ICT for Sustainable Manufacturing. A European Perspective

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Abstract. The challenges associated with environmental sustainability and greenhouse gas emissions are increasingly affecting policy making and global economic activity. Since energy use accounts for eighty percent of all greenhouse gas emissions in Europe, the European Union is determined to fight against climate change and reduce emissions by at least twenty percent in 2020. Although information and communication technologies (ICT) account for approximately two percent of global CO_2 emissions, they can significantly contribute to reducing the ninety-eight percent of CO_2 emissions caused by other activities. This requires the ICT sector to lead developments towards environmental sustainability. The paper provides an overview of the European policy landscape (regulations, incentives) with a particular emphasis on issues pertaining to the role of ICT in reducing the CO_2 footprint of manufacturing.

Keywords. ICT, sustainable manufacturing, CO_2 emissions

1 Introduction

One of the major challenges for industry today is to be competitive in global markets whilst also being conscious of achieving environmental objectives. Sustainability considerations regarding the development, manufacturing, distribution and maintenance of industrial products not only determine the environmental footprint of manufactured products but increasingly contribute to industrial competitiveness.

In May 2008, the European Commission presented a policy paper "Addressing the Challenges of Energy Efficiency through Information and Communication Technologies" [1] underlining the role of ICT as enabler of energy efficiency across the economy. It was accompanied by a stakeholder consultation investigating opportunities for energy efficiency. An ICT-enabled systems approach, transcending process and sector boundaries, seems to offer significant potential for savings.

2 Environmental Policies and Legislation

The key objectives of European environmental legislation are to lay down rules aimed at preventing pollution and repairing damages caused to the environment. European policies however, also foresee measures that promote the development of environmentally friendly industrial activity.

Article 174 of the Lisbon Treaty [2] sets out the basic principles of European policy action on the environment, in particular the precautionary principle and the 'polluter pays' principle. These general principles are implemented by specific legislation applicable to industrial activities in Europe [3]. The Treaty also requires environmental protection to be integrated into European policies with a view to promote sustainable development.

To prevent or to minimise the amount of pollutants and waste from industrial plants being released into air, water and soil, the *Integrated Pollution Prevention and Control* Directive establishes a procedure for authorising activities with a high pollution potential and sets minimum requirements to be included in all permits, particularly in terms of pollutants released [4].

Waste management [5] is increasingly seen as one key stage in the lifecycle of resources and products. Thematic strategies on preventing and recycling waste focus mainly on ways to promote sustainable waste management, by reducing the amount of waste produced, by minimising its environmental impact or by reducing resource use. This lifecycle-based approach obligates businesses to manage natural resources and their products in a sustainable way.

In their conclusions in May 2001, ministers of the European Council stated that an effective strategy for integrating sustainable development into industrial policy should not be based on legislation alone, but should to a large extent also come from *market-based and voluntary approaches*. While this mainstreaming of sustainable development is a challenge, it should also be seen as an opportunity to stimulate innovation and to create new economic prospects and a competitive advantage for European business.

The European Commission has put instruments in place that favour the development of environmentally friendly economic activity. Businesses are offered funding in the form of co-financing or loans through various financial instruments and programmes, such as the LIFE+ programme [6] or successive Framework Programmes for research and development [7], or support through other financing institutions such as the European Investment Bank or the Structural Funds [8]. Other incentives focus on improving business visibility and image. Main examples are the 'Ecolabel' and the Community Eco-Management and Audit Scheme (EMAS) [9]. Instruments to improve regulatory management include an action plan in favour of eco-technologies, the EMAS system and the promotion of voluntary agreements.

Activities also aim to spread best practices from instruments such as integrated pollution prevention and control, integrated product policy and standards. Integrated product policy [10] is the main policy for promoting sustainable production and consumption.

Energy accounts for 80 % of all greenhouse gas emissions in the EU. Determined to fight against climate change, the EU is committed to reducing its own emissions by at least 20 % until 2020. Reducing greenhouse gas emissions involves using less energy and more clean energy.

In its *Action Plan for Energy Efficiency* [11], the European Union sets out ways to achieve its 20 % objective by 2020. Efforts include in particular energy saving measures for the transport sector, the development of minimum efficiency requirements for energy-using appliances [12], awareness-raising measures targeting consumers with respect to sensible and economic energy use, improving the efficiency of production, transport and distribution of energy (heat and electricity), improving the energy performance of buildings and also developing energy technologies.

3 Towards Sustainable Manufacturing: The Role of ICT

A report published by the European ICT Industry Association (EICTA) [13] highlights efforts of the electronics industry to reduce waste and energy use in manufacturing as well as efforts focused on *eco-design*, i.e. to reduce energy use and packaging waste of modern electronics devices.

As an example of a voluntary agreement, the Energy Star programme [14] sets minimum standards for energy efficiency. Products that comply can display an appropriate logo. Other agreements involve the application of standards – e.g. a group of mobile phone manufacturers under the auspices of the International Telecommunications Union have recently agreed to standardise the charging system for mobile phones so that in the future all chargers will work from the same kind of USB connection [15].

