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The Implications of ICT for **Energy Consumption**

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e-Mail: entr-innov-ict-ebiz@ec.europa.eu,
info@ebusiness-watch.org

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The Implications of ICT for Energy Consumption

A cross-sectoral study by

RWTH Aachen University & DIW Berlin

Final Report

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This report was prepared by empirica GmbH on behalf of the European Commission, Enterprise & Industry Directorate General, in the context of the "Sectoral e-Business Watch" programme. The Sectoral e-Business Watch is implemented by empirica GmbH in cooperation with Altran Group, Databank Consulting, DIW Berlin, IDC EMEA, Ipsos, GOPA-Cartermill and Rambøll Management based on a service contract with the European Commission.

About the Sectoral e-Business Watch and this report

The European Commission, Enterprise & Industry Directorate General, launched the Sectoral e-Business Watch (SeBW) to study and assess the impact of ICT on enterprises, industries and the economy in general across different sectors of the economy in the enlarged European Union, EEA and Accession countries. SeBW continues the successful work of the *e-Business W@tch* which, since January 2002, has analysed e-business developments and impacts in manufacturing, construction, financial and service sectors. All results are available on the internet and can be accessed or ordered via the Europa server or directly at the SeBW website (www.europa.eu.int/comm/enterprise/ict/policy/watch/index.htm, www.ebusiness-watch.org).

This document is a final report of a Cross-Sectoral Thematic Study, focusing on the implications of ICT for energy consumption. The study describes how companies use ICT for conducting business, and, above all, assesses implications thereof for firms and for the industry as a whole. The elaborations are based on econometric analyses, expert interviews and case studies.

Disclaimer

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Contact

For further information about this Sector Study or the Sectoral e-Business Watch, please contact:

RWTH AACHEN UNIVERSITY	e-Business W@tch	
RWTH Aachen University Prof. Dr. Reinhard Madlener Templergraben 55, 52056 Aachen, Germany rmadlener@eonerc.rwth-aachen.de	***Sectoral e-Business Watch*** c/o empirica GmbH Oxfordstr. 2, 53111 Bonn, Germany info@ebusiness-watch.org	**European Commission** Enterprise & Industry Directorate-General ICT for Competitiveness and Innovation entr-innov-ict-ebiz@ec.europa.eu

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Executive Summary

About this study

This study by the Sectoral e-Business Watch explores links between ICT diffusion and energy consumption in different sectors at the aggregate level. There is not much economic research which uses quantitative analysis to determine the relationships between ICT usage and energy use. Qualitative studies have typically focused on the energy efficiency potentials. In contrast to these existing and mainly analytical-descriptive studies, this study aims to empirically test several hypotheses derived from economic theory. The motivation for undertaking this kind of analysis is twofold:

- The main motivation is to determine which effect dominates in European industries (i.e. the energy-saving or energy-increasing effect of ICT diffusion at the aggregate level), an issue of great importance in the light of global climate change and concerns about future energy supply security.
- A second motivation is the desire to study the impact of changes in the relative prices of input factors, and the price of energy in particular, on ICT diffusion.

Income vs. substitution effects

The role of ICT and e-business in shaping energy needs and energy consumer behaviour has significantly increased. ICT and e-business can help to reduce energy consumption and thus costs by reorganising production processes in a more efficient manner, but it can also lead to additional demand for energy due to new products and services provided and the energy consumption of the ICT capital stock itself. Hence, the overall impact of ICT on energy consumption is ambiguous, and depends on the relative magnitude of two countervailing forces:

(1) an *income effect*, caused by the economic boost accruing from increased ICT use (increase in energy consumption) and

(2) a *substitution effect*, caused by changes in the industrial structure and the capital stock towards higher productivity (decrease in energy consumption).

Furthermore, there might also be some substitution of ICT and energy for labour and other production input factors, so that it seems useful to look at the relative impacts of the various input factors.

Decoupling of GDP and energy use

Empirically, a certain *decoupling of GDP and energy use* has been observed. In the U.S., for instance, GDP and energy consumption grew on average by 3.2% and 2.4% annually in the “pre-Internet era” (1992-1996) and by 4% and 1% in the “Internet era” (1996-2000). Note, however, that this observed overall decrease in energy intensity, measured as the ratio between energy consumption and production, may not be the case in every single sector of the economy. Moreover, the ICT sectors in particular seem to be less energy intensive than the overall economy (U.S. figures for 1996: 4.4% vs. 0.8%). In contrast to energy intensity, the *intensity of electricity use* is rising in many countries. It is thus interesting to study this potential causality between the diffusion of ICT capital goods and the observed decrease in energy (or electricity) intensity of production.

Methodological considerations for an econometric analysis

Methodologically, however, the evaluation of the causality is more complicated, due to the manifold consequences of ICT diffusion on the structures of the economy and society. Romm (2000) suggests to distinguish two types of energy gains related to the diffusion of ICT capital: (1) *efficiency gains*, for instance due to improved management of an assembly line, and (2) *structural gains*, for instance due to lowered individual transport needs because of increased Internet shopping. While appealing at first sight, these two kinds of gains, and especially structural gains, are very difficult to quantify empirically.

This report surveys some of the relevant literature on ICT and energy consumption, and provides a description of the research objectives and hypotheses followed, the methodologies and data used, and the results obtained from this initial study. Specifically, it contains the synopsis of three case studies conducted on the role of ICT to reduce energy consumption, and the results obtained from the econometric analysis.

Econometric analysis

Econometric studies focusing on the links (and causality) between the diffusion of ICT capital and energy consumption (or energy intensity of production, respectively) are still scarce, and complement (typically case-based) expert analysis and microeconomic studies. Our empirical econometric research for selected countries and industry sectors indicates that ICT, at the aggregate level, may not necessarily reduce energy (electricity) intensity, let alone absolute levels of energy (electricity) consumption, and that generalisations have to be made with care. In this respect, we show that an analysis on a still more disaggregate level, where communications devices and computers and software are analysed separately, can yield important additional insights. The last-mentioned disaggregation, however, is only feasible for value terms, due to current data restrictions.

While it is premature to come up with far-reaching conclusions and policy implications from this initial research, we have gained the following empirical results:

Results based on the CFP model

Chemicals industry: Communications technology has a positive impact on electricity efficiency (0.4); We find some (weak) evidence for electricity-augmenting technical change (0.03); transport equipment has a negative influence on electricity efficiency (0.5); computers and software are found to have an insignificant influence on electricity efficiency (0.13-0.15).

Metals industry: Communications technology has a positive impact on electricity efficiency (0.11-0.13); computers and software exert a negative influence on electricity efficiency (0.4-0.5), which is in line with what Collard, Fève and Portier (CFP) (2005), have found for the French services sector; (weak) evidence for electricity-augmenting technical change (0.01);

Transport industry: We find an electricity-augmenting impact of technical change (0.01); communications technology has a positive impact on electricity efficiency (0.25); transport equipment has a negative influence on electricity efficiency (0.40).

Results based on the Cobb-Douglas model

Chemicals industry (volumes): The largest impact on gross output in the chemicals industry is exerted by material inputs (0.39), followed by energy (0.19) and service (0.08) inputs. ICT capital (0.04) and technical change (0.02) have the weakest effect on output, while non-ICT capital is statistically insignificant.

Metals industry (volumes): In the metals industry material inputs (0.57) exceeds all other input factors by far. The next largest effect is exerted by service (0.12) and energy (0.11) inputs, followed by non-ICT (0.06) and ICT (0.02) capital.

Transport industry (volumes): Service inputs (0.52) have the decidedly greatest effect among all input factors in the transport industry. Material inputs and ICT capital (0.06) are followed by non-ICT capital (0.02), while energy inputs and technical change do not have a statistically significant impact on gross output.

Chemicals industry (values): The two largest effects on gross output in the chemical industry are exerted by material (0.37) and service (0.30) inputs. Non-ICT capital (0.16) and energy inputs (0.06) are followed by computers & software (0.05) and communication devices (0.01).

Metals industry (values): Material inputs (0.57) have the largest impact on gross output in the metals industry by far. The next largest effect is exerted by service (0.15) and energy (0.03) inputs. Computers & software (0.02), communication devices (0.01) and technical change (0.003) have the weakest influence on the sector's gross output.

Transport industry (values): The largest impact on gross output in the transport industry is exerted by service inputs (0.38), followed by material (0.13), non-ICT capital (0.10) and energy inputs (0.04). Computers & software and technical change (0.01) again have the weakest effect on output.

Case studies

As complementary evidence at the firm level, three case studies were conducted on how companies use ICT-based tools to save energy and thus energy costs. The cases are intended to support the understanding of aggregate results, but also to indicate whether there could be an untapped potential which is not yet reflected in the aggregate picture at the sectoral level.

Erdemir is Turkey's largest iron and steel producer, and accounts for 1.7% of Turkey's entire energy consumption. The company used IT applications to bring together all its control systems under one switch, and to provide an on-screen Plant Information System as a means of monitoring energy consumption. This has resulted in energy savings of up to 5%, and an early-warning system for any anomalies (e.g. pressurised air leakages) within the production system.

Irish food producer **Jacob Fruitfield** has introduced an Energy Monitoring System to tackle deficiencies identified in an energy audit. The system has helped to reduce gas consumption by 9%, provided better understanding of consumption patterns, and has instilled greater energy awareness among staff.

Coop, Switzerland's second-largest retailer has implemented an Energy Management System in an attempt to reduce electricity and heat consumption, and to meet its commitments under national climate policy. The system combines data collection from its 950 food retail stores with a comprehensive building management system, which makes sure that target values for temperature and consumption of fuel, electricity and water are met. It also oversees the recovery of energy from the cooling system, which has reduced heat energy demand by some 60%.

Implications and outlook

It is of great policy relevance to better understand whether and under what particular circumstances the promotion of ICT and e-business can actually help to reduce energy consumption by increasing energy efficiency. In the literature, the majority of the research undertaken so far is based on case studies and qualitative analysis and has focused on the residential sector (e.g. PCs) and service sectors (e.g. data centres), rather than on the industrial sectors, as it is done in the sectoral econometric studies presented in this report.

Due to the heterogeneity of industrial structures and ICT diffusion patterns across different industries, such an analysis is likely most useful at the sectoral level. Moreover, it seems useful to also look at the role of other input factors of production than energy, such as material input, service input, and non-ICT capital stock, for assessing their impact on production output.

The main results from this study can be summarised as follows

(1) The study of the relationship between ICT and energy consumption at the aggregate industry level has proven to be an innovative and fruitful area of research from which many new insights can be gained. An improved data basis is needed to be able to undertake further empirical econometric studies, both in terms of countries covered and disaggregation by capital input factors. So far, based on EU-KLEMS and Eurostat data and due to data restrictions (in terms of a lack of data or of disaggregation), it was only possible to account for a relatively small number of EU member countries.

Also, in many cases only the impact of ICT and non-ICT capital can be distinguished, which makes it impossible to find out more about the relative impact of computers, software, communications technology etc. Given that more and more ICT intelligence is built into products not explicitly tagged as ICT capital, new ways have to be found to identify the impact of this "hidden" part of the ICT story.

(2) From the empirical analysis, we find that the relative impact of the various input factors depends strongly on the sector studied, and that ICT capital often has a minor impact only on production output and/or electricity intensity.

(3) In line with a study on the French services sector, we find some empirical evidence for the chemicals, metals and transport industries that computers and software have a very different impact on electricity intensity than communications devices, and that the former seemingly tend to increase electricity intensity, while the impact of communications devices apparently helps to mitigate the intensity of electricity use.

1 Introduction

Energy markets have seen major changes in recent years, driven mainly by liberalisation efforts, unbundling of vertically integrated industries, and the emergence of new (and often decentralised) energy technologies. At the same time, the role of information and communications technologies (ICT) and e-business in shaping energy needs and energy consumer behaviour has increased tremendously. ICT and e-business can help to reduce energy consumption and thus costs, e.g. by reorganising production processes and better monitoring, but it can also lead to additional demand for energy due to new products and services provided as well as changes in relative prices of goods and services offered in the various markets. ICT and e-business induce considerable change in the social and economic structures and behaviour, so that in turn the intensity and structure of energy consumption can be expected to be substantially affected by these induced changes as well.

Energy-intensive industrial businesses (such as chemicals and steel), for instance, may be able to raise revenues (and thus profitability) by trading self-generated surplus electricity as peak-power or reserve capacity on the (exchange-based) electricity spot market. In contrast, smaller firms and private households are enabled to cut on their energy bills by using new devices for visualising energy consumption by appliance, by differentiating tariffs by time-of-use, and by facilitating the switching among energy suppliers. The use of Broadband Internet and wireless ICT (e.g. GSM, UMTS, Wimax, DSL) plays an important role in this development. By means of ICT and related services, passive market participants can turn into active participants, offering significant potentials for the creation of value added from a whole range of new services and for making markets more efficient.

The overall impact of the diffusion of ICT and e-business on energy consumption (and hence also on air pollutant and greenhouse gas emissions) in ICT-using sectors is ambiguous, and depends on the relative magnitude of two countervailing forces: (1) an *income effect* caused by the economic boost accruing from increased ICT use (increase in energy consumption) and (2) a *substitution effect* caused by changes in the industrial structure and the capital stock towards higher productivity (decrease in energy consumption). Furthermore, there might also be some substitution of ICT and energy for labour and/or other input factors.

The outcome of higher ICT use on energy consumption depends on a number of other factors as well, such as the industrial structure and the *ex ante* patterns of energy use. Takase and Murota (2004), for example, found that Japan could save energy by promoting ICT in the years to come, while further penetration of ICT in the U.S., where the substitution effect is already more pronounced, might actually increase energy use. Hence it is of great policy relevance to better understand whether and under what particular circumstances the promotion of ICT and e-business can actually help to reduce energy consumption levels. Due to the heterogeneity of industrial structures and ICT diffusion patterns, such an analysis is likely most useful at the sectoral level. Generally speaking, ICT is most helpful where processes are very complex (multiple processes). It is obvious that econometric studies at the sectoral level can only address a limited range of topics, and only to the extent that suitable and sufficient data are available.

Another important aspect is the impact of rising energy prices on the deployment of energy-efficient and energy-saving ICT applications, i.e. the innovativeness of the ICT-manufacturing sector. In this context, two aspects are of particular interest: First, it can be expected that due to rising energy prices (and thus costs), both firms and private households will increase their demand for ICT applications that support the efficient management of energy use. This will create a market for novel ICT tools (hardware and software), which in turn will affect the overall cost of doing business and, as a result, firm performance. Energy price rises can be expected to spur the use of ICT that enables to reduce energy costs. As the growth in the ICT stock, together with rising energy prices, considerably increases the cost of doing business, ICT-using sectors can be expected to exercise pressure on the ICT-manufacturing sector to develop more efficient hardware. The existence of this feedback effect has already been confirmed in empirical research. According to Popp (2002), for example, energy prices and the quality of existing knowledge on the supply-side have strong positive effects on innovations. In short, the demand for ICT-enabled energy management tools and more energy-efficient applications will drive the technological progress in the ICT-producing sector. The feedback effect just mentioned will consequently have an influence on the competitiveness of both the ICT-using sectors and ICT manufacturers.

In the following, we first introduce the main research objectives and the specific research questions tackled in our research, after which we describe the specific methodology used. Section 2 provides a survey of the related literature, section 3 describes the econometric modelling, and section 4 the reports on the case studies conducted. Section 5 concludes with an outlook on trends and policy implications.

1.1 Research motivation

So far very little research has focused on quantitative analysis aimed at determining the relationships between ICT usage and energy use (e.g. Romm, 2002; Takase and Murota, 2004; Collard et al., 2005; Cho et al., 2007). Qualitative studies have typically focused on the energy efficiency potentials offered by ICT, such as the project “eEnergy” (Franz et al., 2006). In contrast to these existing and mainly analytical-descriptive studies, this research wants to empirically test several hypotheses derived from economic theory. In essence the motivation for undertaking this kind of analysis is twofold:

The *prime motivation* is to determine which effect dominates in European industries (i.e. the energy-saving/substitution or energy-increasing/income effect of ICT diffusion at the aggregate, sectoral level), an issue of great importance in the light of global climate change, other environmental problems, and concerns about future energy supply security. The analysis focuses on the energy consumption changes induced by the spread of ICT in ICT-using sectors. It is often claimed that the diffusion of ICT drastically increased energy consumption. For instance, in 2006, businesses world-wide spent approximately $55 billion on new servers alone (Lawton, 2006). To power and cool those machines they spent $29 billion, almost one half of the cost of the equipment itself. One of the questions arising in this context is whether the energy efficiency increases that accrue from the use of this modern equipment compensates for higher energy consumption that arises from the use of additional (new and/or more numerous) equipment.

A *second motivation* for our analysis is the desire to study the impact of changes in the relative prices of input factors, and the price of energy in particular, on ICT diffusion. Particularly, it is interesting to investigate the relative and the combined impact of ICT diffusion and energy prices on energy consumption of ICT-using industries, and also to study the extent to which the spreading of ICT in the sectors studied are able to affect the price responsiveness of energy demand.

In this Sectoral e-Business Watch study we aim at theoretically and empirically investigating the above-mentioned issues. The empirical work is guided by the availability of data and appropriate econometric model specifications that allow for the testing of various hypotheses derived from the theoretical considerations.

