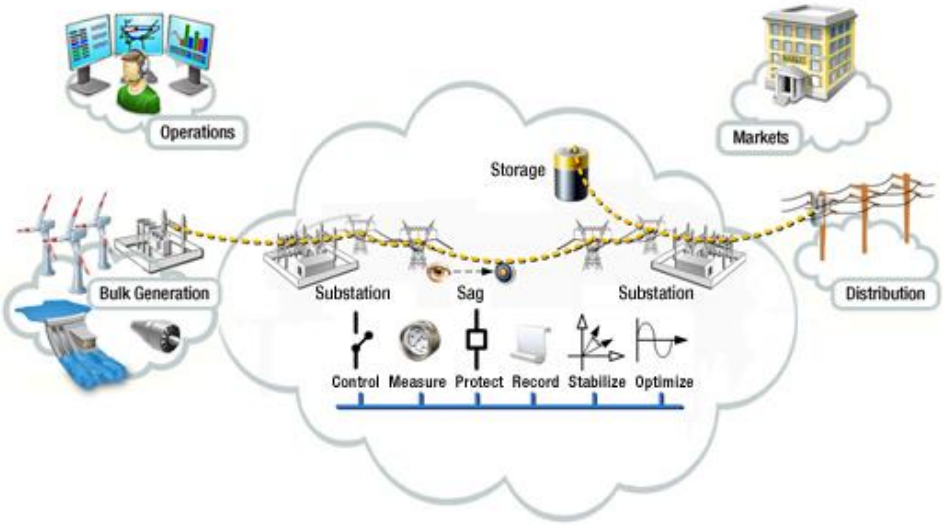

Figure 20 Transmission Domain

The **Transmission** Domain carries bulk electricity over power transmission lines over long distances, connecting the bulk generation to the energy consumption centers of the smart grid. It also contains the power system substations; the transmission and the distribution

substations. It may also connects to energy storage facilities and alternative distributed energy resources at the transmission level.

Distribution:

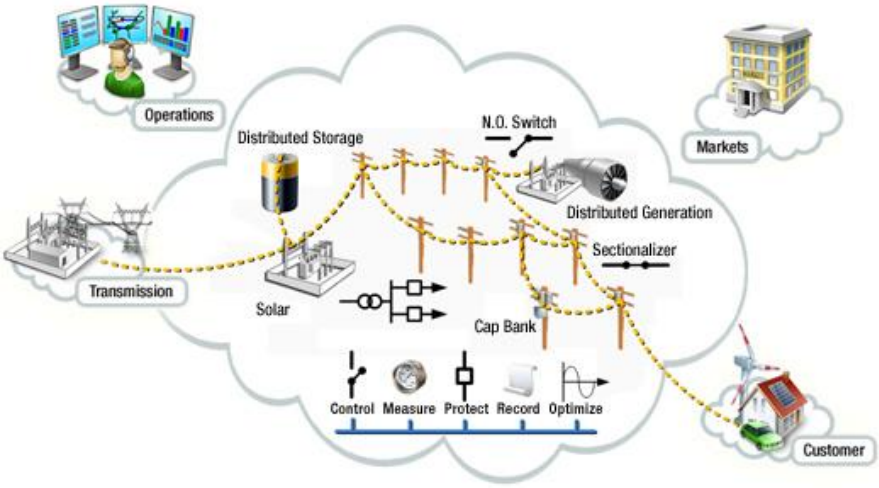

Figure 21 Distribution Domain

The **Distribution** Domain distributes the electricity to and from the end customers. The distribution network connects the smart meters and all intelligent field devices; manages and controls them through a two-way wireless or wireline communications network. It may also connects to energy storage facilities and alternative distributed energy resources at the distribution level.

Customer:

