ICT FOR ENERGY EFFICIENCY: TOWARDS SMART BUILDINGS, MANUFACTURING, LIGHTING AND GRIDS

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ABSTRACT

The European Union (EU) has set its specific target of a 20% energy reduction in EU energy consumption by 2020. Achieving this goal will require major breakthroughs in the research and development (R&D) of new technologies. Information and Communication Technologies (ICT) are today pervasive to all industrial and business sectors. They are expected to have a significant impact on energy efficiency in the future.

In this paper, the four industrial disciplines of buildings, manufacturing, lighting and power grids are identified to have great potential to deploy ICT to improve their energy efficiency. These four sectors often come together in delivering infrastructures and environments for production, business and living, and together they produce and consume a significant proportion of Europe's energy. The state-of-the-art ICT for Energy Efficiency (ICT4EE) in these four sectors are discussed with focuses mainly on their available data on the potential impact, potential to improve through research, development and deployment, obstacles impeding the realisation of full potential, and actions which can be taken to accelerate achievement of potential. This leads to an ICT4EE impact assessment model which is needed to identify complementarities and synergies among these four sectors, harmonising common research and technological development (RTD) priorities, and establishing a cross-sectoral community with links to key stakeholders from them. A methodology for impact assessment model of ICT4EE has been designed on the basis of life cycle assessment and causal relationships which come from the currently existing research. The paper concludes that in order to achieve the full potential of ICT4EE, further support of multidisciplinary R&D and innovation demonstrating the potential of ICT based solutions are needed to boost, reinforce, foster and accelerate the deployment of energy efficient solutions in these four industrial domains.

Keywords: ICT for energy efficiency, smart buildings, smart manufacturing, smart lighting, smart grids

1. INTRODUCTION

Information and Communication Technologies (ICT) are today pervasive to all industrial and business sectors. They are expected to have a significant impact on reducing energy use and increasing energy efficiency in most industry sectors, e.g. buildings, manufacturing, lighting and power grids. Although versatile statistical information is available on energy saving in different sectors, there is still limited understanding of the potential of ICT to improve energy efficiency in these sectors. In order to put ICT at the core of the energy efficiency effort and to enable them reaching their full potential, it is necessary to foster research and development (R&D) into novel ICT-based solutions and strengthen their take-up – so that the energy use in these sectors can be further reduced by adding intelligence to components, equipments, processes and services. Within this context, there is an urgent need for a shared vision and roadmaps towards ICT-based demand-driven innovation and optimised solutions for energy efficiency that will identify the ICT research and technological development (RTD), business, training and education needs for an appropriate transformation to maintain competitiveness, social progress and environmental improvements.

In this paper, ICT as an enabler to energy efficiency is investigated in four industrial disciplines - buildings, manufacturing, lighting and power grids. A framework consisting of state-of-the-art, potentials, obstacles and actions (SPOA) is discussed followed by the assessment of ICT impacts on smart building, manufacturing, lighting and power grids respectively using the SPOA framework. A methodology for impact assessment model of ICT for Energy Efficiency (ICT4EE) has been designed on the basis of life cycle assessment (LCA) and causal relationships. The REViSITE (Roadmap Enabling Vision and Strategy for ICT-enabled Energy Efficiency) project is described as the follow-up research on ICT4EE in these four industry sectors. Finally, conclusions are summarised and follow-up research recommendations are provided at the end of this paper.

2. THE SPOA FRAMEWORK

In order to have an enhanced holistic understanding of ICT4EE in the fields of buildings, manufacturing, lighting and power grids, an approach called the SPOA framework (shown in Table 1) is developed to benchmark RTD activities that evaluate ICT impacts from four key aspects: state-of-the-art, potentials, obstacles and actions that indicate corporate knowledge, experience and behaviour in different industry sectors. These terms are defined as follows:

- State-of-the-art: Review and assess current available data on the impacts of ICT on energy efficiency and energy end use.
- Potential: Identify opportunities for ICT in enabling energy efficiency through applied research, technology development and industry deployment.
- Obstacles: External and internal barriers that impede the realisation of full potential to improve energy efficiency and reduce energy intensity of a sustainable information society.
- Actions: Approaches and solutions which can be taken to accelerate achievement of ICT4EE.

Applying the SPOA framework to smart building, manufacturing, lighting and power grids are discussed in detail in the following sections.