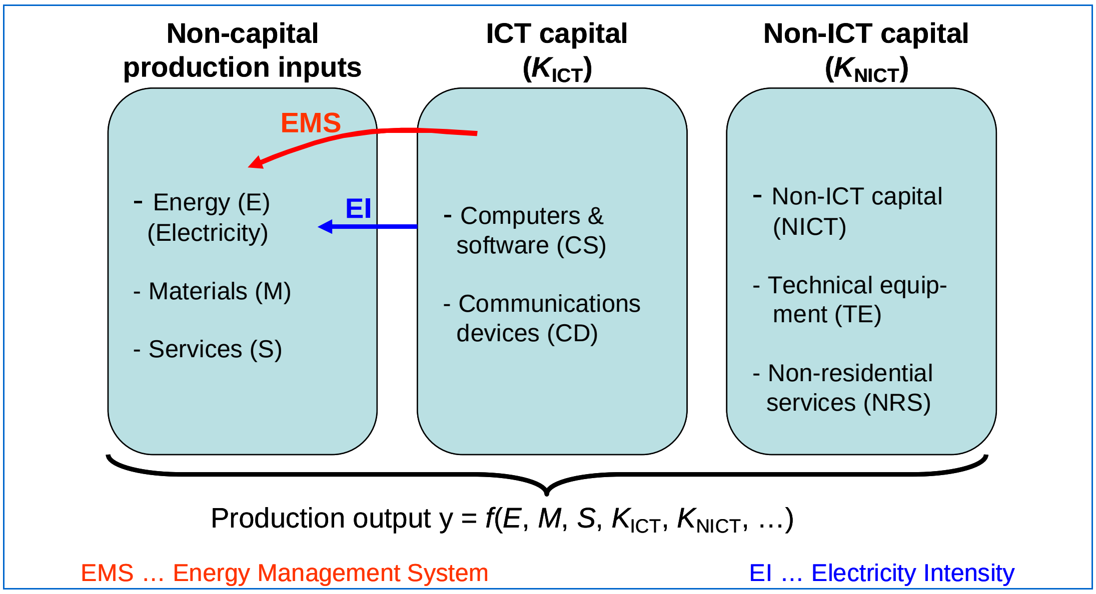
1.2 Study methodology and objectives

Several specific topics are addressed in this study. In particular, we aim

- to determine whether income or substitution effects of ICT diffusion viewed against energy use dominate in selected European industries covered by e-Business Sectoral Watch;
- to identify cross-sectoral differences in the way ICT diffusion impacts energy consumption patterns in selected ICT-using industries;
- to scrutinise the responsiveness of gross output with respect to ICT capital, energy input and other production factors for the industries scrutinised;
- to assess the impact of ICT and other production input factors on electricity intensity for the selected industries.

Figure 1 depicts the conceptual framework used for the analysis. As can be seen the focus is on non-capital production inputs (energy, materials, services), ICT capital (computers and software, communications devices), and non-ICT capital (non-ICT capital, technical equipment, non-residential services).[1]

Figure 1: Conceptual framework for the analysis of ICT and energy consumption



Source: own illustration

[1] Note that these variables are the ones contained in the EU KLEMS database. In contrast to most earlier studies, an analysis on such a detailed aggregation level has not been possible before for sets of European member countries.

In order to make use of the conceptual framework depicted in Figure 1, a mix of methodologies is used. First, *desk research* is undertaken to study the literature on ICT and energy and electricity consumption. This also helps to better assess the original contribution made by our research to the existing body of literature.

Second, three *case studies* are conducted based on face-to-face or telephone interviews that were preceded by an evaluation of written documentation of the companies investigated and in particular the role of ICT for reducing energy and electricity consumption.

Third, *econometric analysis* is undertaken. To this end, we take the current state-of-the-art of structural econometric research on ICT and energy use as a starting point. A set of theory-guided hypotheses regarding ICT impact on the above mentioned energy-related factors is formulated and econometrically tested. After the stage of model estimation is completed, model specification tests will be performed in order to check the models' accuracy and performance (e.g. in terms of possible misspecification and the robustness of the results). If the diagnostics are satisfactory, hypothesis testing and the assessing of the validity of the theoretical predictions can follow. Finally, the outcomes of the empirical analyses are compared with the insights from the literature and Sectoral e-Business Watch survey and the case studies, and then used for deriving policy implications. Finally, we also screened the Sectoral e-Business Watch 2007 survey data with respect to energy-related questions and their usefulness to corroborate (or invalidate) our hypotheses, and incorporated the findings into this report.

1.2.1 Sectoral focus

The impact of ICT on energy use is closely linked to the extent to which different ICT applications have spread across different industries (we use examples from the sectors analysed in this project). This is partly so because ICT is a network technology (i.e. the more people or entities use ICT, the larger the accruing benefits tend to be). Consequently, despite the fact that a single firm is interested in the benefits it can derive individually from the use of ICT, high levels of ICT usage in one industry may lead to positive externalities at the sectoral level. Furthermore, industry-specific factors determine the speed of ICT diffusion, the type of applications being adopted, and the benefits that can be reaped in the short and the longer term (e.g. energy-intensive industries can be expected to enjoy larger benefits from adopting ICT to better manage energy use). Consequently, sectoral characteristics influence not only the intensity of ICT and energy use, but the economic impact of ICT and eventual energy consumption patterns as well. This clearly calls for a disaggregated (sectoral) level of analysis, as it is envisaged in the Sectoral e-Business Watch project.

1.2.2 Extensive approach

An important problem of determining the impact of ICT on energy use is related to the fact that the use of ICT influences firm performance primarily when accompanied by other changes and investments, which are not necessarily classified as such. This includes, for example, investments in skills, organisational arrangements, or the availability of external expertise. Another factor contributing to the positive impact of ICT usage is that it fosters innovation of the adopting firms. Users often help to make investment in ICT more valuable through their own experimentation and invention. Without this process of *co-*

invention, which often has a slower pace than technological innovation, the economic impact of ICT and its impact on energy consumption would be more limited (Pilat, 2005). Moreover, *learning-by-using* can lead to important improvements of the technology. Thus, the case study analysis will not only focus on the diffusion of ICT with respect to energy use, but will aim to account for factors accompanying the process of ICT adoption. Particular emphasis will be placed on skills, skill development and organisational change.

1.2.3 Dynamic perspective

Results from recent empirical research suggest that the returns to ICT investments usually do not occur immediately, but only with significant time lags (Brynjolfsson and Hitt, 2003). For example, computers make a positive and significant contribution to output growth at the firm level, but the implied returns tend to increase over time, suggesting that time-intensive complementary investments into organisational restructuring have to be undertaken as well. Moreover, the potential of ICT to increase factor productivity and operational efficiency, and in particular concerning energy use, does not remain constant. The positive effects are particularly strong in the early times of technology use and tend to diminish. Reasons include the fact that system optimisation is often not done on a continuous basis, but only when major changes occur, leading to gradual losses in system efficiency. Thus, the adoption of a particular technology is a step in levels, rather than a permanent increase in the rate of growth. Consequently, the analysis performed will to a certain extent also have to account for the dynamics of the ICT-driven change.

1.2.4 Analytical techniques

The analytical techniques, which will be considered for their suitability to assess the impact of ICT and e-Business on energy use, include the following:[2]

- **Multiple regression models**: There is plenty of evidence in the literature that the diffusion of ICT is not the only relevant factor that influences firm performance and economic transformation (Kohli et al. 2003). The same can be said for energy use patterns. Thus, whenever assessing the drivers of innovation or changes in energy consumption patterns, other variables than only ICT-related ones should be included in the econometric model as well. Multiple regression models account for various factors affecting the dependent variable and allow assessing the relative strength of their impact.

- **Panel data models**: Panel data models are considered to be the most efficient analytical method for using econometric data. They allow the inclusion of data that cover a number of cross-sections and time periods. The combined panel matrix set consists of a time series for each cross-sectional member in the data set, and offers a variety of estimation methods. Examples of different methods of panel data estimations include the common constant method, the fixed effects method and the random effects method, among others. The advantage of using panel methods has

[2] Note that the econometric techniques used are similar to those applied for the general analysis on the economic drivers and impacts of ICT and e-Business, with the major difference that the model specifications are different and that the techniques are applied in a different context. For a more detailed and formal description of the econometric methods listed see, e.g., Greene (1997) and Astriou (2006).

already been proven in a number of empirical studies analysing the impact of ICT (see Hitt et al. 1999; Vecchi et al. 2003). In recent years, panel data models have also been extensively used in the energy economics literature, although studies that combine ICT usage and energy use patterns are still few and far between.

1.2.5 Data and information sources

In this study we make use of several distinct data sources (EU KLEMS, Eurostat, e-Business Watch Survey), which are briefly described in the following. We also describe in some detail the data limitations encountered, which prevented us from covering a larger number of countries and industry sectors.

EU KLEMS data

The aim of the EU KLEMS research project is to create a database on measures of economic growth, productivity, employment creation, capital formation and technological change at the industry level for all European Union member states from 1970 onwards. The database uses a 63-industry breakdown for the major of the EU-25 Member States as well as for the U.S., Japan and Canada. Depending on the sectoral level and the country concerned, the length of the time series data varies (the oldest figures included are for 1970, and for the recently acceded Member States for 1990).

Table 1 EU KLEMS data availability by time ranges for the metals industry as an example (basic metals and fabricated metal products industries, NACE classification No. 27t28)

Country	IIE, IIM, IIS	IIE-QI, IIM-QI, IIS-QI	LAB, CAP	LAB-QI	CAP-QI	CAPIT, CAPNIT	CAPIT-QI, CAPNIT-QI
Austria	80-04	80-04	70-04	80-04 (27t28)	76-04 (27t28)	76-04(27t28)	76-04 (27t28)
Belgium	95-04	95-04	70-04(27t28)	86-04 (27t28)	70-04 (27t28)	70-04(27t28)	70-04 (27t28)
Cyprus	x	x	95-04	x	x	x	x
Czech Republic	95-04	95-04	95-04	95-05 (27t28)	95-04 (27t28)	95-04 (27t28)	95-04 (27t28)
Denmark	70-05	70-05	70-05	80-04 (27t28)	70-05 (27t28)	70-05 (27t28)	70-05 (27t28)
Estonia	00-02	x	95-04	x	x	x	x
Finland	70-04	70-04	70-04	70-04 (27t28)	70-04 (27t28)	70-04 (27t28)	70-04 (27t28)
France	78-04	78-04	70-04	80-04 (27t28)	70-05 (27t28)	70-04 (27t28)	70-05 (27t28)
Germany	78-90(t), 91-04	78-90(t), 91-04	70-04	70-04 (27t28)	70-04 (27t28)	70-04 (27t28)	70-04 (27t28)
Greece	95-99	95-99	70-04	x	x	x	x
Hungary	95-04	95-04	92-04	95-04 (27t28)	95-04 (27t28)	95-04 (27t28)	95-04 (27t28)
Ireland	x	x	70-04	x	x	x	x
Italy	70-91(t), 92-04	70-91(t), 92-04	70-04	70-04 (27t28)	70-04 (27t28)	70-04 (27t28)	70-04 (27t28)
Latvia	x	x	95-04	x	x	x	x
Lithuania	x	x	95-04	x	x	x	x
Luxembourg	95-04	95-04	70-04	x	70-04 (27t28)	70-04 (27t28)	70-04 (27t28)
Malta	00-01	x	95-04	x	x	x	x
Netherlands	81-86(t), 87-04	80-86(t), 87-04	70-04	79-04 (27t28)	70-04 (27t28)	70-04 (27t28)	70-04 (27t28)
Poland	95-04	95-04	95-04	95-05 (27t28)	95-04 (27t28)	x	x
Portugal	x	x	70-04	x	x	x	x
Slowak Republic	95-05	95-05	95-05	95-05 (27t28)	x	x	x
Slovenia	95-04	x	95-04	95-04 (27t28)	95-04 (27t28)	95-04 (27t28)	95-04 (27t28)
Spain	80-04	80-04	70-04	80-04 (27t28)	70-05 (27t28)	70-04 (27t28)	70-05 (27t28)
Sweden	93-03	93-03	70-04	93-04 (27t28)	1993-2004	1993-2004	1993-2004
UK	70-04	70-04	70-04	70-04 (27t28)	70-04 (27t28)	70-04 (27t28)	70-04 (27t28)
EU-25	x	x	95-04	x	x	x	x

Note: The variable name tags in the table are the ones used in EU KLEMS: IIE, IIM and IIS denote energy, materials and service inputs, respectively, LAB stands for labour, CAP for capital, CAPIT for ICT capital, and CAPNIT for non-ICT capital. The extension "-QI" denotes that the data concerned are expressed in volume (in contrast to value) terms.

The data used from the EU KLEMS database for the present study comprise intermediate energy, materials and service inputs, labour input, and ICT and non-ICT capital. Due to limited availability of data (cf. Table 1), we have decided to use time series cross-sectional data from 1980 to 2004 for eight EU member countries[3]. EU KLEMS is an extensive database provided by the Groningen Growth Development Center (GGDC).

Note that the NACE classifications covered by our analysis are much broader than the ones addressed by Sectoral e-Business Watch. Due to these limitations in data availability, the adoption of a somewhat broader research focus was unavoidable.

Eurostat data

For the econometric analysis focusing on ICT usage and electricity consumption as well as some of the descriptive analysis, we have also made use of EUROSTAT data (Eurostat, 2006) of electricity consumption and electricity prices. Unfortunately, the disaggregation of the former is still fairly limited, again restricting the depth of the analysis that can be performed.

e-Business Watch Survey data

We also screened the e-Business Watch Survey Data (CATI Sectoral e-Business Watch Survey 2007) for their coverage of energy use and ICT, which was the case for the Transport & logistics sector only (see Section 1.1.5).

1.2.6 Descriptive data analysis

The SeBW project uses both descriptive and analytical methods. Descriptive methods are used to present survey results (from other sources as well as from the SeBW Surveys) on ICT adoption and e-business activity. Analytical statistical methods are applied for the study of ICT impact.

Experience from the past shows that survey results in the form of simple frequencies of enterprises reporting particular activities or influences, as well as compound indicators derived from these frequencies, have limited power in explaining ICT impact. Analysis of appropriate data sets using advanced statistical methods is required to gain robust and meaningful evidence on ICT effects. This is the main aim of Section 2.

Here we present some descriptive analysis related to ICT and energy consumption that helps to gain some feeling for and general insights from the data used. One way to study the relationship between ICT and energy (electricity) consumption is by means of computing ratios and looking at energy (electricity) intensities relative to the level of ICT capital services used.

As can be seen, the ratio for total industries varies quite substantially among the EU member countries investigated, and the ratio for the chemical industries in some member countries is considerably higher and lower in others (i.e. there is no clear pattern across the member countries). Specifically, when looking at all industries, we can see that industries in Finland, France, Germany, Italy and Spain are above the EU average in terms of electricity-intensity, while Austria, Denmark and the UK are below the average value. Regarding the chemical industries, the difference to total industries is that France is now also below the EU average.

[3] These are: Austria (AUT), Denmark (DNK), Spain (ESP), Finland (FIN), France (FRA), Germany (GER), Italy (ITA), and Great Britain (GBR). For all other countries the time series of the variables needed were considered as too short for being included in the econometric analysis.

Table 2 shows the ratio between electricity consumption and ICT capital for all industries jointly, and for the chemical industries as a specific example, for the years 2003 and 2004.

As can be seen, the ratio for total industries varies quite substantially among the EU member countries investigated, and the ratio for the chemical industries in some member countries is considerably higher and lower in others (i.e. there is no clear pattern across the member countries). Specifically, when looking at all industries, we can see that industries in Finland, France, Germany, Italy and Spain are above the EU average in terms of electricity-intensity, while Austria, Denmark and the UK are below the average value. Regarding the chemical industries, the difference to total industries is that France is now also below the EU average.

Table 2: Ratio between electricity consumption and ICT capital services, total and chemical industries, selected EU members (index ratio 1995= 1)

	Total Industries		**Chemical Industries**	
	2003	*2004*	*2003*	*2004*
Austria	0.31	0.30	0.31	0.31
Denmark	0.23	0.21	0.17	0.14
Finland	0.55	0.53	0.57	0.55
France	0.53	0.51	0.45	0.39
Germany	0.41	0.40	0.51	0.52
Italy	0.49	0.48	1.41	1.82
Spain	0.61	0.60	0.60	0.63
UK	0.30	0.28	0.35	0.34
EU-15	0.40	0.38	0.50	0.49

Source: Data from EU KLEMS and Eurostat, own calculations

Figure 2 depicts the development of the ratio between intermediate energy inputs and the ICT capital stock for the basic metals and fabricated metal products industry for the selected EU member countries (Austria, Denmark, Spain, Finland, France, Germany, Italy, and the UK). It can be seen that Denmark and the UK have seen the most significant reduction in the ratio, followed by Austria and France, and then Spain (where the ratio flattens out much earlier than for the before-mentioned countries), while the other three countries have experienced a less rapid development and several up- and down-swings.