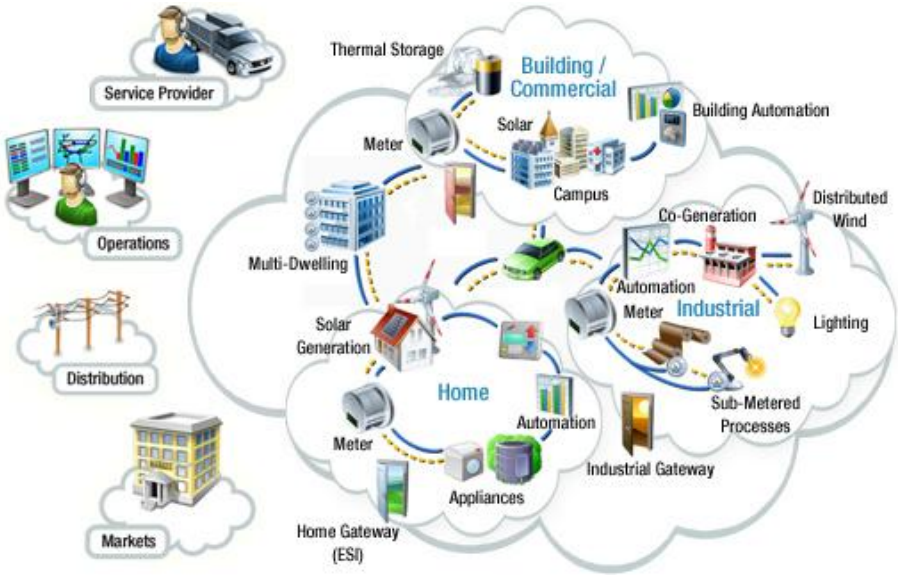

Figure 22 Customer Domain

The Customer Domain is where the end users (home, commercial/building, and industrial) of electricity are connected to the electric distribution network through the smart meters. The smart meters control and manage the flow of electricity to and from the customers and provide energy information about energy usage and patterns. Each customer has its own

domain comprised of electricity premise and two-way communications networks. It may also generate, store, and manage the use of energy and the connectivity with plug-in-vehicles.

Operations:

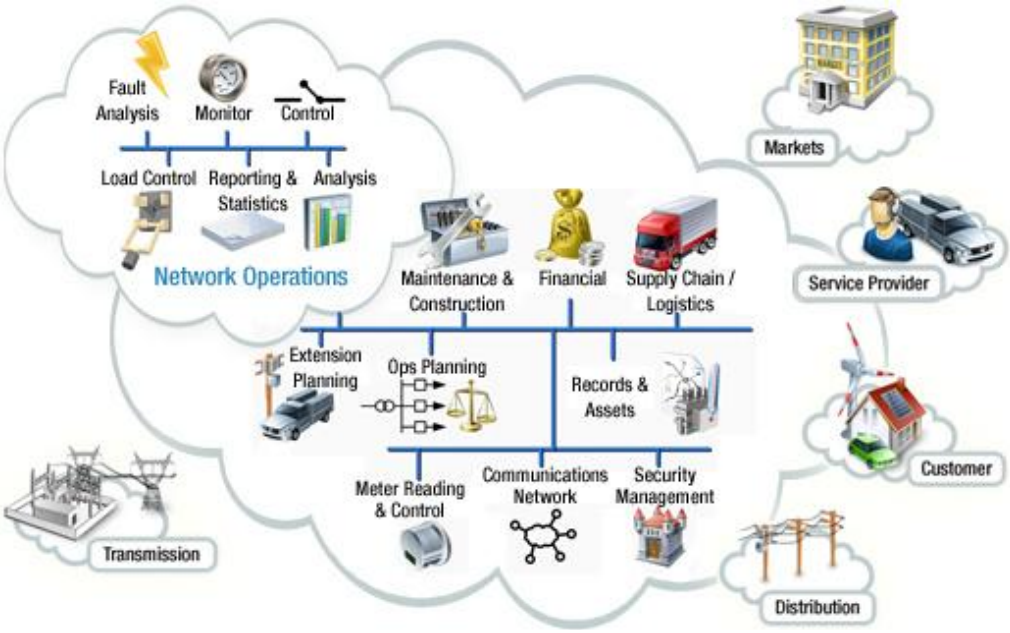

Figure 23 Operations Domain

The Operations Domain manages and controls the electricity flow of all other domains. It uses a two-way communications network to connect to substations, customer premises networks and other intelligent field devices, providing monitoring, reporting, controlling and supervision status and important process information decision. Business intelligence processes gathers data from the customer and network and provides intelligence to support the decision making.

Markets:

Figure 24 Energy Markets Domain

The Markets Domain operates and coordinates the participants in electricity markets. It provides the market management, the wholesaling, the retailing and trading of energy services

operation. It interfaces with all other domains and makes sure they are coordinated in a competitive market environment. The markets also handles the energy information clearinghouse operation and information exchange with third party service providers, like the inter utility plug-in-vehicle roaming billing information.

Service Provider:

Figure 25 Service Provider Domain

The Service Provider Domain handles all third party operations within the domains, such as the end customers energy efficiency management through energy web portals, data exchange for energy management between customer and the utilities, and the electricity supplied to homes and buildings. It may also manage other utilities processes such as demand response programs, outage management and field services.