Gartner estimates that ICT accounts for approximately 2 % of global CO_2 emissions [16]. The industry is focused on constantly delivering products that provide increased functionality alongside improved energy performance. However, since there are substantial inefficiencies in technology use and in human behaviour, ICT may significantly contribute to reducing the 98 % of CO_2 emissions caused by non-ICT activities. A smart implementation of ICT therefore requires policy support as well as standardisation efforts, e.g. for the adequate measurement of energy consumption.

3.1 Resource use efficiency in semiconductor manufacturing

The unprecedented success of CMOS technology - offering more functionality in an ever more affordable manner - accounts for almost all recent developments in ICT. But, even if Moore's law reduces power consumption with each CMOS generation, the sheer number of proliferating semiconductor-based devices and increase of demand for computing and storage functionality ultimately leads to an overall increase in ICT-induced electricity consumption.

The industry represented in the meeting of the Smart Manufacturing Consultation Group [17] includes the process industries, discrete manufacturing sectors as well as the semiconductor manufacturing sector. The statements and the figures presented below are summarised in the report of this Consultation Group [18].

Energy efficiency and energy productivity in semiconductor manufacturing is continuously improving. The World Semiconductor Council has set up a common global metric for relevant electricity parameters and has agreed on a global definition of expectation levels for the reduction of electricity consumption in semiconductor manufacturing. The expectation level for a normalised reduction in electricity consumption between 2001 and 2010 has been set to 30 %.

The productivity of the manufacturing line as a whole within a wafer fabrication line is increased by using complex ICT systems that improve and automate manufacturing decisions in situ, on the basis of previously gathered data that is stored in ever growing databases, e.g. the automated precision manufacturing system that was developed by AMD and is used in its fabrication sites in Dresden. Infineon reported that through consistent efforts to cut down energy consumption at front end manufacturing sites, the cumulative non-used energy (measured in 'negajoules') in the period 2002-2007 exceeded the output of the coal-fired power plant in Goldenhagen, Germany: more than 1.5 TWh in 2007. IBM reported having implemented numerous measures for energy conservation and resource use efficiency in its semiconductor manufacturing facilities. Intel reported having reduced energy consumption in its operations by 20 % per production unit over the last three years (equal to a saving of 160 million kWh in 2006).

3.2 Research and the role of standards

Research is needed to model complex manufacturing lines with respect to tool energy consumption. Breakthroughs are needed to maximise the utilisation of the tools and for load management in a way that the sensitive fabrication process is not disrupted. Techniques have been developed in different industries that could have applicability across sectors. To be able to drive improvements, it is critical to be able to measure the current state and to understand what an achievable value should be. All levels of a factory ecosystem need to become measurable. Sensors do exist to measure energy use of components and subsystems, but not of all of them.

Smart power electronics components and systems are a prerequisite to energy saving in all ICT application areas [19]. The total savings due to the use of smart power electronics components and systems within the whole power generation chain can amount to 50 %. Therefore, the need for R&D in smart power electronics is outlined in the strategic research agendas of the SmartGrids [20] and the ENIAC [21] Technology Platforms.

The link between nanoelectronics and energy efficiency has been addressed by the 7th European R&D Framework Programme, and has been put forward in both, the ICT Work Programme 2009-10 and the Annual Work Programmes 2009 and 2010 of the ENIAC Joint Undertaking. Within the nanoelectronics part of the ICT Work Programme 2009-10 one objective has focused on 'design' and another on 'technology' aspects. The microsystems part addressed energy efficiency under 'autonomous energy efficient smart systems'. Energy efficiency will continue to be a focus area in the 2011-12 Work Programme of the ICT Theme.

Some equipment suppliers, such as vacuum pump and point of use abatement vendors, have made significant improvements with energy consumption. Examples of this are the introduction of high efficiency motors, lower cooling water flow, higher temperature gradients, and utility consumption control.

Regarding the characterisation of tool energy consumption, SEMI has developed an international industry standard, the SEMI S23 Guide for Conservation of Energy, Utilities and Materials Used by Semiconductor Manufacturing Equipment [22]. An example of a regional, sector-independent, standard is the Irish Energy Management

System Standard IS 393 [23]. It is a standard that enables companies to engage in, to document their energy management systems and to drive continuous improvement at a pace appropriate to the company's size. The rules facilitate and enable widespread engagement. Intel Ireland has been certified according to this standard.

3.3 Resource use efficiency in discrete manufacturing

The experts involved in the Smart Manufacturing Consultation Group assessed the potential for energy efficiency also in the other manufacturing sectors and provided detailed recommendations [18]. Savings potentials for discrete manufacturing are seen in the following areas:

Process stability: Achieving energy and material efficiency through better process stability. “Zero waste production” avoids the manufacturing of defective parts. 100 % quality control can help achieve this goal. ICT-driven control systems can considerably reduce unproductive time during ramp-up. Operation and maintenance cycles can be optimised.