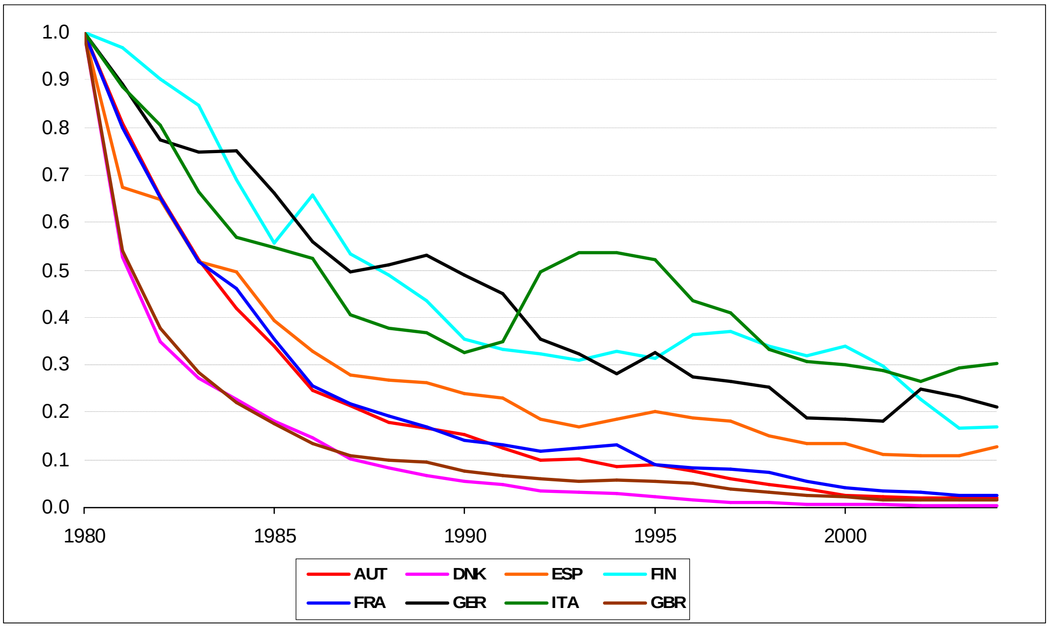


Figure 2: Ratio between energy inputs and ICT capital, metals industry, selected EU member countries, 1980-2004, (data in volumes, indexed ratio, 1980=1)

Source: Data from EU KLEMS, own calculations

As a next step in our descriptive data analysis, we made a visual inspection of the time series data by country for the different input factors considered, both in value (in billion €) and in volume (indexed, 1995=1), i.e. based on the EU KLEMS data. The following twelve plots depicted in Figures 3-8 show the trends in value and in volume terms of the intermediate input factors (energy, materials, services and labour, IT capital, non-IT capital) for the basic metals and fabricated metal products industry.

According to Figure 3, energy inputs per hour worked in value terms reach by far the highest numbers in Denmark. In recent year, energy input per work hour rose also steeply in Germany (left plot). The other countries reported exhibit a very similar performance, with UK at the lower end. In value terms, Finland overarches all other countries by far (right plot).

Figure 4 shows that in terms of materials input per hour worked again Denmark and Finland show an outstanding performance in value and volume terms, respectively. Other countries do not significantly differ from one another. Again, the UK is at the lower end of the curves, indicating a much lesser material input per work hour.

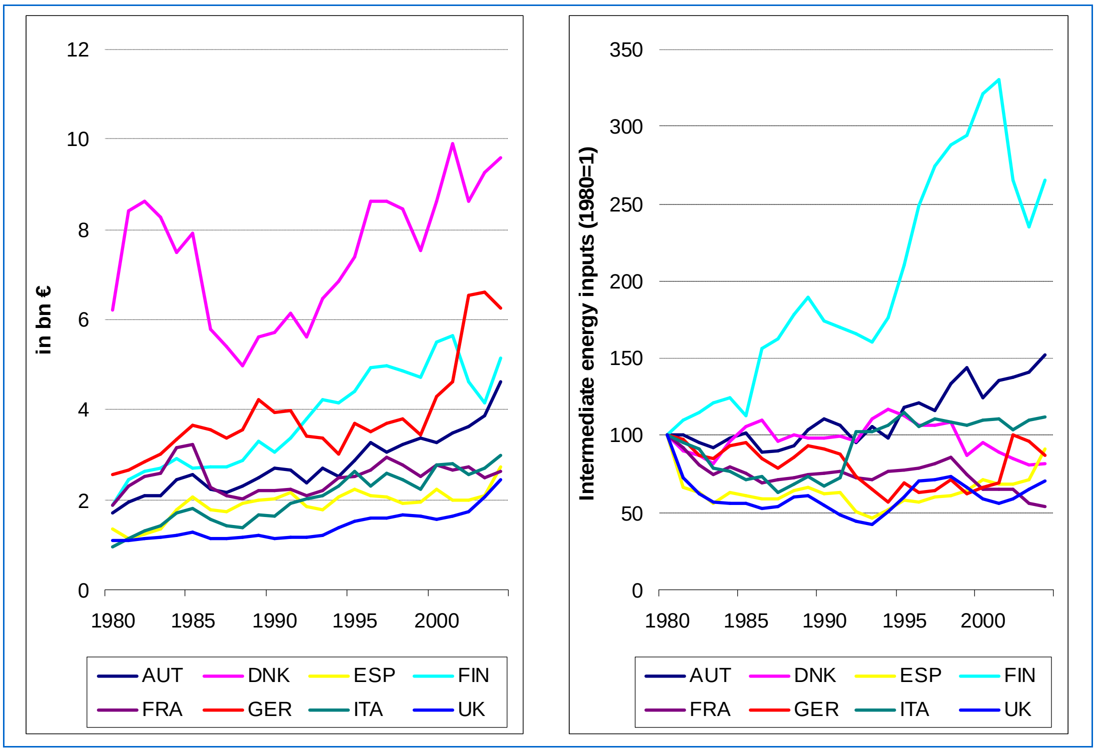


Figure 3: Energy input per hour worked in the metals industry, selected EU member countries, 1980-2004 (left plot: values, right plot: volumes)

Source: Data from EU KLEMS, own calculations

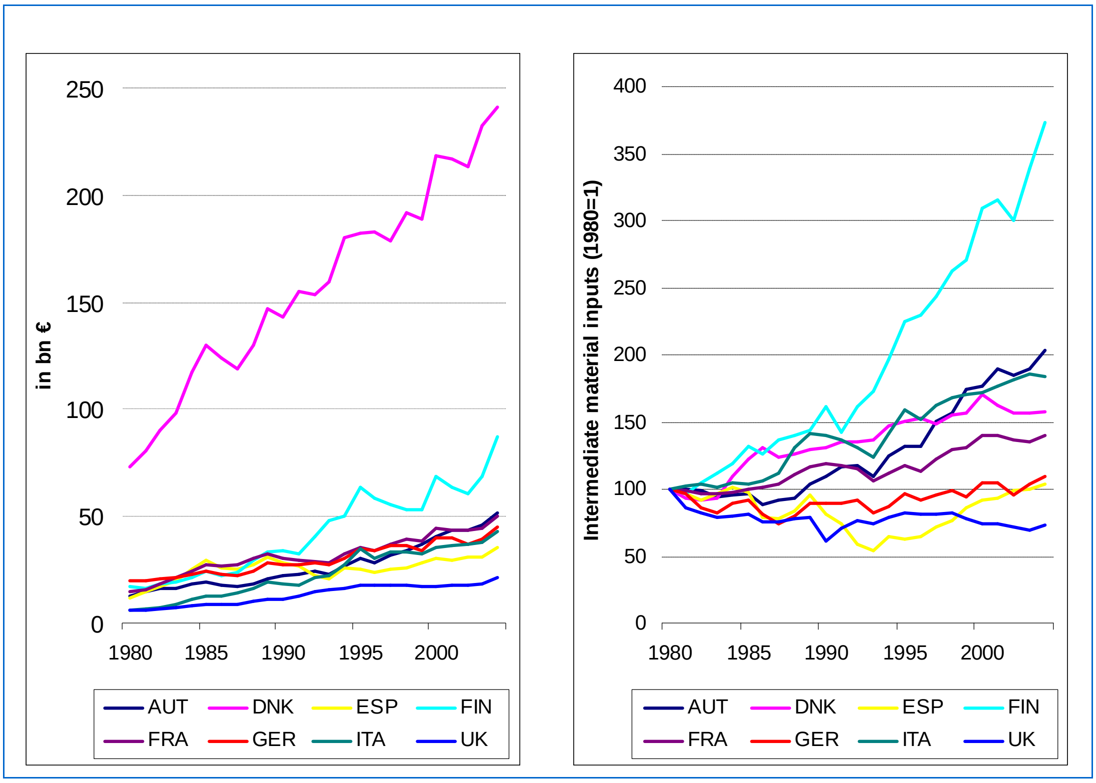


Figure 4: Material input per hour worked in the metals industry, selected EU member countries, 1980-2004 (left plot: values, right plot: volumes)

Source: Data from EU KLEMS, own calculations

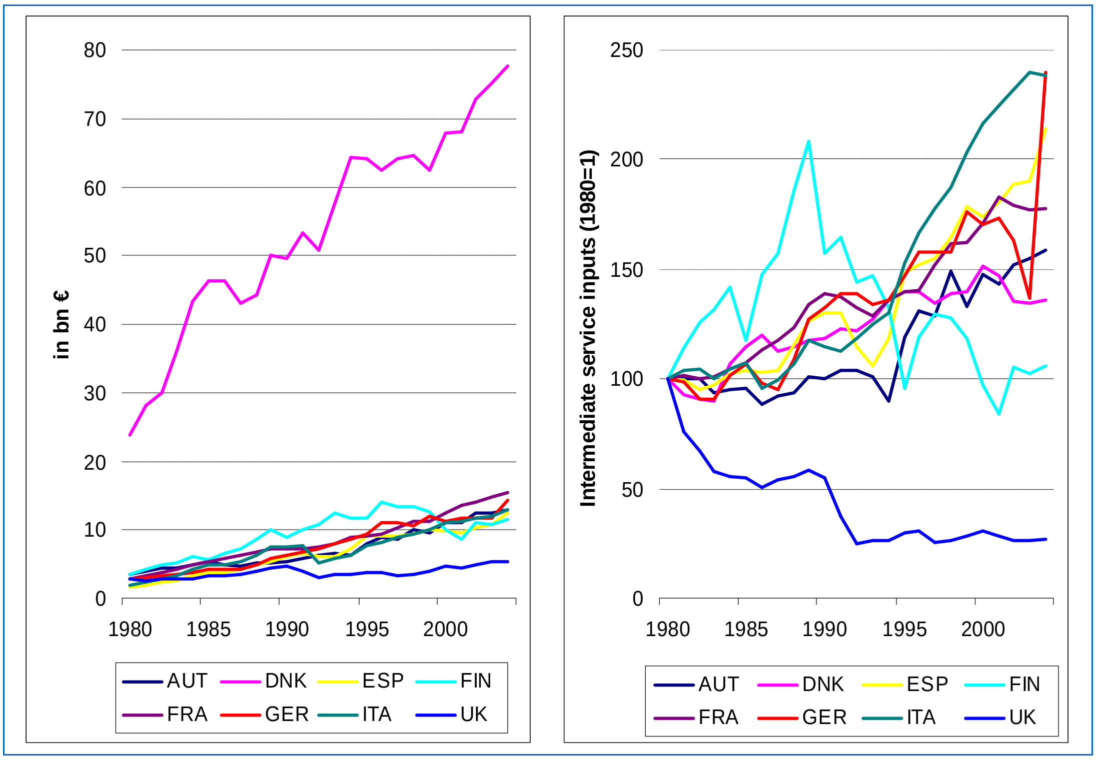


Figure 5: Service input per hour worked in the metals industry, selected EU member countries, 1980-2004 (left plot: values, right plot: volumes)

Source: Data from EU KLEMS, own calculations

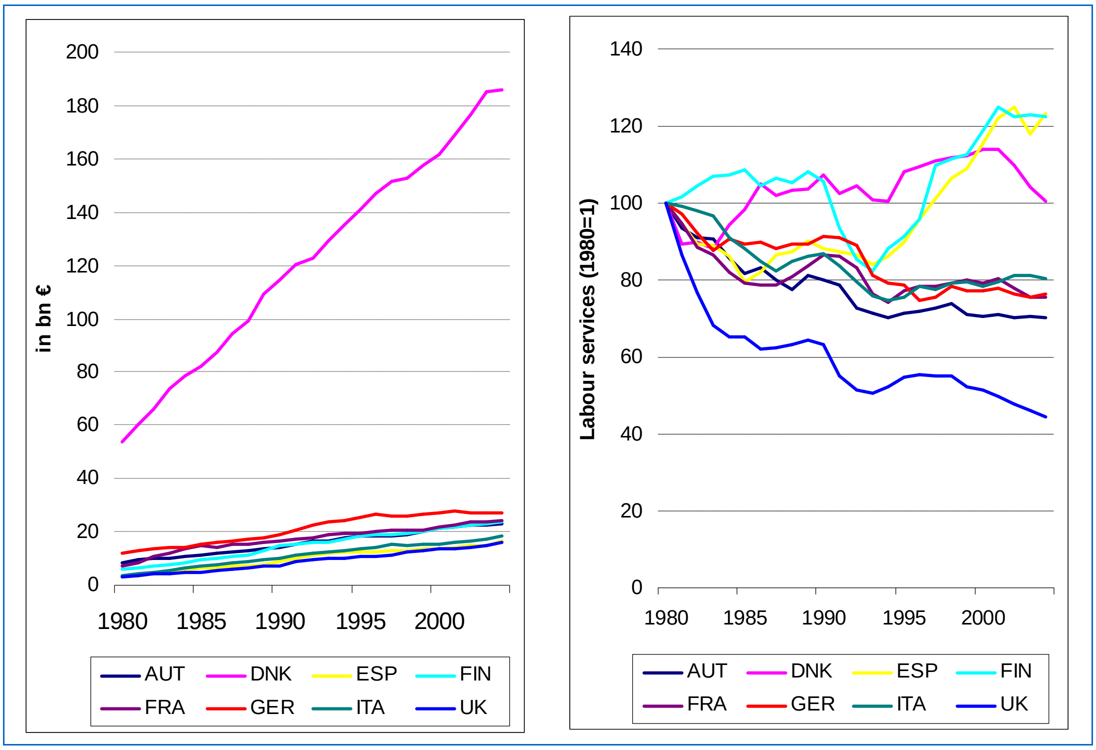


Figure 6: Labour input per hour worked in the metals industry, selected EU member countries, 1980-2004 (left plot: values, right plot: volumes)

Source: Data from EU KLEMS, own calculations

Figure 5 shows the analogous graphs for the service inputs in the metals industry. In terms of value, the countries' results are homogeneous except for the UK and Denmark. On the other hand, it is eye-catching that the right plot (volumes) is much more heterogeneous. Overall, an increase in the mean values can be found but variances for the different countries vary widely.

Figure 6 depicts the development for the labour inputs in the metals industry The same remarks as in the previous figure can be given here. Once again, the UK figures in terms of volume distinctly undercut those of all other member countries reported.

Figure 7 presents the corresponding data for ICT capital compensation shares and ICT capital in volume terms for the metals industry. As can be seen, the share of ICT in total capital compensation has increased steadily in France, Austria and Italy since 1980, while the shares of the other countries fluctuated strongly in the past years. In terms of volume, it can be seen that Denmark increased its ICT capital services input per hour worked most distinctly, especially over the last decade.

Finally, Figure 8 shows the development of the non-ICT capital compensation shares and non-ICT capital services inputs in volume terms for the metals industry from 1980-2004. A general decrease in the shares of non-ICT in total capital compensation can be detected for all countries reported, whereas a general increase in terms of volume can be identified for all countries but the UK.

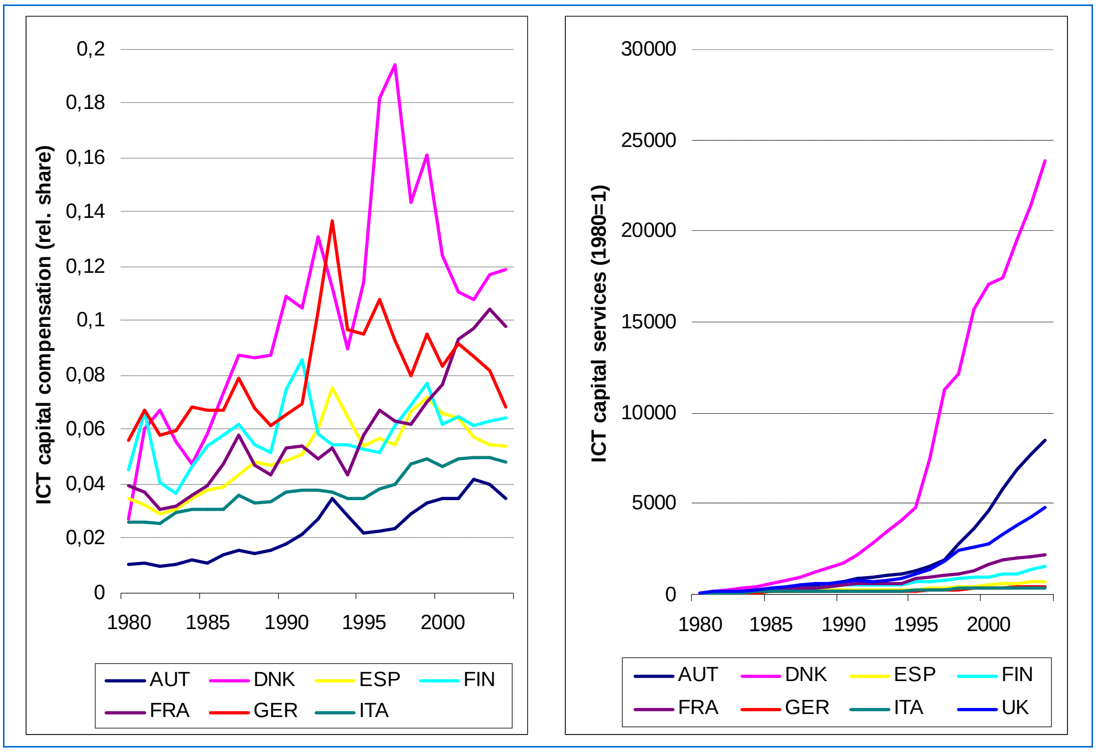


Figure 7: Shares of ICT capital compensation (left plot) and volume of ICT capital services in the metals industries, selected EU member countries, 1980-2004

