Summary Report

The workshop was organized by the ICT-Energy CSA (www.ict-energy.eu) with the support of the European Commission

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Area: Future ICT-Energy Concepts for Energy Efficiency & Sustainability

Challenge: The reliance of our society on ICT is intensifying with the translation of entertainment, telephones, TV and media onto mobile and distributed ICT devices and systems and with the increasing number of interconnected smart objects. There is also a growing demand to convert everyday objects into sources of information to achieve energy and resource savings for the new Internet of Things era.[1] These advances increase the energy footprint of ICT (the electricity consumption and CO_2 emissions directly attributed to ICT devices and systems are soon expected to surpass the 10% and 5% marks respectively)[2] and put severe constraints on the energy and power requirements for devices and systems. To make this progress sustainable, it is both necessary to reduce the energy consumed in the total system via energy-efficient software and hardware integrated solutions and to achieve energy autonomy through harvesting and the improved management of energy sources available in the environment.

Scope: Research and innovation activities are required aimed at jointly exploring scientific directions and technological options to establish a solid baseline of knowledge and skills for transformational innovation, and to foster the emergence of a broader innovation ecosystem as well as a fertile ground for its future take-up (e.g., through public engagement processes when relevant, or through formal and informal training and education). More specifically research should focus on developing **breakthrough technologies** based on **interdisciplinary** and **holistic** approach for ultra-low power consumption computing paradigms. Ideally, the proposals should benchmark their power and energy savings at the hardware and software level and aim to produce an energy sustainable system for specific tasks.

We identify the following topics where research activity can be focussed with the aim of producing **at least two orders of magnitude improvement** in energy efficiency for the target application:

a) **Energy efficient computing paradigms and systems –** exploration and demonstration of new computing paradigms ans systems (like non-Boolean, analogue, hybrid electrical-mechanical,

[1] See full report of ICT Consultation workshop on 'Impact ICT-Energy Consumption' (to be published in ICT-Energy Letters, July 2016).
[2] ICT-Energy SRA and refs. therein

to mention a few) pushing energy consumption **below conventional transistor based circuits**. It is essential to apply a holistic approach from devices through circuit architectures as necessary for specific application implementations, aiming at the limits of energy consumption for each layer and as a whole. The possibility to **integrate new logic and device architectures** and apply novel system integration schemes should be considered. Open source aspects of design tools and computing platforms may be addressed to achieve an innovation ecosystem. Attention should be given also to novel paradigms that exploit the unreliability of ultra-low energy devices.

b) **Energy autonomous miniaturised smart objects –** Demonstrate novel approaches and applications of 'sensing, analysing and communicating' using energy autonomous systems with small form factor (approximately **1 mm^3 and below**) that go **beyond what is presently available**. Explore the fundamental limits of energy harvesters, managing hybrid energy harvesting and integrating novel energy storage with high-energy density and high-power capability. The use of novel computation paradigms or transmission protocols with improved signal-to-noise ratio may be considered for "intelligence at the edge" applications.

c) **Energy transparent and energy adaptive systems –** Explore energy transparency mapping energy-related data and requirements between hardware and software and demonstrate systems (hardware-software) that adapt their energy demands in real time depending on the resources available and performance requirements. Using energy transparency tools, develop new energy-efficient algorithms and systems optimising the tradeoffs of computation and communication and that go **beyond the tradition dichotomy between application software and universal computing hardware**.

As potential impact we identify the following:

- Reduction of the environmental impact of ICT technologies.
- Establishment of a solid baseline of knowledge and skills for a future ICT technology with a significant reduction in energy consumption.
- Development of energy-efficient autonomous sensor for the Internet of Things era.
- Characterisation of novel device technologies as for beyond the CMOS era.
- Development of new energy-efficient computing paradigms that operate close to the fundamental energy limits.
- Design of problem-specific accelerator modules for orders of magnitude energy reduction.
- Demonstration of the emergence of an ecosystem around future low energy technologies with a clear innovation pathways through outreach to and partnership with high potential actors in research and innovation, and from wider stakeholder/public engagement.
- Structuring of a goal oriented community and true interdisciplinary collaboration.