Table 1 The SPOA Framework

State-of-the-art	Potential	Obstacles	Actions
• Available data on the potential impact (e.g. existing knowledge and information).	• Prospects and areas where ICT act as an enabler to improve energy efficiency and reduce energy intensity.	• Barriers that prevent the realisation of full potential of ICT4EE.	• Recommended solutions to speed up the accomplishments of ICT for energy efficiency.

3. ICT IMPACTS ON SMART BUILDINGS

3.1 State-of-the-art

Buildings – commercial, industrial and residential – consume about 40% of the energy used in the world and are responsible for nearly 40% of greenhouse gas emissions (IEA, 2008). The majority of energy consumption is due to space and water heating within households, 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). Energy efficiency in buildings has been recognised as one of the six most important themes of stakeholder requirements identified within the Industrialised, Integrated and Intelligent Construction research project (Ye, et.al, 2008). The opportunity for improving energy efficiency in buildings is tremendous. With products and technology available today, energy consumption in buildings could be cut by up to 70%, the equivalent of taking every single car, truck and bus in the world off the road (NSTC, 2008). This level of energy reduction is achievable, but it requires an integrated approach to how buildings are designed, operated and maintained with the support of ICT-based innovation and solutions.

3.2 Potential

The Smart Buildings Group Report (De Las Heras and Zarli, 2008) has identified five key areas where there is potential to improve energy efficiency in buildings through the use of ICT.

- Integrated design and simulation: The use of building information models including energy simulations across the entire life of the building will result in achieving significant improvements in buildings' energy performance by providing monitors and sensors throughout that can help more accurately measure usage, system status and equipment conditions as well as full price information, dynamic tariff and demand response and allowing more energy efficient customer choices, value added services and more integrated demand side automation.
- Interoperability: There are significant opportunities for efficiency but most are lost due to lack of integration and compatibility.
- Intelligent and integrated control: Building control systems are intended to improve the quality of comfort, health and safety conditions of indoor environments in an effective and efficient manner.
- Smart metering: Smart metering enables more accurate measurement of consumption via the use of advanced meters which are connected to a central unit through a communications network, improving data collection for billing purposes. Smart metering provides information on consumption patterns contributing to more sustainable consumption and energy savings.
- User-awareness and decision support: The provision of intuitive feedback to users on real time energy consumption has significant potential to change behaviour on energy-intensive systems usage. In addition, there is a need to ensure the acceptance of embedded systems and other ICT-based solutions at home through the use of human-centric graphic interfaces for different user profiles.

3.3 Obstacles

There are several barriers identified to be overcome in order to achieve energy reduction in buildings:

- Lack of agreement of what sustainable and energy-efficient buildings are.
- Incompatibility between different control systems and sensors.
- Lack of real-time energy measurement and management tools of energy consumption.
- Lack of intuitive user energy consumption awareness tools.
- Lack of incentives for architects, builders, developers and owners to invest in smart building technology from which they will not benefit or payback periods are too long.
- A lack of skilled technicians to handle complex building management system (BMS) design and operation.
- Each building is unique - difficulty in applying common standards for efficiency and operations.
- Lack of incentives for energy companies to sell less energy and encourage efficiency among customers.

3.4 Actions

In order to improve energy efficiency in buildings, the following actions should be taken to accelerate the deployment of energy efficient solutions in buildings:

- Standardisation of sensor and BMS interfaces.
- Development of standard business models.

- A comprehensive and systematic view needs to consider future construction including life-cycle aspects (of buildings materials, design, and demolition), use (including on-site power generation and its interface with the power grid), and location (in terms of urban densities and access to employment and services).
- The recast Energy Performance in Buildings Directive (EPBD) should strengthen the energy efficiency requirements for new and renovated buildings including considerations on the potential of ICT enabled energy efficiency. Moreover this recast should include a clause on best-performing component refurbishment/replacement: It should be a mandatory requirement that, when refurbishment or replacement of components takes place, the opportunity to maximise the energy efficiency potential should always be taken.
- Additionally, the EPBD mandates inspections on heating and cooling equipments. Such inspections should be made to cover the entire heating, ventilating, and air conditioning system and installation – including looking at ICT enabled potentials at a system management and control level.

4. ICT IMPACTS ON SMART MANUFACTURING

4.1 State-of-the-art

Manufacturing is one of the key industries, representing about 30% of Europe's primary energy consumption, and contributing 22% to Europe’s gross domestic product. The MANUFUTURE High-Level group estimated that 70% of jobs in the EU directly or indirectly depend on manufacturing (MANUFUTURE, 2004). Keeping manufacturing industries strong is essential for Europe's sustainable growth and welfare. The significance of manufacturing makes its energy efficiency efforts a non-negligible contribution to reach European 2020 policy targets (COM, 2008).