Source*:* Data from EU KLEMS, own calculations

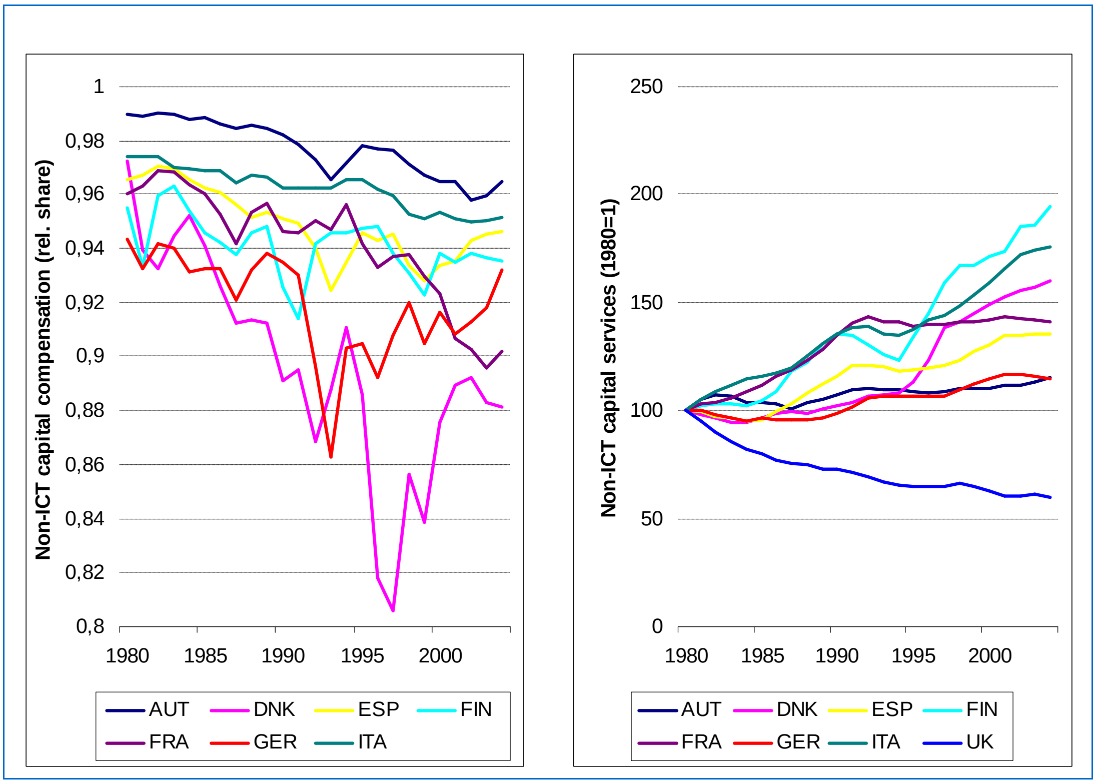


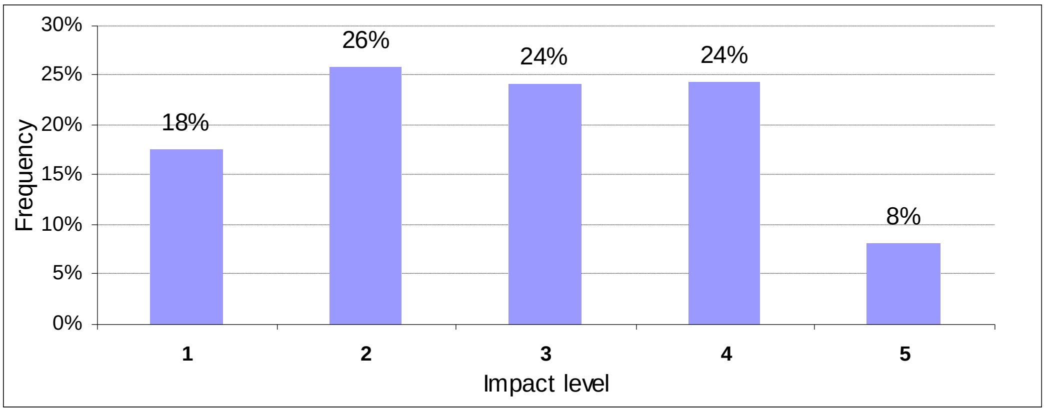
Figure 8: Shares of non-ICT capital compensation (left plot) and volume of non-ICT capital services in the metals industry, selected EU member countries, 1980-2004

Source: Data from EU KLEMS, own calculations

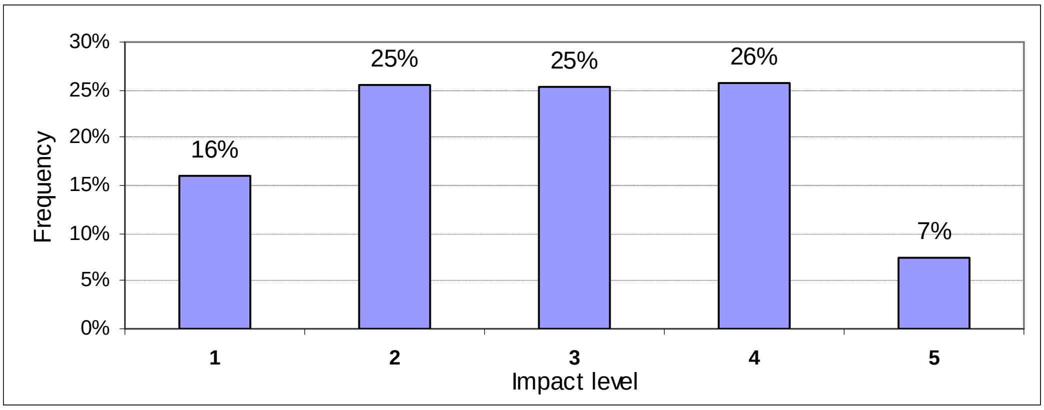
e-Business Watch Survey Data

We also had a look at the data from the Sectoral e-Business Watch Survey 2007, and found that only one question was relevant for our study. In particular, with the question "Would you say that ICT has a high, medium, low or no impact on the following transport and logistics aspects", interviewees from the transport and logistics industry were asked about the impact of ICT on energy consumption in transport systems, the results of which are reported in the frequency plots depicted in Figure 9.

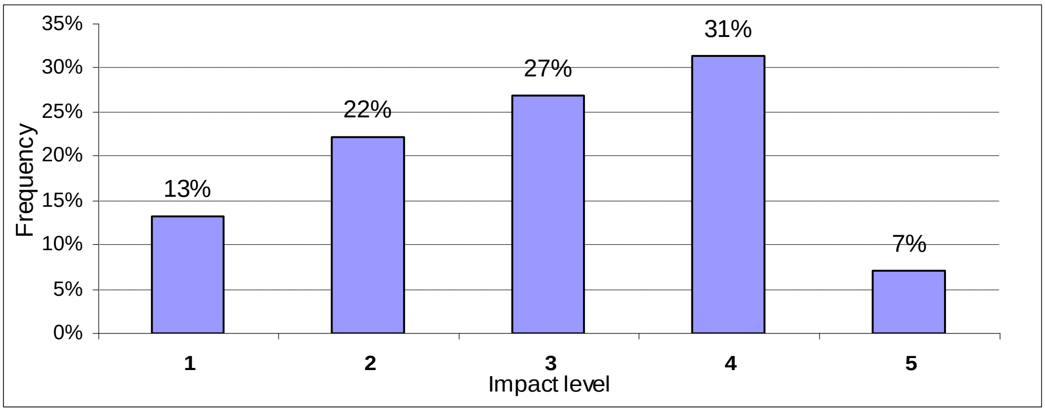
Interestingly, as can be seen from these plots, only 13-18% consider ICT to have a high impact, 22-26% to have a medium impact, 24-27% to have a low impact, and remarkably 24-31% that it has no impact (7-8% DK).



(a) France, Germany, Italy, Spain, Sweden, Poland, and the UK[4]



(b) France, Germany, Italy, Spain, and the UK



(c) Germany, Italy, and the UK[5]

Figure 9: Frequency distribution of the impact of ICT on energy consumption in transport systems, selected EU member countries

Likert scale: 1 = high impact, 2 = medium impact, 3 = low impact, 4 = no impact, 5 = don't know

Source*:* Data from SeBW Survey 2007, own calculations

[4] These are the countries listed in Table 1 for which these data are actually available from the SeBW survey.

[5] Countries used in the econometric modelling in Section 2.1 (without Denmark, for which no data from the SeBW Survey 2007 are available for this issue).

1.2.7 Validation of results

The study was conducted in consultation with an Advisory Board that was specifically implemented to critically accompany the study from the start. Members of the Advisory Board for this study were:

- Bernard Aebischer, Centre for Energy Policy and Economics (CEPE), ETH Zurich, Switzerland
- Maher Chebbo, SAP AG, Paris, France
- Lorenz Hilti, EMPA, St. Gallen, Switzerland
- Petteri Repo, National Consumer Research Centre (NCRC), Helsinki, Finland
- Martin Wörter, Swiss Economic Institute (KOF), ETH Zurich, Switzerland

For each Advisory Board, in addition to informal exchanges with the respective study teams during the research phase (e.g. via telephone, e-mail and in bilateral meetings), two meetings were foreseen. The **first meeting** took place on 29/30 May 2007 in Brussels, during the inception phase. At this meeting, the study exposé and research plan was discussed. A **second meeting** was held on 7 February 2008 in Brussels with the objective to discuss and validate the findings of the interim report.

1.3 Literature Review

In this impact study on ICT and energy consumption, the focus is put mainly on economic aspects and the econometric modelling and inference at the sectoral level. Hence we will start by an overview of relevant economic studies, followed by a selection of other studies which we found interesting and useful.

1.3.1 Economic studies on the relation between ICT and energy

In the economics literature, there is a vast body of more general studies focusing on energy price, technical change, and energy consumption. In contrast, few studies so far have dealt with the relationship between ICT and energy consumption. In the following, we summarise some of the studies more closely related to ours.

Popp (2001), as part of a broader study of the effect of energy prices on the development of new technologies for energy conservation or the provision of new energy sources, uses patent data to estimate the effect of new technologies on industrial energy consumption. He simulates the effect of an energy tax of 10% on induced innovation, and finds that factor substitution plays a greater role than induced innovation in the short run, while it has a much larger role than factor substitution in the long run, due to the cumulative nature of research.

Laitner (2000) finds that energy intensity was 4.4% in 1996, while for ICT sectors it amounted only to 0.8%. He argues that the deterioration of the U.S. energy intensity over the past three years, in the absence of any considerable price signals or policy initiatives could have been caused by a structural change encouraged by ICT. This structural change can enhance economic output and yield climate benefits.

Romm (2002) observes for the U.S. that GDP and energy consumption grew at a yearly average rate of 3.2% and 2.4% in the “pre-Internet era” (1992-1996), and 4% and 1% in the “Internet era” (1996-2000). The decoupling of GDP and energy consumption growth is based on two different effects. First, the IT sector is less energy-intensive than traditional manufacturing and, second, the Internet economy appears to be increasing energy efficiency in every sector of the economy. Hence the Internet is driving energy efficiencies above the acceleration of electricity demand.

Takase and Murota (2004) study the relative size of the impact of IT investment on energy consumption and CO_2 emissions in Japan and the U.S. by means of an economic and an energy model, for a business-as-usual case and a stimulated IT investment case. Their main findings are: (1) increasing IT lowers energy (and CO_2) intensity; (2) whether an increase or a decrease in energy consumption happens depends on which effect is stronger – the income or the substitution effect; (3) by promoting IT, Japan could conserve energy, while the US would likely increase its energy use.

Cho et al. (2007) study the impact of ICT investment and energy price on industrial electricity demand in South Korea (11 sectors) by means of a dynamic logistic growth model and data from 1991-2003. They find evidence that (1) ICT investment in electricity intensive manufacturing industries promotes factor substitution away from labour to electricity; (2) ICT investment reduces electricity consumption only in some manufacturing sectors, but in the service sector and most manufacturing sectors it actually increases electricity consumption; (3) electricity price affects electricity consumption critically only in half of the industrial sectors, but not in the other half. Nevertheless, the increase of ICT use causes a higher efficiency, as Carpintero (2003) emphasises. Thus it is possible to maintain the current pattern of economic growth without increasing its environmental costs by integrating more ICT in industrial economies. The background is the fact that service sector and ICTs are less intensive in energy and materials use in comparison to traditional branches such as industry or agriculture. Several factors substantiate the efficiency boost through ICT, as well as the economic shift toward less energy intensive sectors; on that account the diffusion of ICT into business processes seems to be the most improving factor (Romm 2002).

Collard et al. (2005) investigate the development of electricity use and ICT in the French services sector. They use a simple factor demand model (based on a nested CES constant returns to scale production function), and study the effect of ICT capital goods, divided into computers and software on the one hand, and communication devices on the other hand, on the efficiency of electricity production. The six sectors studied are: (1) bars, hotels, and restaurants; (2) health and social services; (3) education and research; (4) sport, culture, and other recreational activities; (5) offices and administration; and (6) trade. By using a dynamic panel approach on a data set from 1986-1998 (6 x 13 = 78 observations) they find that the electricity intensity of production increases with the increased use of computers and software, while it decreases with the diffusion of communications devices.

A different approach has been adopted by Ishida and Yanagisawa (2003). They use a macro impact assessment model to study the impact of more intensive ICT use on energy consumption 10-20 years later from 2003, preparing two cases, a Base Case and an ICT Case. The latter assumes a more ICT-orientated socio-economic structure (while economic growth is assumed to be the same), and allows to calculate the impacts of intensified ICT bias from the differences between the two cases. Their conclusion is a diminuition of primary energy supply in 2010 by 1.4%, and a decline of final energy consumption in 2010 by 1.9% in the ICT case. Based on this analysis, even with an extra economic growth of 0.3% per year substantiated by ICT, energy consumption in Japan is not expected to increase overall.

1.3.2 Other studies

According to the suggestion made in Berkhout and Hertin's (2001) study for the OECD, the environmental impacts of ICT can be subdivided into three groups:

- *First-order impacts*, i.e. direct negative environmental effects from production, use and disposal of ICT components and positive effects, including the use of ICT for environmental protection purposes (e.g. by monitoring toxic emissions etc.).
- *Second-order impacts*, i.e. indirect effects mainly through dematerialisation (getting more input for less resource input), virtualisation (the substitution of information goods for tangible goods), demobilisation (the substitution of communication at a distance for travel), and
- *Third-order impacts*, i.e. structural and behavioural effects (economic growth / lifestyle changes / rebound effects).

Berkhout and Hertin state that the direct effects are mainly negative, whereas the indirect efficiency effects are largely positive and the structural effects highly argumentative. Similar classifications are adopted in other studies, Hilty et al. (2006) use a dynamic system approach in combination with scenario techniques and expert consultation for revealing great potential for ICT-supported energy management and structural changes towards a less material-intensive economy. Jørgensen et al. (2006) convert the classification marginally, considering first, second and third order relationships.

First order relationships refer to the *direct environmental impact* from ICT equipment and ICT infrastructure, e.g. the use of resources for the production, operation and disposal of ICT equipment. Second order relationships arise from the use of ICT in different applications and the influence on processes and products, e.g. intelligent product and processes. Third order relationships concern the changing structural composition of business product areas as broader social and structural changes, e.g. increasing travel due to increasing correspondence between people from different nations through e-mails.

The *indirect environmental impact* through dematerialisation is observed by Heiskanen et al. (2001). Their aim is to evaluate the potential of services and ICT to achieve a significant reduction of natural resource use. To this end they use data from Finland. It is mentioned that services and ICT do not automatically lead to significant absolute dematerialisation. Furthermore, they find that ICT and services have three roles in dematerialisation: (1) process efficiency; (2) the efficiency of value chains; and (3) providing an outlet for new consumption activities. First, ICT can improve efficiency within individual operations to increase resource productivity. Second, it can be conducive for a shift within sectors, changing the way the established sectors produce value (e.g. more services instead of natural resources). Finally, ICT can lead to a shift in consumption from one sector to another (e.g. material goods to ICT services). All of the three types of efficiencies are required for explicit dematerialisation. It is important to execute operations efficiently (e.g. paper needs to be manufactured efficiently). The value chain needs to improve further (e.g. reducing paper use through digital data transfer) and also the consumer need to change behaviour, such as borrowing books and magazines from the library instead of buying them.

In most of the recent publications it is argued that the increase of ICT use leads to a higher process and energy efficiency. Romm (2002) exposed that the Internet is not driving an acceleration of electricity demand; instead, it appears likely to be driving efficiencies.

The process efficiency can also imply economic structural change, an issue which is taken up by Laitner (2003). He claims that the possible impacts resulting from accelerated growth in the information economy are more efficient use of energy resources as in the use of pinch technology or microprocessors that optimise energy use across many dimensions of time and tasks and economic structural change (from manufacturing to services). Aebischer (2006) agrees with Laitner, he reasons that ICT will play an important role on inter- and intrasectoral structural changes. Basically, he sees an increase in ICT use of 60% until 2010. In a very recent study, Laitner and Ehrhardt-Martinez (2008) notes that ICT has increased the economic productivity and energy efficiency of the U.S. economy dramatically, and that the potential for further improvements in energy intensity by ICT is even more dramatic. These technologies helped developing a new socio-economic infrastructure, including worldwide digital telecommunications, internet service, electronic mail etc., which drives the expansion and diffusion of new applications, thus enabling the development of additional high-tech products and services, new investments and possibilities of doing things. All this led to increasing productivity and efficient use of energy and raw materials. Furthermore, ICT provides net savings of energy across the U.S. economy. Compared to 1970, the U.S. economy so far only spends half the energy to produce a dollar of economic output. ICT, he argues, has decoupled the relationship between economic production and energy consumption throughout the economy. The different applications and technologies enabled considerable energy savings, and system-wide energy savings arose from the omnipresence of ICT.