Rethinking production process technology: Mechanical, thermal and chemical processes and production systems overall have to be reconsidered with respect to their energy savings potential, which can be estimated to 25 %. Processes which lead to changes in the state of materials, such as heat treatments, lead to high material losses. Sensor-based ICT-infrastructures should be used to monitor and analyse energy-relevant parameters. Detection of the beginning and end of down times, intelligent monitoring, system diagnosis and auto-correction should be implemented. The base load on machine tools is responsible for up to ¾ of the total power consumption, while ¼ is used for the process itself. An optimisation of waiting/start-up times has a savings potential of 10-25 %. For example, coating of sheets before forming results in less energy consumption, less loss of lacquer or powder in the process and less time for the process.

Lossless infrastructure operations in manufacturing plants and factories: This production area, including the transportation of goods, accounts for more than 40 % of energy consumption in discrete manufacturing.

Intelligent motor drives: Technologies to increase energy efficiency are readily available: motors are installed in all manufacturing plants; 88 % of the motor drives today are not electronically controlled. Out of these, an estimated 50 % can be equipped with variable speed drives to achieve energy savings, during partial load, of up to 50 %. The savings potential from the use of power electronics is estimated as follows: 20-30 % traction drives using power semiconductors, e.g. through the recuperation of braking energy; 30-40 % motor control using inverters; 30-40 % air conditioning, using intelligent compressor control. There is a lack of information about energy consumption of motor systems and where savings can be made within a factory. The main role of ICT in the short term will be to monitor energy use and provide data for decision making on energy and cost reduction. Wireless networks that allow inter-machine and inter-system communication would help improve energy efficiency across the entire factory.

Energy savings in the use of compressed air: In case studies of compressed air technology it was found that energy savings are achievable in the range of 10-50 %.

3.4 Energy efficiency and the process industries

Almost all options identified in the section on discrete manufacturing are also applicable to the process industries. The estimated savings potential in this industry domain is as follows:

The *steel industry* has reduced its energy consumption and CO_2 generation by 50-60 % respectively over the past 40 years. Steel can be generated from an integrated route or from a recycling route. To use the integrated route means to start with ore. The recycling route makes use of shredded material. The integrated route needs 18 GJ per ton of slab while the recycling route needs about 2.5 GJ per ton of steel. The share of the recycling route has risen from 25 % in the eighties to 41 % today. The recycling route will be further increased as steel is fully recyclable. Further savings lie in the continuous improvement in heat recovery and waste steam utilisation, and through the use of ICT.

The *chemical industry* sees in the improvement of reaction and process design a direct relevance for more energy efficient chemical production. Recent accelerating developments in high performance computing, process systems engineering, chemical sensing technology and distributed process control will ensure that 'in silico' techniques have a revolutionary impact on the way chemical industries will operate in the next twenty years. Model-based catalysis can theoretically lead to improvements up to 50 % if fundamental process improvements can be achieved. Model-based synthesis concepts (excluding catalysis) can lead to improvements of 20 %.

3.5 The Factories of the Future initiative

The Economic Recovery Plan proposed by the European Commission on 26 November 2008 [24] includes measures for research and innovation, in particular through public-private partnerships 'Factories of the Future', 'Energy-Efficient Buildings' and 'Green Cars'. There is a clear shift towards 'green' technologies associated with this Plan. The Factories of the Future initiative in particular, aims at improving manufacturing enterprises' technological capability of adapting to environmental pressures and of adequately responding to increasing global consumer demand for greener, more customised and higher quality products. It is expected that these accelerated research and innovation efforts will lead to a paradigm shift towards a demand-driven industry with lower waste generation and less energy consumption. In the Recovery Plan, ICT is seen as an enabling technology.

In July 2009, the first call for proposals was launched under this initiative with an available funding of € 95 million, addressing the topics (a) Smart Factories: ICT for agile and environmentally friendly manufacturing; (b) Plug-and-produce components for adaptive control; (c) Supply-chain approaches for small series industrial production; (d) Intelligent, scalable, manufacturing platforms and equipment for components with micro- and nano-scale functional features. The Work Programme related to these activities was inspired by the expert recommendations given in the report regarding ICT for energy efficiency in manufacturing [18]. The response to this first call was high. Twenty-five out of a total of ninety-seven R&D proposals were selected for support. The success rate was about one in four. Industrial participation was at nearly 50 %, with 31 % being small and medium-size enterprises.

4 Conclusions

The paper highlighted the importance of ICT as an enabler of sustainable manufacturing. However, ICT and automation may not be sufficient to bring about the required paradigm shift away from 'maximum gain out of minimum capital' towards 'maximum added value with minimal resources'. A holistic perspective of manufacturing is needed with specific measures targeting resource use efficiency of factories, but also of related supply chains and of distribution and use patterns.

Like many high-tech branches, the ICT sector, and in particular the semiconductor industry, consists of a complex arrangement of various processes and technologies requiring meticulous optimisation and control to achieve sustainable and competitive manufacturing yields. The sector appears ever more conscious of its own environmental footprint and has already established sophisticated methodologies and processes in a self-regulatory manner at international level. The strategic importance of the sector for the whole economy makes energy efficiency considerations both, at product (development) and at manufacturing level, ever more important.

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