4.2 Potential

ICT have a key role in improving energy efficiency in manufacturing through supporting optimisation approaches both for product development and production processes. The potential impacts and savings of the deployment of ICT4EE in manufacturing can be summarised as follows:

- Production optimisation: The overall medium term achievable industrial production savings potential is 25-30 % (Neugebauer, 2008).The EC estimates the energy savings potential by 2020 of being 95 Mtoe (mega tons of oil equivalent), or a full energy savings potential of 25% by 2020. Savings of up to 65%, at least in many production processes, can reasonably be expected (Electra, 2008).
- Design and management of manufacturing processes: It is necessary to develop tools and relevant algorithms which will be able to take energy efficiency into account as a significant parameter of the process, and to calculate best energy performance results along with other desired process results.
- Overall equipment effectiveness: Savings can be achieved through preventive maintenance, the use of condition monitoring systems, and the use of intelligent components and systems solutions (Radgen and Blaustein, 2001).
- Motor system intelligent control and optimisation: The Smart2020 and ELECTRA reports highlight the level of inefficiency in motor system control. Up to 88% of the world’s motor drives are not electronically controlled making them up to 50% less efficient compared to an electronically controlled equivalent. Up to 50% of these inefficient motor drives could be retrofitted.
- ICT-optimised logistics in manufacturing: This could result in a 16% reduction in transport emissions and a 27% reduction in storage emissions globally (Smart, 2008). These improvements can be made in a number of ways: through software to improve the design of transport routes and networks, route optimisation and inventory reduction.

4.3 Obstacles

Several obstacles listed below have been identified which currently impede the rate of improvement in energy efficiency in manufacturing:

- Lack of reliable and coherent data with respect to energy efficiency: Eurostat provides interesting data, but they do not reflect the needs of the sectors with respect to energy efficiency. The data are only rarely comparable between industries.
- Lack of visibility of best practices: Best practices is a means where companies benchmark to find out how problems are solved in other companies or industries.
- Lack of standards: There is a lack of energy management standards against which manufacturing companies can be measured and certified i.e. compared to the framework of standards covering quality management or safety management.

4.4 Actions

Towards energy-smarter manufacturing, recommended actions to accelerate the deployment of smart manufacturing are described below:

- Information on energy consumption and the carbon footprint throughout the manufacturing supply chain should be collected and made available.
- Certification schemes for companies based on a standardised approach.
- Energy labelling from products (today) to processes (tomorrow).
- Demonstration the symbiosis between ICT and manufacturing.
- Support simulation, modelling, monitoring and control.

5. ICT IMPACTS ON SMART LIGHTING

5.1 State-of-the-art

According to the Action Plan on Energy Efficiency, about one fifth of the world's electricity consumption is for lighting, presenting a major potential for savings (COM, 2006). The adoption of high efficiency light-emitting diode (LED) technology, already available on the market, could save 30% of today's consumption by 2015 and up to 50% by 2025. By adding sensing and actuation capabilities to energy-efficient bulbs, so that they automatically adjust to the environment (e.g. to natural light, people's presence) — intelligent lighting – further improvements are possible.

5.2 Potential

Solid-state light (SSL) sources, i.e. LED and organic light-emitting diodes (OLED), may in the future outperform almost all other light sources in terms of efficiency and thus provide a saving potential of about 50% of the electrical energy used for lighting.

- Intelligent lighting management system: If the advanced LED technology is combined with intelligent light management system, which will control the light output according to ambient lighting conditions or people's presence, another 20% can be saved a total of 70%. Thus, with regards to the above mentioned 30% in Section 5.1, an additional saving potential of 40% will be provided by intelligent solid-state lighting solutions.
- New lighting technologies and applications: OLED constitute a promising technology under development. OLED have the advantage of possessing a uniformly diffuse emitting surface, while remaining very energy-efficient and environmentally safe. Furthermore, OLED are form-free and could be made on flexible materials, opening up a wide range of new possibilities.

5.3 Obstacles

Obstacles impeding the realisation of smart lighting are found as below:

- Lack of public awareness of scale of benefits and cost effectiveness in terms of cost of ownership.
- Consumer resistance due to high initial investment in "long life" bulbs.
- Poor public perception due to lower quality of lighting achieved in early implementations.
- Inconsistent metrics, codes, and standards.
- Lack of compatibility of new formats to existing stock of luminaries.