With regard to the substitution of energy intensive transportation towards less energy intensive ICT, the role of teleconferencing, telework and telemedicine is analysed by Arnfalk (2002) for Sweden and Postel-Vinay (2002) for France. The implementation of these substitutes could lead to a reduction of a third of transportation in Sweden, while using teleconferencing, telework and telemedicine to the utmost potential. New advanced technologies that facilitate “tele-presence” (eye contact between subscribers, life size images) will support the substitution effect.

A heated discussion arose from some provocative statement of Huber and Mills (1999) approaching a significant share, as much as eight percent, of electricity use of computers and the Internet. Their statements and data of the future development of the energy consumption of computers and the Internet are criticised and repudiated by a lot of other authors. A short summary about the debate can be found in Laitner (2003) and Cole (2003). Nevertheless scientists from Lawrence Berkeley National Laboratory (Romm 2001) revised the statements by Huber and Mills and calculated the electricity consumption of computers and all office equipment to be at most three percent.

The increasing standby electricity demand of ICT components as an important section of the total electricity consumption was first mentioned by Sandberg (1993). Since then, many other studies seized the same topic in different variations e.g. Aebischer et al. (2001) analysed the upper boundary for the increase of electricity demand in the average household attributable to interconnection while distinguishing between “On” and “Stand by/Off” mode. They predicted no sufficient increase of electricity demand from 2000 to 2005 and after this period an annual growth of +1.3% for a long period. Similary, Meier estimated the international standby consumption in households about 4-11% of the total electricity consumption (Meier 2005). There are different possibilities to reduce standby consumption, on the one hand, labelling and former types of product regulation towards less energy intensive appliances (Jones 2006; Murakoshi et al. 2005; Aebischer et al. 2001), and, on the other hand, to prompt users to turn off their devices instead of leaving them on standby. The positive energy saving potential of consumer behaviour has been mainly discussed at a national level, e.g. in some Swiss and German works (Aebischer and Huser 2000; Cremer et al., 2003). A Danish study placed emphasis on household's concern about the prospects to reduce their standby consumption (Gram-Hanssen and Gudbjerg 2006). The conclusions suggest that the adoption of behavioural changes in family routines differ quite much. Some families have no problem with changing their habits and cut off most of the standby consumption however others are uncomfortable with modifying their routines.

Another important alternative to reduce the electricity demand in the use phase is the power management of ICT components (Røpke et al. 2007). For example, Thomas and Barthel (2002) determined the German energy consumption of many different information and communication technology devices and stated that optimising equipment and power management can save up to 85 % of the electricity demand of these devices.

Technical aspects play a very minor role in most macro studies on ICT and energy. Predominantly macroeconomic perspectives are focused, such as "ICT and Energy Demand: An overview" (2002), which sums up the central propositions. The increases of the demand of input (including energy) are contained as well as the economic structural change. In particular the service sector is outstanding. In regard to this, Collard et al. (2005) have investigated the development of electricity use and ICT in the French service sector. They find that the electricity intensity of production increases with the increased use of computers and software, while it decreases with the diffusion of communications devices. Some possible ways to improve environmental sustainability through ICT, like rationalising energy management in housing or facilities are given by Rodrigues and van Wunnik (2005), who outline the results of a research project of the Institute for Prospective Technology Studies on a set of environmental indicators in 2020. Popp (2001) analyses this topic from a more global point of view. As part of a broader study of the effect of energy prices on the development of new technologies for energy conservation or the provision of new energy sources, he uses patent data to estimate the effect of new technologies on industrial energy consumption.

Another aspect, which is often disregarded, represents the methodological approach. Sanstad (2002) tried to observe the methods to study IT and aggregate energy demand. He proposes a conventional approach. e.g. a basic model for sectoral-level production.

2 Econometric modelling

In the following, two econometric modelling approaches are introduced, and the empirical results that have been obtained with them reported. Moreover, we present some descriptive statistics for each of them. Both approaches investigate the same industry aggregates which in the following are subsumed as the chemicals, metals and transport industry. In detail the single industries correspond to the NACE classifications as follows: chemicals = 24; metals = 27 & 28; transport = 60 & 63.

2.1 Impact of ICT capital goods on the efficiency of electricity use in production (CFP model)

2.1.1 Introduction

The main research goal in this section is to determine the effect of ICT capital goods on the efficiency of electricity use in industrial production. Such efficiency increases in electricity use can be due to gains in production efficiency (i.e. a better plant management) or structural gains (i.e. changes in market demand). Our analysis conducted here is mainly concerned with efficiency gains. The starting point of our analysis is the simple factor demand model introduced by Collard, Fève and Portier (CFP)(2005) for studying the relation between electricity consumption and ICT capital in the French service sector.

Based on theoretical considerations and empirical evidence from the literature (esp. Collard et al., 2005) we formulate the following two research hypothesis:

- **H1:** Electricity intensity of production in the industrial sectors studied increases with the diffusion of computers and software, and decreases with the diffusion of communications devices.
- **H2:** Communications equipment exerts a greater influence on electricity intensity of production in the industrial sectors studied than computers and software.

2.1.2 Model set-up

Collard et al. (2005) derive a structural estimation equation from a simple factor demand model (eq. (1)], which is based on a production function with constant returns to scale.[6] The endogenous change in the production process is modelled by electricity-augmenting technological progress, which is proxied by three variables and related coefficients (q_{CS}, q_C, q_{HA}): computer devices & software (K_{CS}), communication devices (K_C) and heated areas (HA)[7]. All three input factors are normalised by the total capital stock (K). Moreover, a log-linear time trend ($\theta_T t$), which accounts for exogenous energy-saving technological progress, is included. σ is the coefficient of the price ratio, P_E/P, denoting the elasticity of

6 The production function used is a CES (constant elasticity of substitution) function (see Glossary in the Appendix C).

7 The latter variable is used to control for changes in the production process that are uncorrelated with the diffusion of ICT.

substitution between energy and the other production factors. Formally the model is specified as follows (estimable equation if an error-term is added):

$$\log\left(\frac{E_t}{Y_t}\right) = s\ \log(w) - s\ \log\left(\frac{P_{E,t}}{P_t}\right) + (s-1)\left[q_0 + q_t t + q_C \log\left(\frac{K_{C,t}}{K_t}\right) + q_{CS} \log\left(\frac{K_{CS,t}}{K_t}\right) + q_{HA} \log\left(\frac{HA_t}{K_t}\right)\right] \quad (1)$$

As can be seen from eq. (1) the variable *E*/*Y* (electricity content of production) is dependant on the term representing the aforementioned electricity augmenting technological progress and on the ratio between the user price of electricity (P_E) and the production price (*P*). Hence, depending on the algebraic sign of the coefficients, the individual variables either have a positive or a negative effect on the demand for electricity. The estimation of the sign and size of the coefficients are the objective of the following econometric analysis.

2.1.3 Data

As can be seen from eq. (1), the data needed to conduct the econometric analysis include electricity consumption (*E*), gross output of production (*Y*), electricity price (P_E), production price (*P*), computing equipment & software (K_{CS}), communications equipment (K_C), heated areas (*HA*) and the total capital stock (*K*). Since not all these data are available from one single source, two data sets had to be matched. Information on electricity consumption and prices is provided by Eurostat, whereas all other data are taken from the EU-KLEMS data base.

Unfortunately the disaggregation of electricity consumption is restricted to the chemicals, metals and transport sector. Hence, the primary plan to perform the analysis for the six sectors and eight different EU member countries addressed by Sectoral e-Business Watch had to be abandoned. Instead, our econometric analysis relies on data for three energy-intensive sectors (chemicals, metals and transport) and four countries (Denmark, Germany, Italy, and the UK) for the time span from 1991 through 2005. Since data for *HA* was not available for the countries and sectors studied, we used transport equipment (*TE*) instead to control for the size of operations, a variable contained in the EU-KLEMS data base. Table 3 summarises the available data.

Table 3: Data availability in time ranges

Countries	Y	P	E	P_E	K	K_{CS}	K_{CD}	TE
Austria	70-05	70-05	90-05	95-05[a]	76-05	76-05	76-05	76-05
Belgium	70-05	70-05	90-05	85-05	X	X	X	X
Cyprus	95-05	95-05	90-05[b]	99-05	X	X	X	X
Czech Republic	95-05	95-05	90-05	00-05	95-05	95-05	95-05	95-05
Denmark	70-05	70-05	90-05	91-07	70-05	70-05	70-05	70-05
Estonia	95-05	95-05	90-05[c]	02-05	X	X	X	X
Finland	70-05	70-05	90-05	95-05	70-05	70-05	75-05[d]	70-05
France	70-05	70-05	90-05	91-05	X	X	X	X
Germany	70-05	70-05	90-05	91-07	91-05	91-05	91-05	91-05
Greece	70-05	70-05	90-05	91-05	X	X	X	X
Hungary	91-05	91-05	90-05	92-05	X	X	X	X
Ireland	70-05	70-05	90-05	91-05	X	X	X	X
Italy	70-05	70-05	90-05	91-07	70-05	70-05	70-05	70-05
Latvia	95-05	95-05	90-05	04-05	X	X	X	X
Lithuania	95-05	95-05	90-05	03-05	X	X	X	X
Luxembourg	70-05	70-05	90-05	85-05	X	X	X	X
Malta	95-05	95-05	X	91-05	X	X	X	X
Netherlands	70-05	70-05	90-05	91-05[e]	70-05	70-05[f]	70-05	70-05
Poland	95-05	95-05	90-05	01-05	X	X	X	X
Spain	70-05	70-05	90-05	90-05	X	X	X	X
UK	70-05	70-05	90-05	91-07	70-05	70-05	70-05	70-05
Data sources:	*EU-Klems*		*Eurostat*		*EU-Klems*			

Notes: [a] Data from 2000-03 are missing; [b] for metals only 2005; [c] data for metals only from 93-05; [d] data for transports from 1970-2005; [e] data from 2002-04 are missing; [f] data for transport only from 1973-2005.

2.1.4 Estimation

Collard et al. (2005) use 13 annual observations (1986-1998) for six subsectors of the French service sector and a dynamic panel approach (i.e. 6 x 13 = 78 obs.). In contrast, our analysis relies on 15 annual observations (1991-2005) of four different EU member countries (i.e. 4 x 15 = 60 obs.) for three distinct industry sectors. Following Collard et al., we estimate the vector of structural parameters $\Phi \equiv (s, q_t, q_{HA}, q_C, q_{CS})$ from equation (1) and a constant by applying a non-linear least squares (NLS) and a two-stage nonlinear least squares (2-stage NLS[8]) regression method.[9] The latter is conducted in order to correct for potential endogeneity of explanatory variables entering electricity-augmenting technical progress (TE/K, K_C/K, K_{CS}/K). In the adopted panel approach, which combines the cross-section and time series dimension of the data, we account for fixed effects by estimating country-specific constant terms.

8 Stage (1): OLS regression of a VAR(1) model for TE/K, K_C/K, K_{CS}/K, in logs, where the actual values are replaced by predicted values in the structural model. Stage (2): Estimation using NLS method.

9 For the interested reader: the parameter estimates correspond to the value of vector F that minimises the loss function $e_t{}'We_{\partial t}$, with e the stacked residuals vector, and W a consistent estimate of covariance matrix of residuals.

2.1.5 Results

Before presenting our own results, we reiterate the results obtained by Collard et al. (2005) for comparison. The two main findings of Collard et al. (2005) are that (1) electricity intensity of production has increased with computers and software, and decreased with the diffusion of communications devices; (2) communications devices have, *ceteris paribus*, exerted a greater effect on electricity intensity than computers and software. Collard et al. further find ambiguous results for the heated areas-to-capital ratio (sign of coefficient is not robust), and they find that $q_{IC} > 0$, which means that IC capital has increased the productive efficiency of electricity and contributed to the reduction in electricity intensity in the service sector. They further find that the impact of IC capital diffusion on electricity intensity differs a great deal, depending on the type of ICT (computers and software contributed negatively to productive efficiency on electricity, communication devices have exerted a positive influence on it).

Chemicals industry

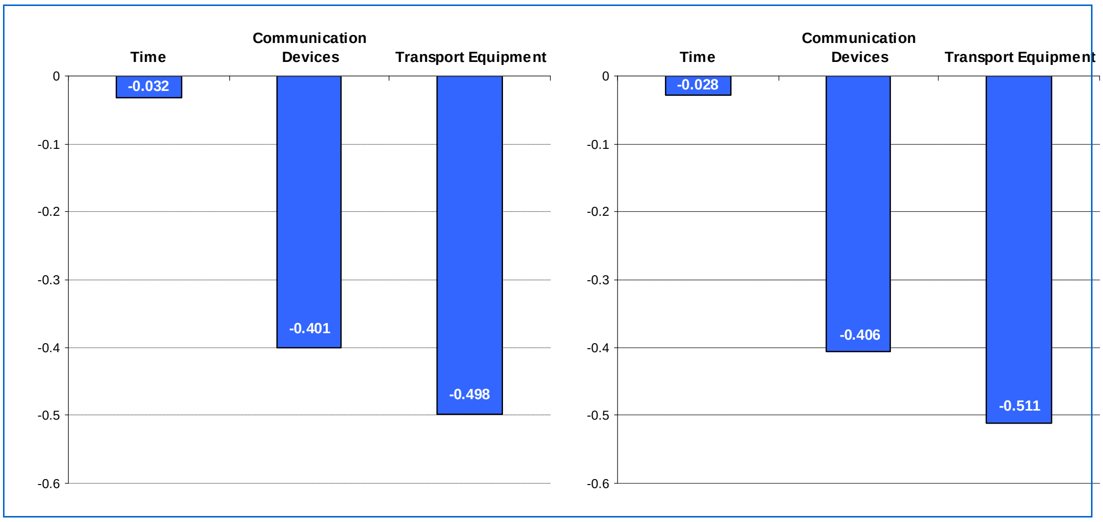
Table 4 shows the estimation results for the chemicals industry for two estimation techniques (non-linear least squares – NLS and two-stage non-linear least squares – 2-stage NLS) and for the explanatory variables computer & software (CS) and communications device (CD) capital and aggregated information and communication technology capital (ICT), respectively. The results from the latter analysis will not be reported further since the results are less convincing, but can be obtained from the authors upon request.

Table 4: Estimation results – chemicals industry

Model *(Method)*	**(I) CS & C** ***NLS***	**(II) CS & C** ***TSNLS***	**(III) ICT** ***NLS***	**(IV) ICT** ***TSNLS***
Structural Parameters				
σ :	0.326 [1.86]	0.368 [1.94]	-0.082 [-0.52]	-0.037 [-0.23]
θ_T :	0.047 [3.33]	0.044 [2.83]	0.024 [4.01]	0.024 [3.71]
θ_{CS} :	0.185 [1.26]	0.242 [1.26]		
θ_C :	0.594 [2.60]	0.642 [2.34]		
θ_{ICT} :			0.158 [2.50]	0.183 [2.50]
θ_{TE} :	0.739 [2.48]	0.809 [2.22]	0.561 [3.36]	0.651 [3.27]
Elasticities				
Time:	-0.032	-0.028	-0.026	-0.025
CS:	-0.125	-0.153		
C:	-0.401	-0.406		
ICT:			-0.17	-0.19
TE:	-0.498	-0.511	-0.607	-0.675

Notes: NLS = non-linear least squares; 2SNLS = two-stage NLS. *t*-statistics in parenthesis and insignificant estimates printed in italics. We do not report the estimated constant.

Figure 10 summarises the estimation results for those elasticities that turned out to be statistically significant. As can be seen, from the ICT section only communications devices have has a statistically significant effect on electricity intensity (-0.4). Computers & software capital is found to be statistically insignificant and is therefore not included in Figure 9. The effect of technical progress is slightest (-0.03) and that of transport equipment is even stronger than that of communications devices (-0.5). The elasticities derived from the structural coefficients can be interpreted in such a way that e.g. any 1% increase in the communications capital (transport equipment capital) to total capital ratio (i.e. the communications or transport capital intensity) led to a 0.4% (0.5%) decrease in electricity intensity in the chemicals sector.



(a) NLS (b) 2-stage NLS

Figure 10: Electricity intensity elasticities – chemicals industry

We conclude the following for the chemicals industry:[10] (1) We cannot identify a significant influence of computer devices and software on electricity intensity (the coefficient θ_{CS} is statistically insignificant); (2) Communications technology is shown to have an enhancing influence on the efficiency of electricity use in the chemical industries' production processes ($\theta_C > 0$); (3) There is evidence for electricity augmenting technological progress ($\theta_T > 0$); (4) We find a negative[11] effect of transport equipment on the intensity of electricity use ($\theta_{TE} > 0$), which gives reason to believe that other energy carriers are more important and that the substitution effect might indeed be substantial.

Metals industry

Table 5: summarises the results obtained for the metals sector, both for the computers & software (CS) and the communications device (CD) capital and aggregated information and communications technology (ICT) capital, and for the two estimation techniques (non-linear least squares and 2-stage non-linear least squares) yielding comparable results.

10 Based on data for Denmark, Germany, Italy, and the UK.

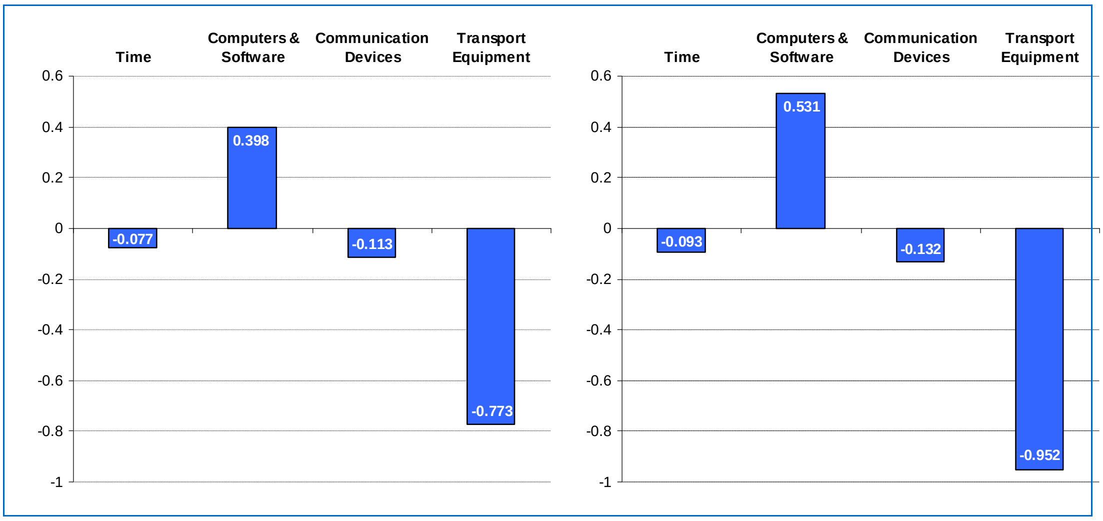
11 Note, that negative refers to the sign of the coefficient (i.e. an increase in transport equipment is associated with a reduction of electricity intensity and thus consumption)

Table 5: Estimation results – metals industry

Model ***(Method)***	**(I) CS & C** ***NLS***	**(II) CS & C** ***TSNLS***	**(III) ICT** ***NLS***	**(IV) ICT** ***TSNLS***
Structural Parameters				
σ :	-0.218 [-1.32]	-0.167 [-0.92]	-0.170 [-1.03]	-0.140 [-0.77]
θ_T :	0.063 [3.65]	0.080 [3.32]	0.041 [2.61]	0.046 [2.33]
θ_{CS} :	-0.327 [-2.77]	-0.455 [-2.75]		
θ_C :	0.093 [2.06]	0.113 [2.21]		
θ_{ICT} :			-0.117 [-1.15]	-0.157 [-1.21]
θ_{TE} :	0.635 [2.35]	0.816 [2.28]	0.501 [1.73]	0.575 [1.57]
Elasticities				
Time:	-0.077	-0.093	-0.048	-0.052
CS:	0.398	0.531		
C:	-0.113	-0.132		
ICT:			0.137	0.179
TE:	-0.773	-0.952	-0.586	-0.656

Notes: NLS = non-linear least squares; 2SNLS = two-stage NLS. *t*-statistics in parenthesis and insignificant estimates printed in italics. We do not report the estimated constant.

Figure 11 depicts the elasticities estimated when the CS&CD technology capital is included in the model. As can be seen, the results obtained with the two estimation techniques are very similar. Computers and software have a strong positive influence (0.4) whereas the influence of transport equipment is strongly negative (-0.8) and that of communications devices to a lesser extent negative as well (-0.1).



(a) NLS (b) 2-stage NLS

Figure 11: Electricity intensity elasticities – metals industry

We conclude for the metals industry:[12] (1) In line with the results obtained in Collard et al. (2005) for the French services industry, we find a negative influence on the efficiency of electricity use in the metals industry ($\theta_{CS} < 0$); (2) Communications technology has a positive influence on the efficiency of electricity in the production processes of the metals industry ($\theta_C > 0$); (3) There is evidence for electricity augmenting technological progress ($\theta_T > 0$); (4) We find a negative influence of transport equipment on the intensity of electricity use ($\theta_{TE} > 0$), which gives reason to believe that other energy carriers are more important and that substitution among energy carriers may play an important role.

Transport industry

Table 6 provides a synopsis of the estimation results with non-linear least squares and 2-stage non-linear least squares estimation for computer & software (CS) and communications devices (CD) capital as well as for information and communication technology (ICT) capital. Further results on the latter are not reported, but can be obtained from the authors upon request. As can be seen NLS and 2-stage NLS yield similar results.

Table 6: Estimation results – transport industry

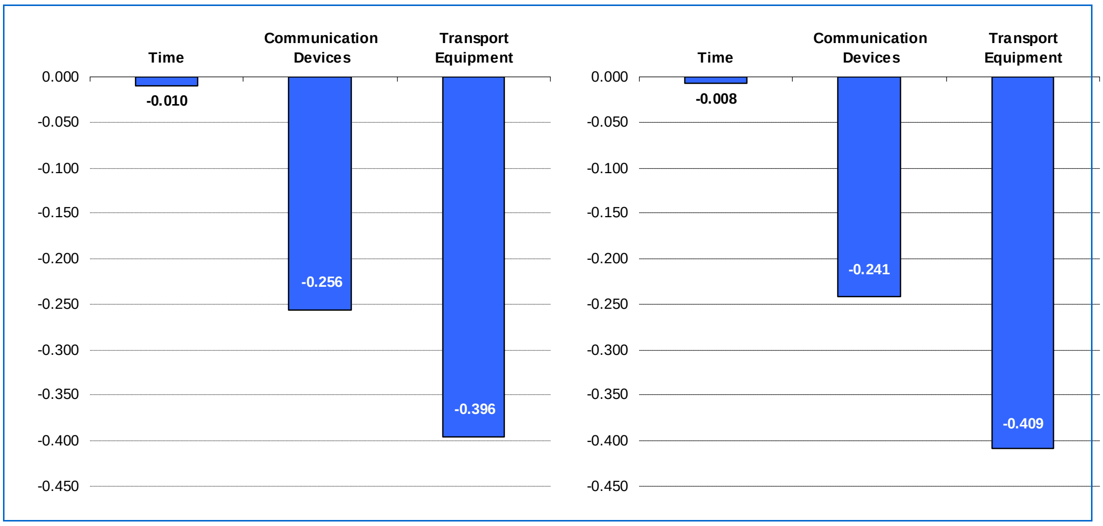
Model ***(Method)***	**(I) CS & C** ***NLS***	**(II) CS & C** ***TSNLS***	**(III) ICT** ***NLS***	**(IV) ICT** ***TSNLS***
Structural Parameters				
σ :	-0.005 [-0.62]	0.002 [0.02]	0.238 [2.83]	0.214 [2.48]
θ_T :	0.010 [2.12]	0.008 [1.66]	0.001 [0.36]	0.0004 [0.10]
θ_{CS} :	-0.004 [-0.08]	0.012 [0.26]		
θ_C :	0.255 [6.87]	0.241 [6.18]		
θ_{ICT} :			0.118 [2.19]	0.142 [2.61]
θ_{TE} :	0.394 [5.01]	0.410 [5.08]	0.504 [3.51]	0.568 [3.97]
Elasticities				
Time:	-0.010	-0.008	-0.0008	-0.0003
CS:	0.004	-0.012		
C:	-0.256	-0.241		
ICT:			-0.090	-0.112
TE:	-0.396	-0.409	-0.384	-0.446

Notes: NLS = non-linear least squares; 2SNLS = two-stage NLS. *t*-statistics in parenthesis and insignificant estimates printed in italics. We do not report the estimated constant.

Figure 12 depicts the estimated elasticities in graphical form. Again, the results obtained with the two estimation methods are very robust, indicating that transport equipment features an elasticity of about -0.4, communications devices of -0.25, and an elasticity estimate for the electricity-augmenting technical change close to zero (-0.01). As

[12] Based on data for Denmark, Germany, Italy, and the UK.

computer & software (CS) capital is found to be statistically insignificant, the corresponding coefficient is not included in Figure 11.



(a) NLS (b) 2-stage NLS

Figure 12: Electricity intensity elasticities – transport industry

We conclude the following from the analysis for the transport industry:[13] (1) Electricity augmenting technological progress negatively correlates with electricity use ($\theta_T > 0$); (2) Communications technology has a positive influence on the efficiency of electricity use in the transport sector's production processes (elasticity of about -0.25); (3) There seems to be a negative correlation between transport equipment and electricity use ($\theta_{TE} > 0$), indicating that transport equipment likely depends on other energy carriers.

For all three industrial sectors studied we can conclude the following: (1) The results for the chemicals and transport industries are quite similar, whereas for the metals industry we find a positive impact of computers and software on electricity intensity, and an even stronger impact of transport equipment (i.e. these input factors contributed to reducing the electricity intensity in these sectors); (2) For all three sectors studied, we find modest electricity-augmenting technological change. Overall, we find some empirical support concerning the postulated hypotheses for all three sectors studied, albeit the results are not straightforward:

- **Ad H1:** On the one hand, the diffusion of communications devices exhibits a negative influence on electricity intensity in all three sectors. On the other hand, the impact of computers & software is statistically only significant in the metals industry, displaying, as postulated, a positive effect on electricity intensity.
- **Ad H2:** For the two sectors for which the impact of computers & software is statistically insignificant (chemicals and transport), communications equipment does indeed exert a greater influence on electricity intensity. However, in the metals sector the magnitude of the impact of computers & software greatly exceeds that of the communications technologies influence.

[13] Based on data for Denmark, Germany, Italy, and the UK.

2.2 Impact of ICT capital, energy, and other input factors on production output (Cobb-Douglas model)

2.2.1 Introduction

The objective of our second econometric approach is the (empirical) assessment of the relationship between various input factors and gross output. Hereby, especially the input factor ICT capital is of particular interest. The hypothesis accompanying the analysis is:

- **H3:** The diffusion of ICT capital goods has a greater impact on gross output than the diffusion of non-ICT capital goods.

2.2.2 Model set-up

In economic theory the relationship between input factors and output is usually described as a production function, the simplest of which is the Cobb-Douglas (CD) functional form. We specify the CD production function in double-logarithmic form. Constant returns to scale are assured by normalising inputs and output to total hours worked (*WH*). Formally, our estimable equation can be specified as follows:

$$\begin{aligned}\log(Y_t) = a_0 + b_{E,t}\log(E_t) + b_{M,t}\log(M_t) + b_{S,t}\log(S_t) \\ + b_{ICT,t}\log(ICT_t) + b_{NICT,t}\log(NICT_t) + b_T time\end{aligned} \qquad (2)$$

Eq. (2) states that gross output (*Y*) is dependant on various input factors and time, which all appear on the right hand side of the equation. Note that the double-logarithmic formulation allows us again to interpret the estimated coefficients (a_0, $b_{i,t}$) directly as output elasticities (i.e. by how much output changes in percent when the respective input is changed by 1%; e.g. b_{ICT} = 0.3 would indicate that if ICT capital increased by 10% output would increase by 3%, and provide some evidence that the use of ICT capital actually helps to increase production output).

Moreover, we have looked at the relevance of cross-terms and quadratic terms in order to check for cross elasticities and size effects (see Appendix eq. (3)). Since most coefficients turned out to be statistically insignificant, they were left out from the further considerations and reporting.

2.2.3 Data

Data for gross output (*Y*), energy (*E*), material (*M*), service (*S*) inputs, ICT capital (*ICT*), non-ICT capital (*NICT*) and total hours worked by persons engaged (WH) are needed to estimate eq. (2) which are all available from the EU-KLEMS data base for various industries and EU member countries for a sufficient long time span. As EU-KLEMS provides these data in volume indices (see Table 1), as well as in values, we perform the analysis for both types of data. Note that data in values are delivered at current basic prices in local currency. In order to ensure comparability between countries and over time, we therefore transformed the series as follows: (i) we deflate the variables using production price and intermediate input price indices (1995=100), (ii) we use 1995 PPP conversion factors (US$=100, available from UN data) to account for the country specific purchasing powers. The transformed variables can be interpreted as the yearly amount of US-dollars one would have needed in the USA in 1995, to reach the same living standard as a foreigner in the respective country and year. In contrast to the volumes data, the ICT data in values[14] are provided by EU-KLEMS in a more disaggregated form. While the data in volumes are only distinguishable by ICT and non-ICT capital, the ICT data in values are, as in the first part of the econometric analysis, additionally disaggregated into computers & software (CS) on the one hand and communication devices (CD) on the other hand. This allows us to account for possible differences in the direction and magnitude of the two ICT components. The drawback of using the data in values in the present case is the limited data availability, as the capital input files, which contain the disaggregated ICT data, are not available for all countries. Hence the number of observations is smaller in the values case. The data included in this analysis are for Austria, Denmark, Finland, France, Germany, Italy, Spain and the UK for a time span from 1980 through 2004 (for the analysis with variables in values no data for France and Spain were available).

2.2.4 Estimation

Eq. (2) (plus an error-term) is estimated using straightforward OLS regression method, both with variables in volume and in value terms. Moreover, as the series might contain unit roots, we estimate both data sets in first differences as well.[15] If statistically not significant at least at the 10% level, the respective variable was omitted from the estimation.[16]

2.2.5 Results – variables expressed in volume terms

In what follows we present the results from estimating the Cobb-Douglas production function for the metals, chemicals and transport industries when the variables are expressed in volumes (in the full study report we also report on the results obtained when the variables are expressed in values, cf. www.ebusiness-watch.org). While we also did some analogous estimations for the banking and retail sectors, the results were often found to be statistically insignificant or counterintuitive, and therefore not reported.

Chemicals industry

Figure 13 reports on the results for the chemicals industry. In the case of the chemicals industry, interestingly, non-ICT capital turned out to be insignificant and therefore was removed, while the time trend reflecting technological change could be kept. Note that for the chemicals industry production output reacts most sensitively to material inputs (0.39), about half as sensitive to energy inputs (0.19) and much less to service inputs (0.08) and ICT capital inputs (0.04).

---

14 As the original value variables were transformed using price indices, the evolution of the series only reflects real changes, thereby, strictly speaking, being volume indicators as well (Note: Nonetheless the series remain being in money units). Thus the only difference between the two variable sets concerns the dimension in absolute values and index form.

15 All regressions in levels reveal a disturbingly low Durbin-Watson statistic, indicating possibly spurious regressions.

16 Note that the results reported in the Interim Report have been relegated to Appendix B.

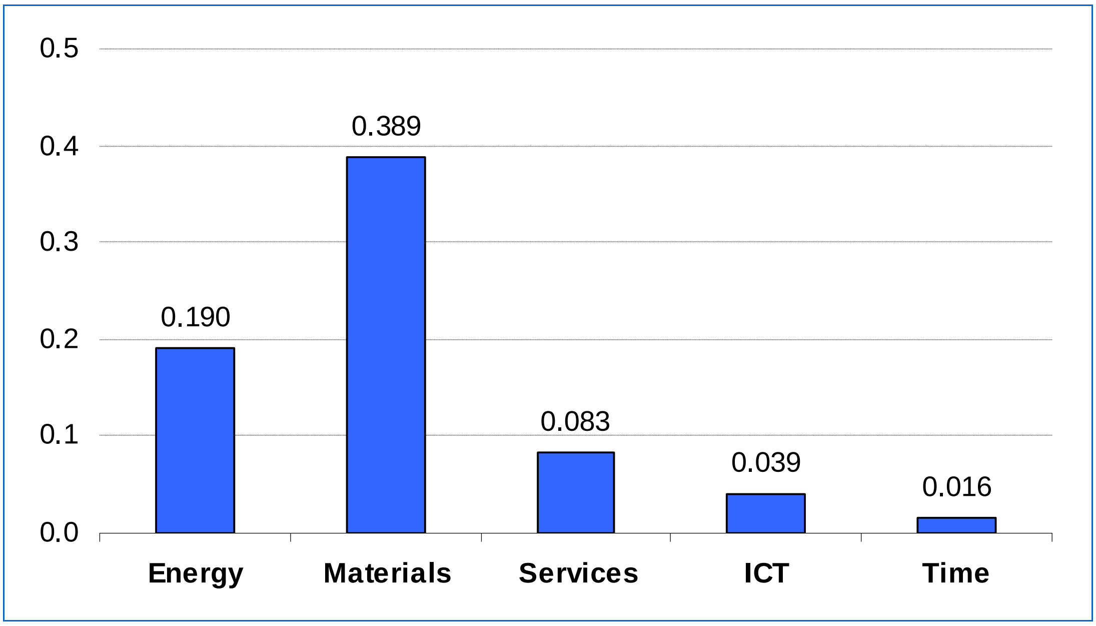


Figure 13: Output elasticities – chemicals industry (volumes)

Metals industry

Figure 14 shows the analogous results for the metals industries. As can be seen, all estimated output elasticities turn out to have a positive sign. Material inputs again exhibit the largest elasticity (0.57), followed by services (0.12) and energy inputs (0.11), and then by non-ICT capital inputs (0.06) and capital inputs (0.02). Note that the time trend turned out to be insignificant and hence was eliminated. We conclude from this result that changes in the use of ICT capital only play a minor role in explaining changes in gross production output in the metals industry, while material inputs play a dominant role.