5.4 Actions

The high performance technology is not available yet to its full extent and slow market adaptation and acceptance limit the realisation of these intelligent LED solutions. In order to speed up steps towards smart lighting, the following measures should be taken into consideration:

- Set binding minimum efficiency targets for the different lighting segments in line with the advancement in technology.
- Provide fiscal incentives for intelligent energy efficient lighting technologies.
- Demonstrate the benefits of intelligent SSL lighting technology and study its acceptance and determine its economical cost.
- Increase support for research on SSL targeting both indoor & outdoor applications, especially addressing high quality white LED sources with improved efficiency.
- Extend its present research focus beyond photonic components, i.e. LED and sensors, to the ambient intelligent lighting solutions, system integration.
- Industry must cooperate on open standards and norms in order to guarantee interoperability of the future lighting solutions and backward compatibility with existing luminary stock. This effort should extend itself beyond the lighting domain and cover interfacing with building and power management systems.

6. ICT IMPACTS IN SMART GRIDS

6.1 State-of-the-art

Energy generation and distribution uses one third of all primary energy. Electricity generation could be made more efficient by 40% and its transport and distribution by 10%. ICT could make not only the management of power grids more efficient but also facilitate the integration of renewable energy sources. The integration of ICT tools for management of distribution and the smart meters at the consumer location with telecommunications networks forming an intelligent network capable of supporting distributed generation plant is generally known as an active distribution networks and advanced metering infrastructure within smart grids (ICT, 2008). ICT enablement of the smart grids should be supported so that it can enable smarter grids via such things as two way communications between grid operators and customers; pervasive control systems through substation, distribution and feeder automation; and decision support systems to increase predictive reliability.

6.2 Potential

Smart grids were the largest opportunity found in the Smart 2020 study and the potential for ICT to reduce carbon emissions through smart grids technology could be huge. Best practices and experiences from European and non-European regions based on specific technologies and processes targeting energy savings lead to positive outcomes, for instance:

- Peak load shaving on specific periods: up to 50% reduction.

- Consumer energy consumption reduction: up to 25%.
- Network losses reduction: up to 50% reduction in the current losses which account for 2%-8% of total losses in general.

6.3 Obstacles

There is a need for greater visibility and communication of the potential benefits of smart grids for customers, producers, equipment & technology suppliers and distributors of energy as an overall strong business case to make the huge transformation in the electricity networks required by 2020 and beyond.

There are standardisation issues in ICT in general, for instance in the overall communication between households and the network and service operators in a liberalised unbundled European market. This covers home appliances, smart metering and concentrators communication standards with customer information systems, field services systems, home area networks, local area networks, wide area networks and overall interoperability across the value chain. Unification and synchronization of data exchange when utilities or metering operators are offering electricity, gas and water meters and when they need to be independent of meter vendors ("plug and play") become mandatory.

There is a need for more research and development in the area of consumer demand side and demand response management, based on real time consumptions and customer behaviour models per customer segment and per spatial location.

There is a need as well for research and development in the area of infrastructure readiness related to the integration of a large scale number of distributed generation and renewable energy resources, in power electronics and intelligent algorithms embedded in the future smarter networks.

There are great opportunities regarding the creation of business cases for smart grid investment, replacement of aging infrastructure and more network and consumers active participation. However, these can be made more complex by the number of owners/stakeholders in the total energy value chain i.e. power generators, power transmission operators, distribution operators, retailers, traders, metering operators, technology and service providers, consumers, regulators, etc, and the unique national structure of the value chain in different countries.

6.4 Actions

The following technologies should be taken into consideration to speed the deployment of smart grids:

- ICT studies, business cases, surveys, projects best practices, Go to Market requirements.
- Customer information and communications enablement (smart metering).
- Demand side and demand response management and real time pricing.
- Home energy management device.
- Readiness of infrastructure network to connect large scale distributed generation and renewable energy resources.

By implementing these actions, significant energy savings can be achieved. The extent of the savings will depend on the successful combination of smart processes (like demand response) and smart technologies (like smart metering).