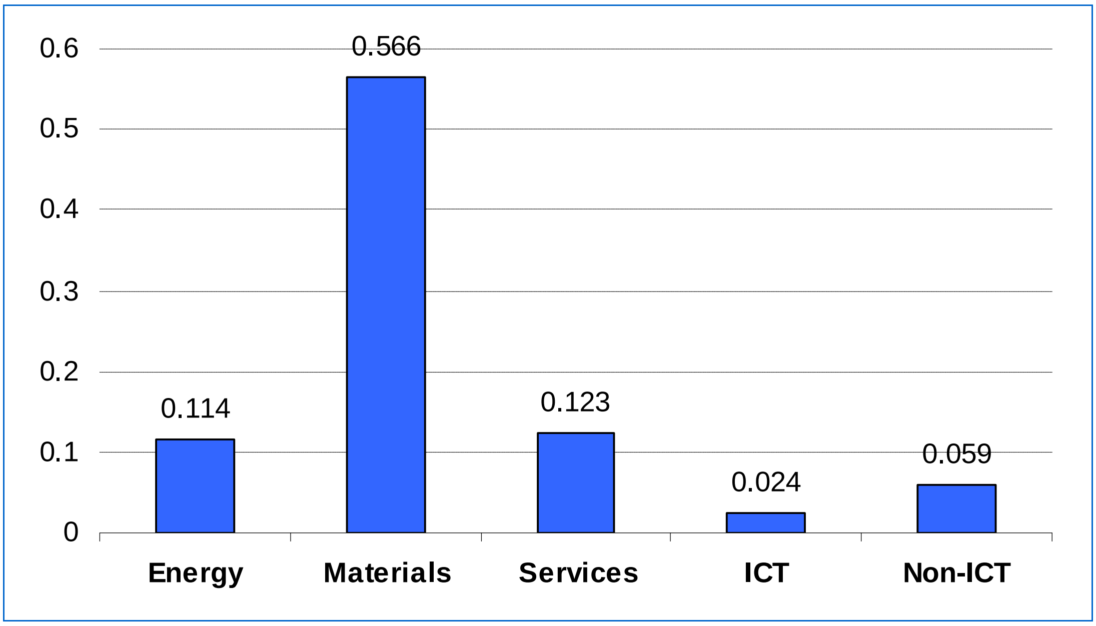


Figure 14: Output elasticities – metals industry (volumes)

Transport industry

Finally, Figure 15 reports on the results for the transport industry. As can be seen, service inputs are shown to exhibit the highest elasticity values (0.53), while the impacts of ICT capital and materials inputs are about the same (0.06), and non-ICT capital at a low value of 0.02. Note that both the time trend and the variable for intermediate energy inputs had to be removed because they were insignificant.

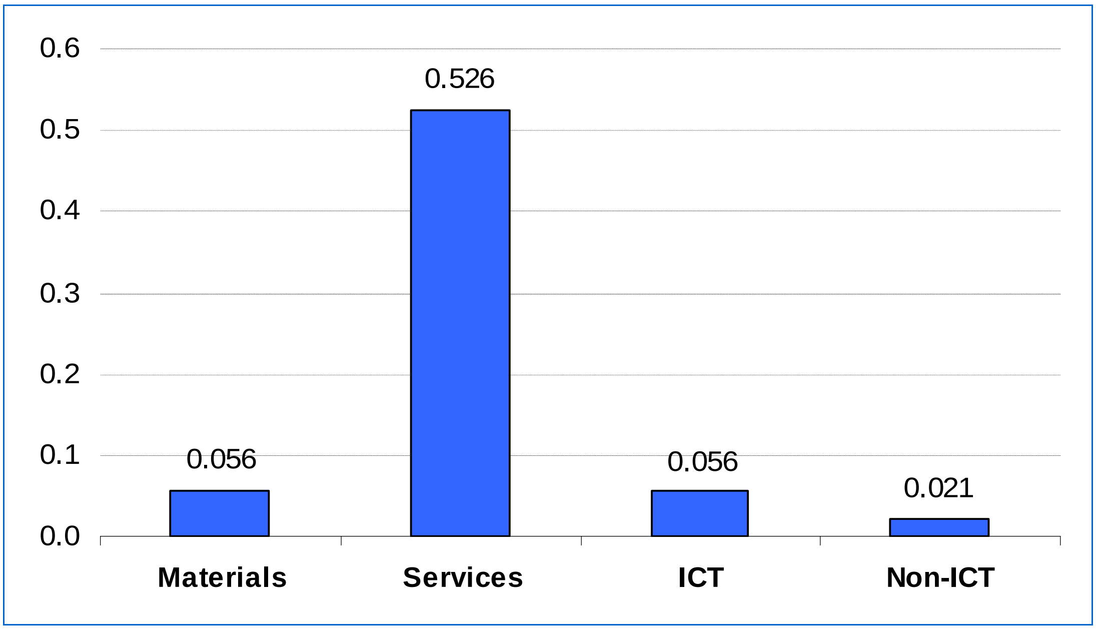


Figure 15: Output elasticities – transport industry (volumes)

2.2.6 Results – variables expressed in value terms

We also used an alternative approach to estimate ouput elasticities based on values instead of volumes. Moreover, the value data allowed us to further disaggregate the ICT capital stock data into computers and software (denoted "CS") and communications technology (denoted "CD"). Again, we report the results for the metals, chemicals and transport industries. The countries included are Austria, Denmark, Finland, Germany, Italy, Netherlands and the UK.

Chemicals industry

Figure 16 shows the results for the chemicals industry. As can be seen, material inputs again show the largest elasticity (0.37), followed by service inputs (0.30) and non-ICT capital (0.16). Compared to these results, energy inputs have a much lesser impact on output (0.06), an elasticity that is of similar magnitude as for computers and software (0.05), and still higher than the value for communications devices (0.007).

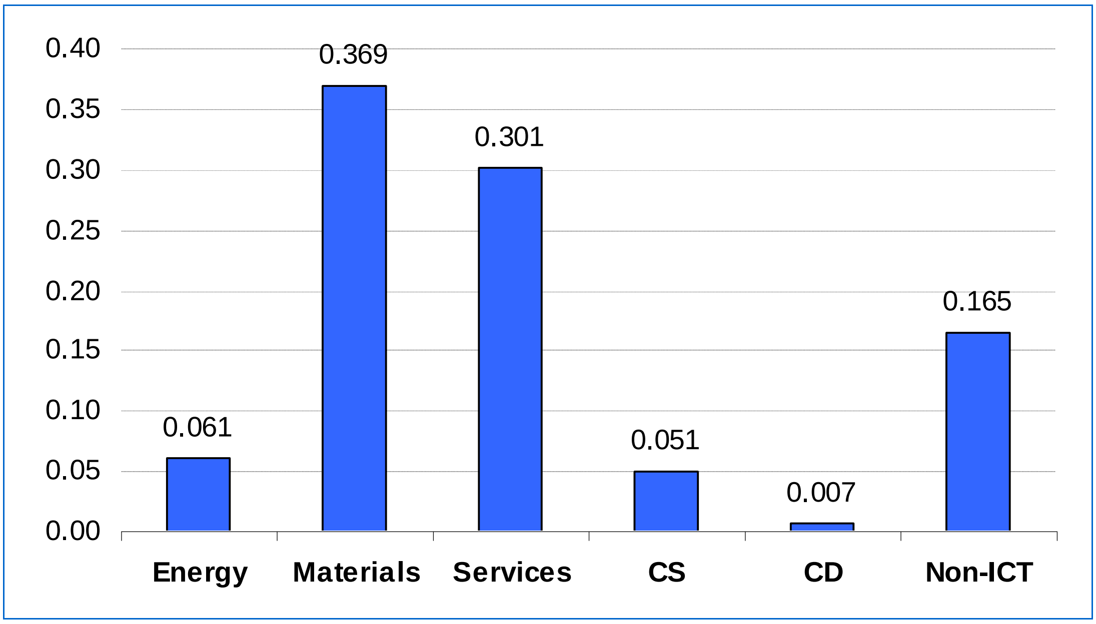


Figure 16: Output elasticities – chemicals industry (values)

Metals industry

Figure 17 presents equivalent the results obtained for the metals industries. It can be seen that material inputs by far exhibit the largest elasticity (0.57), followed by service inputs (0.15) and energy inputs (0.03). Gross output of production is found to react still less to changes in computer technology and software inputs (0.02), and even less so to changes in the value of communications technology (0.01) and technical change (0.003).

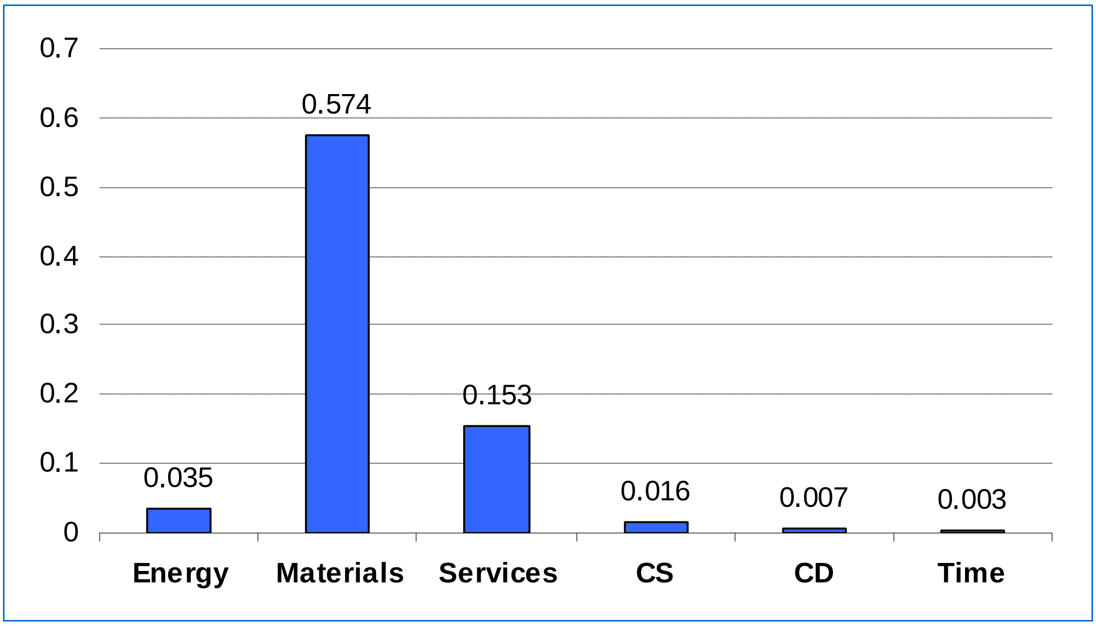


Figure 17: Output elasticities – metals industry (values)

Transport industry

Finally, the results for the transport sector are reported in Figure 18. In this case, it turns out that in contrast to the metals and chemicals industries non-ICT capital changes matter (output elasticity is significant), and that output is most sensitive regarding service inputs (0.38), followed by material inputs (0.13) and non-ICT capital (0.10). Energy inputs do not matter much in this respect (0.04) and even less so computer and software capital or technical change (both at 0.01).

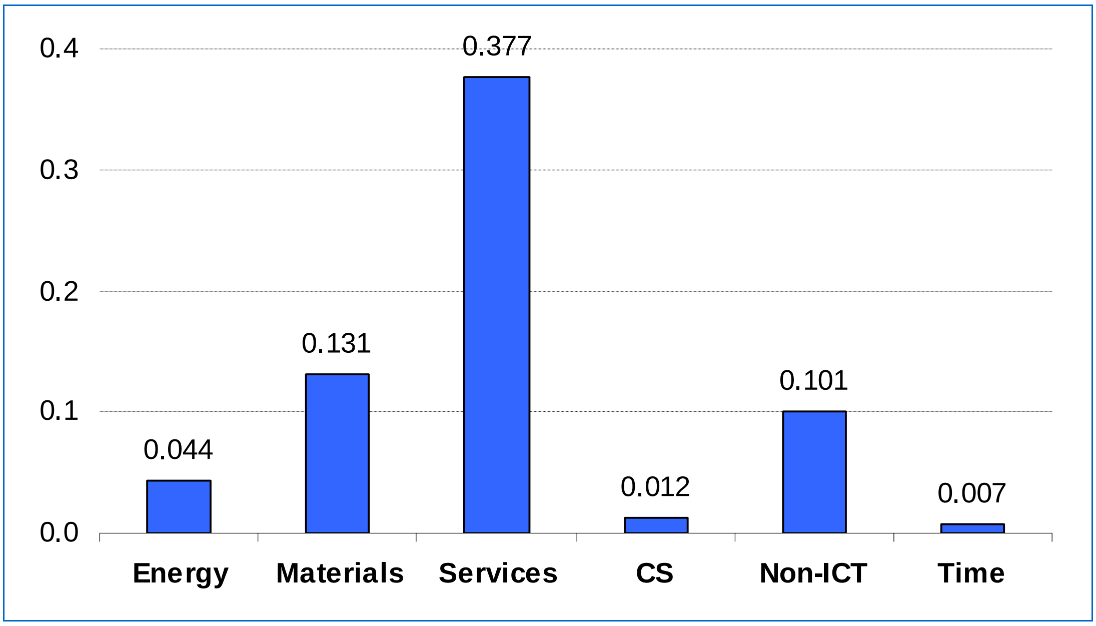


Figure 18: Output elasticities – transport industry (values)

Table 7 provides a qualitative summary of the results obtained. From this it becomes obvious that the value models often perform better (but cover a lower number of countries), and that it is more difficult to come up with useful results for the less energy-intensive sectors such as banking and retail.

Table 7: Summary of the statistical significance and plausibility of input factors of primary interest (Cobb-Douglas model)

<table>
<tr><th></th><th>Industry</th><th colspan="2">Chemicals</th><th colspan="2">Metals</th><th colspan="2">Transport</th><th colspan="2">Banking</th><th colspan="2">Retail</th></tr>
<tr><td rowspan="4">Volumes</td><td rowspan="2">Levels</td><td colspan="2">Energy Δ</td><td colspan="2">Energy Δ</td><td colspan="2">Energy O</td><td colspan="2">Energy Δ (-)</td><td colspan="2">Energy O</td></tr>
<tr><td colspan="2">ICT Δ</td><td colspan="2">ICT Δ</td><td colspan="2">ICT Δ</td><td colspan="2">ICT O</td><td colspan="2">ICT O</td></tr>
<tr><td rowspan="2">Differences</td><td colspan="2">Energy Δ</td><td colspan="2">Energy Δ</td><td colspan="2">Energy Δ</td><td colspan="2">Energy O</td><td colspan="2">Energy Δ</td></tr>
<tr><td colspan="2">ICT O</td><td colspan="2">ICT Δ</td><td colspan="2">ICT Δ</td><td colspan="2">ICT O</td><td colspan="2">ICT O</td></tr>
<tr><td rowspan="4">Values</td><td rowspan="2">Levels</td><td colspan="2">Energy Δ</td><td colspan="2">Energy Δ</td><td colspan="2">Energy Δ</td><td colspan="2">Energy Δ (-)</td><td colspan="2">Energy Δ</td></tr>
<tr><td>CS Δ</td><td>CD Δ</td><td>CS Δ</td><td>CD Δ</td><td>CS Δ</td><td>CD O</td><td>CS O</td><td>CD Δ</td><td>CS Δ (-)</td><td>CD Δ</td></tr>
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</table>

Nomenclature: CS: Computers & Software; CD: Communication devices; ICT: Information and communication technology; E: Energy; (-): negative coefficient (implausible); Δ: Statistically significant; O: Statistically insignificant (at the 10% level).

As previously mentioned, comparisons between results from the volumes and values estimations have to be treated with caution, because the number of countries included differs to some extent. Moreover, the model specifications are not the same, on account of the disaggregation of ICT capital in the values data. Overall the estimations in values as well as in volumes reveal a high impact of intermediate material inputs on gross output for the chemicals and metals industries on the one hand, and a high impact of intermediate service inputs on gross output in the transport industry on the other hand. This does not come as a surprise, as the metals and chemicals industries belong to the manufacturing sector, while the transport industry belongs to the service sector. Energy has a positive impact in all cases except for the transport industry when estimated with volumes data. Apart from communication devices in the transport industry (values), ICT has a significant impact in all estimations, although the size of the effect is never very large. Regarding the postulated hypothesis we can conclude the following:

- **Ad H3:** A comparison between the effects of ICT and non-ICT on gross output does not bring to light a clear result concerning statistical significance and magnitude.

2.3 Findings from the econometric modelling (overall)

While it is premature to come up with far-reaching conclusions and policy implications from this initial research, we have gained the following empirical results:

CFP model

Chemicals industry

- Communications technology has positive impact on electricity efficiency (0.4);
- We find some (weak) evidence for electricity-augmenting technical change (0.03);
- Transport equipment has a negative influence on electricity efficiency (0.5);
- Computers and software are found to have an insignificant influence on electricity efficiency (0.13-0.15).

Metals industry

- Communications technology has a positive impact on electricity efficiency (0.11-0.13);
- Computers and software exert a negative influence on electricity efficiency (0.4-0.5), which is in line what Collard et al. (2005) have found for the French services sector;
- We find some (weak) evidence for electricity-augmenting technical change (0.01);

Transport industry

- We find an electricity-augmenting impact of technical change (0.01);
- Communications technology has a positive impact on electricity efficiency (0.25);
- Transport equipment has a negative influence on electricity efficiency (0.40).

Cobb-Douglas model

Chemicals industry (volumes)

The largest impact on gross output in the chemicals industry is exerted by material inputs (0.39), followed by energy (0.19) and service (0.08) inputs. ICT capital (0.04) and technical change (0.02) have the weakest effect on output, while non-ICT is statistically insignificant.

Metals industry (volumes)

In the Metals industry material inputs (0.57) exceeds all other input factors by far. The next largest effect is exerted by service (0.12) and energy (0.11) inputs, followed by non-ICT (0.06) and ICT (0.02) capital.

Transport industry (volumes)

Service inputs (0.52) have the decidedly greatest effect in the transport industry. Material inputs and ICT capital (0.06) are followed by non-ICT capital (0.02), while energy inputs and technical change do not have a statistically significant impact on gross output.

Chemicals industry (values)

The two largest effects on gross output in the chemical industry are exerted by material (0.37) and service (0.30) inputs. Non-ICT capital (0.16) and energy inputs (0.06) are followed by computers & software (0.05) and communication devices (0.01).

Metals industry (values)

Material inputs (0.57) have the largest impact on gross output in the metals industry by far. The next largest effect is exerted by service (0.15) and energy (0.03) inputs. Computers & software (0.02), communication devices (0.01) and technical change (0.003) have the weakest influence on the sectors gross output.