7. IMPACT ASSESSMENT MODEL OF ICT4EE

There is a common focus on why many energy efficiency actions and initiatives around the world have not reduced energy consumption. It is also agreed among the research and development community that without endorsement from the policy makers little will happen to deliver further energy reductions. These types of initiatives need to generate the right message to make them act, such as sufficient evidence and more expertise-based information and logistics for real impact of ICT4EE. For this purpose a methodology for impact assessment model of ICT4EE is proposed on the basis of LCA and the causal relationships which come from the currently existing research.

In order to develop a generic impact assessment model of ICT4EE, complementarities and synergies among these four sectors are identified. As this impact assessment model is used to evaluate the impacts of specific ICT4EE in the four identified areas, it will shape and influence the development of a roadmap and strategic research agenda for further adoption of ICT4EE, as the model will help in identifying the ICT of most impact and the associated requirements for further RTD.

As an example, Boston Consulting Group was engaged to prepare a US-specific report on ICT potential to reduce carbon dioxide emissions and improve energy efficiency for the global e-sustainability initiative, an international alliance of ICT companies. The project focused on identifying and assessing which ICT solutions were most effective in reducing carbon emissions and energy consumption. The findings and recommendations were published in SMART 2020: United States Report Addendum (USRA, 2008).

8. THE REVISITE PROJECT

A new initiative named REViSITE (Roadmap Enabling Vision and Strategy for ICT-enabled Energy Efficiency) will contribute to the formation of a European multidisciplinary ICT4EE research community by bringing together the ICT community and four important industry sectors: buildings, manufacturing, lighting and power grids, as shown in Figure 1 (REViSITE, 2010). REViSITE will contribute to the coordination of high quality research by capitalising on the results of various national and international initiatives within the domain of ICT4EE. Results from these initiatives, which are in most cases sector specific will be analysed, synthesised with the view of identifying common themes and trends and identifying a common non-sectoral specific methodology to assess the impact of ICT4EE. The efforts of the various currently dispersed RTD communities will be rationalised via a consolidated community enabled by a ‘focus group’ and a dedicated ‘expert group’ brought together under the common theme of ICT4EE. Synergies between the four target sectors (smart buildings, smart manufacturing, smart lighting and smart grids) will be identified together with the potential interfaces and assessment of where interoperability frameworks are required and hence convergence of standards is needed. Based on this analysis, a multi-disciplinary Roadmap together with its associated strategic research agenda and implementation action plan will be developed for ICT4EE.

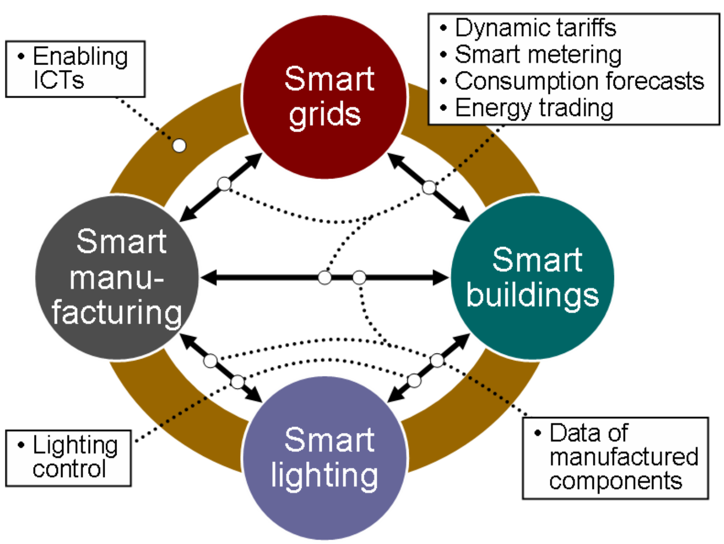

Figure 1: REViSITE context with sample links between the four sectors

9. CONCLUSIONS

This paper has investigated ICT as an enabler to energy efficiency in four important industry sectors: buildings, manufacturing, lighting and power grids. Detailed assessment and evaluation of ICT impacts on smart building, manufacturing, lighting and power grids using the SPOA framework provide an enhanced holistic understanding of ICT4EE in these four sectors. An impact assessment model of ICT4EE has been proposed on the basis of LCA and causal relationships which will shape and influence the development of a roadmap and strategic research agenda for further adoption of ICT4EE. Under the ICT4EE theme, REViSITE will deliver its vision and roadmaps covering buildings, manufacturing, lighting and power grids. In order to achieve energy efficiency in these four application sectors, further support of multidisciplinary R&D and innovation demonstrating the potential of ICT based solutions are needed to foster and accelerate the deployment of energy efficient solutions in these four application sectors.

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