Transport industry (values)

The largest impact on gross output in the transport industry is exerted by service inputs (0.38), followed by material (0.13), non-ICT (0.10) and energy inputs (0.04). Computers & softwares and technical change (0.01) have the weakest effect on output.

3 Case Studies

In this section, we present three case studies that focus on the impact of ICT on energy consumption, and that help to support some of the evidence found in the econometric analysis: First, we present the experience made by Eregli Iron and Steel Works Co, the largest steel manufacturer in Turkey. Second, we report on the strategy of Coop Switzerland, one of the largest retail companies in Switzerland, related to the use of ICT and the aim to reduce energy consumption and CO_2 emissions. Third, we present the results of an interview on ICT and energy use conducted with a representative of the Jacob Fruitfield Food Group, a major Irish manufacturer of biscuits and treats, sauces, jams and preserves.

3.1 Eregli Iron and Steel Works Co (Erdemir), Turkey

Abstract

Erdemir is the largest iron and steel producer in Turkey. As one of the biggest domestic energy consumers and mainly self-supplier, Erdemir has been seriously working on energy-saving activities since 1982. In 2007, the power and steam supply systems have been extended by a plant information system. The perspective for 2008 is to implement an optimisation policy for the existing infrastructure in order to control power and steam production, furnaces, turbines and by-product gases more effectively.

Case study fact sheet

■ *Full name of the company:*	Ereğli Demir Çelik Fabrikaları T.A.Ş (Erdemir)
■ *Location (HQ / main branches):*	Kdz. Ereğli, Zonguldak province, Turkey
■ *Main business activity:*	Production of heavy plates, hot and cold rolled sheets and coils and tinplate
■ *Year of foundation:*	1960
■ *Number of employees:*	14056
■ *Turnover in last financial year:*	TRY 4903 million (€ 2941.8 million)
■ *Primary customers:*	Various sectors, such as defence, construction, automotive, agricultural machinery and shipbuilding
■ *Most significant geographic market:*	Turkey, U.S.A., Europe
■ *Main ICT applications studied:*	Optimisation of energy use in production processes through Plant Information System

3.1.1 Background and objectives

Founded in 1960 with the aim to meet the demand for flat steel in Turkey, Ereğli Demir Çelik Fabrikaları T.A.Ş, (Eregli Iron and Steel Works Co), shortly Erdemir, is today the largest iron and steel factory and the only flat steel producer in Turkey. Headquartered in Eregli, in northern Turkey at the western Black Sea Region, Erdemir is an important local employer and can be considered as one of the nation's industrial giants.

The primary crude steel production capacity of 470,000 tons in 1965 has increased to two million tons per year by the end of the 1980s, and in recent years went up to 5.15 million tons through capacity-augmenting investment schemes, new establishments, and the acquisition of domestic and foreign plants and companies.

Today the Erdemir Group consists of Iskenderun Demir ve Çelik A.Ş. (Isdemir), a steel plant located in Iskenderun, Erdemir Madencilik San ve Tic A.Ş. (Erdemir Maden), a mining company in Sivas, Erdemir Çelik Servis Merkezi, a steel service centre in Gebze near Istanbul, Erdemir Mühendislik Yönetim ve Danışmanlık A.Ş. (Erenco), a provider of engineering, management and consulting services in the iron and steel sector, Erdemir Romania S.R.L., a steel plant in Targovista, Romania, Çelik Çekme Boru San. ve Tic. A.Ş. (Çelbor), a steel tube and pipe producer, Erdemir Lojistik A.Ş., (Erdemir Lojistik), the coordinator of the logistics requirements of the Erdemir Group, and finally Erdemir Gaz San. ve Tic A.Ş. (Erdemir Gaz), the natural gas supplier of the Erdemir Group.

After the Turkish government's privatisation programme in 2006 the ATAER Holding, a subsidiary of OYAK (Armed Forces Pension Fund) purchased 46.12% of Erdemir shares from the Privatisation Administration and further 3.17% from the Turkish Development Bank and has become the largest owner of Erdemir with a share of 49.29% of the total stock. Besides the Erdemir treasury stocks amount 3.08% and the remaining shares are free floating on the Istanbul Stock Exchange.

With the capacity-increasing investments the domestic market leader position could be further expanded, and the increasing demand for flat steel met. It should be noted that the domestic demand for steel products as well as total steel production in Turkey is rapidly growing. The long-term objectives of Erdemir are described as becoming a global player, which involves an adjustment of the business methods to globally recognised standards.

Erdemir as an innovative and developing company contributing to the Turkish economy puts emphasis on savings, acceptance of continuous improvement, innovation and positive change to its values.

With a steel production of more than five million tons of crude steel per year the industrial plants have a huge energy demand: approximately 1.7% of total energy consumption in Turkey is attributed to Erdemir. For obvious reasons, interest in energy-saving technologies is high, since achievable cost savings are sizable and competitive advantages can be safeguarded. Moreover, Erdemir aims at being an environmentally responsible actor with regard to greenhouse gas emissions. Since 1982 remarkable progress in energy saving has been achieved in the Eregli industrial plant, while at the same time productivity has been continuously increasing. Several improvements in the steel production system, like modifications of the blast furnaces, modernisation of the rolling mill and the steel works, technologies for extracting and efficiently using by-product gases, amelioration of the illumination system, renewal of the isolation of the steam distribution network, and the initiation of SCADA (Supervisory Control and Data Acquisition) systems for electrical energy and gas distribution led to marked energy savings (see below). As a consequence, also the specific energy consumption, measured as total energy consumption per ton of crude steel produced, has decreased from 8220 Mcal/TCS in 1982 to approximately 4875 Mcal/TCS (Figure 19). The current target is to reach 4500 Mcal/TCS.

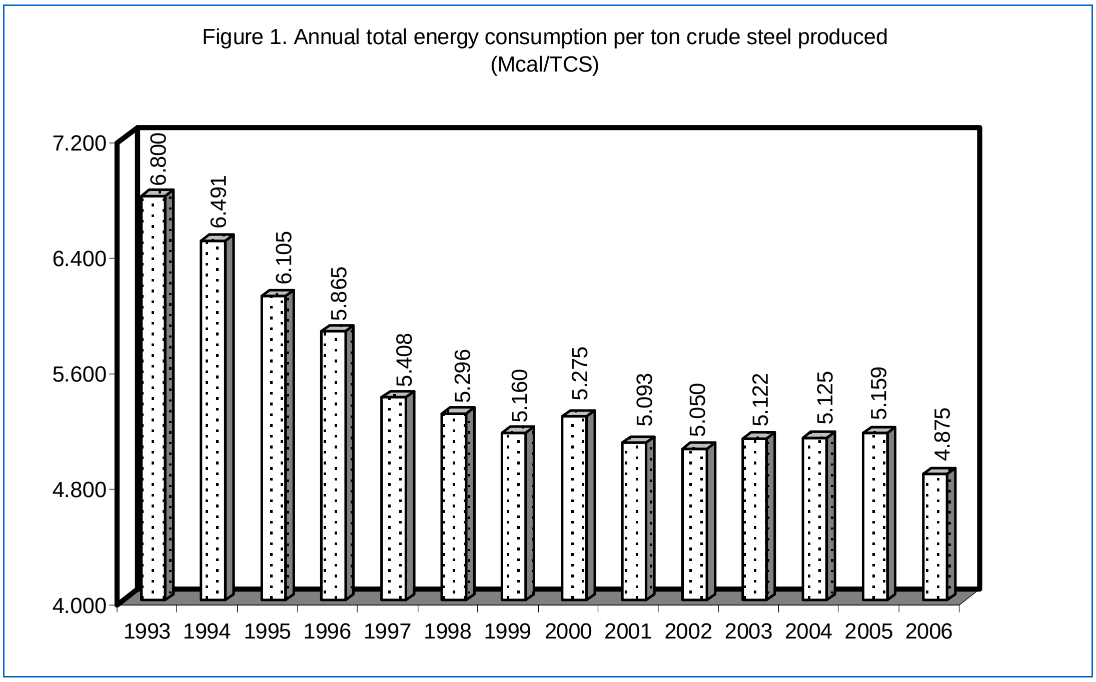


Figure 19: Annual total energy consumption per ton crude steel produced (Mcal/TCS)

With a nominal capacity of 195 MW Erdemir produces most of the electric power needed for the production process itself with steam turbine and gas turbine generators. The power station produces approximately 85% of Erdemir's electric power demand, the rest is provided by the national grid. Moreover, as Erdemir sometimes produces more power than needed, it has gained a licence to sell surplus electricity through bilateral agreements.

3.1.2 ICT activity

Since the beginning of the year 2007 there have also been serious efforts to minimise energy consumption via Information and Communication Technologies. Therefore, Erdemir partially implemented and furthermore planned an optimisation of the electricity and steam cycle divided in four main stages.

At the first stage the control systems of different manufacturers' machinery, which hitherto were independent from each other, were collected at one spot, building a joint communications infrastructure. These systems were connected to a central Ethernet switch, the Ethernet supporting systems directly, and the others using serial Ethernet converters. The system currently has 24 nodes. After the network was established the values were transferred to one server by means of OPC, Modbus TCP/IP, and the monitoring unit's specific drives.

The second step was to create a single database for the parameter values gathered on the server with the OSIsoft PI System (Plant Information System), and to prepare a configuration set-up based on past values. With the PI software graphics were generated that reflect the entire system, which are then made visible and available through the intranet (Figure 20). The furnace, turbine and compressor performance calculations as well as calculations concerning by-product gases production and consumption are made and recorded. With these calculations an ICT-based infrastructure for minimising emissions of by-product gases and distributing loads depending on the effort has been created and established.

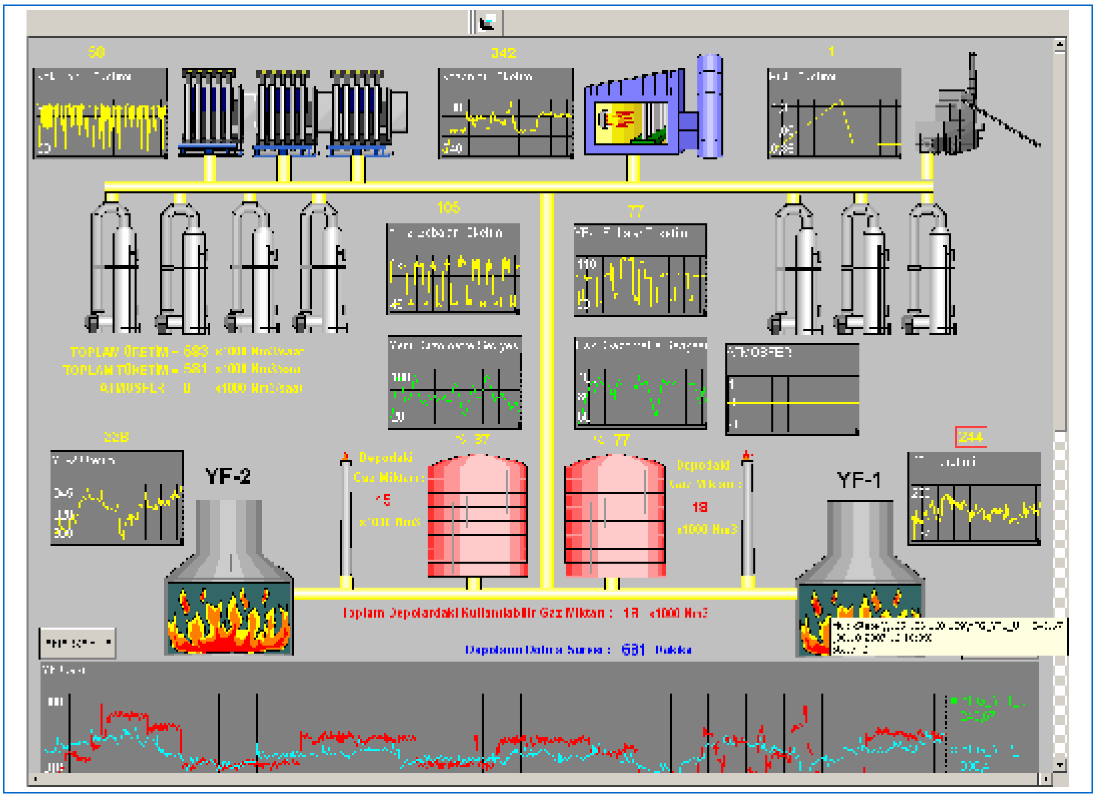


Figure 20: Example of a graphical representation of the OSIsoft Plant Information System

The last two steps are at a test stage at the moment and planned to be completed in 2008. Meetings with the ICT suppliers are still ongoing.

In the third stage it is intended to implement classic output-affecting PID controllers in the existing DCS (Distributed Control System) for pursuing modern control strategies.

Thus the furnace main header pressure, temperature and combustion control will be regulated using predictive algorithms. This will lead to more efficiently loaded furnaces and increasing outputs.

In the last step the system will be modelled entirely. The primary aims of this final step are (1) minimising the gas emissions into the atmosphere by modelling the by-product gas production and consumption system and (2) regulating the usage of the furnaces. So the furnaces will be loaded in a manner that they work at minimum cost with respect to the existing gas use situation. Furthermore, with regard to tariffs the needed electrical energy and steam will be produced at minimum cost, the set values calculated, and the turbines and furnaces loaded correspondingly.

3.1.3 Impact

As the energy optimisation system is still in progress and not fully implemented yet the financial impacts are yet to be determined. The following impacts can be stated at the moment:

- The supplier of the Optimisation System assures cost savings of at least 3%, and realistic estimates predict savings that can reach up to 5%. With an overall installed electrical capacity of 195 MW at Erdemir, significant load reductions ranging between about 6 MW to 9 MW are expected;
- Cost savings depending on saved energy thus can be expected to be at least in the order of $10 million per annum;
- The optimised process thus leads to lower costs for the same output, or constant cost for a higher output, respectively;
- The parameter values of the power and steam system are collected at one server and can be accessed easily via a graphical interface, available for the employees concerned via the intranet;
- Through the newly installed control mechanisms a significant quality improvement of the steam regarding temperature and pressure could be achieved, as well as the internal electricity distribution and load management improved.

3.1.4 Lessons learned

In steel production, due to rapidly increasing energy needs, each energy-saving activity saves costs significantly. Most of these reductions can be achieved through capital asset improvements and a smaller proportion also by ICT applications. It has been shown that ICT solutions can indeed lead to marked cost savings because of the high energy consumption in absolute terms, without disproportionately big changes in the production process, and also to significant quality improvements. So the evaluation of the parameter values delivered by the Plant Information System alone, i.e. without implementing the planned optimisation tools yet, already led to positive changes in the power generation system. For example the rearrangement for the operation of the turbines with regard to their output, resolving vacuum problems by automation of the injectors, a fine-tuning of the steam temperature impact on the turbines, and cleaning procedures after analysing the pressure data were actions taken – after the inadequate conditions were pointed out by the newly installed ICT tools. When the last steps of the ICT development including the optimisation process will be finished in 2008, the Erdemir Energy department can expect further cost savings in the energy production and hence further reduce overall production costs.

3.1.5 References

Research for this case study was conducted by Reinhard Madlener and Koray Karaadak, RWTH Aachen University, Aachen, Germany, on behalf of the Sectoral e-Business Watch. Sources and references:

- Interviews by Koray Karaadak with Tamer Adanir, Superintendent – Erdemir Power Generation and Distribution, 22 and 30 October 2007
- Erdemir Group Annual Report 2006
- www.erdemir.com.tr
- www.osisoft.com.

3.2 Jacob Fruitfield food group, Ireland

Abstract

Jacob Fruitfield is one of the major Irish producers of biscuits & treats, sauces, and jams & preserves, with extensive production facilities just outside of Dublin. Back in 2004, the company adopted an energy monitoring solution to learn about its energy consumption in an energy intensive production environment. Documented in this study is the impact that this application has had on business processes within the company, and in particular the organisational assimilation of an energy monitoring application. Understandings generated provide important lessons for other organisations that intend to adopt energy monitoring solutions. One of the key lessons learned from the Jacob Fruitfield study is that energy education is crucial for the successful assimilation of energy monitoring applications in organisations.

Case study fact sheet

■ *Full name of the company:*	*Jacob Fruitfield Food Group*
■ *Location (headquarters / main branches):*	*Tallaght, Dublin, Ireland*
■ *No. of employees:*	*406*
■ *Year of foundation:*	*2004 (Food Group), parts of the group have been trading since 1851*
■ *Main business activity:*	*Production of biscuits, jam and confectionary*
■ *Primary customers:*	*Supermarkets, Wholesalers & Food Service*
■ *Turnover in last financial year (€):*	*€ 106.6 Million*
■ *Most significant market area:*	*Ireland, UK, Europe & USA*
■ *Main e-business applications studied: **	*ICT and energy saving (Implementation and amalgamation of an energy monitoring solution)*
■ *Case contact person:*	*Natasha Whyte (Fitzgerald), Energy Manager*

3.2.1 Background and objectives

In 2004, the Jacob Fruitfield Food Group was created from a merger of two previously unrelated companies: Fruitfield Foods and Irish Biscuits. Spanning back some 150 years, both of these previously unconnected firms have long traditions in the making of biscuits, sauces, jams, and confectionary. With these strong historical roots in Ireland, the company nowadays prides itself as having become ‘an integral aspect of Irish society’. Brands sold by the food group today include ‘Fig Rolls’, ‘TUC’, ‘Cream Crackers’, ‘Kimberley’, ‘Mikado’, ‘Coconut Creams’ and ‘Oat Crumbles’ in the biscuit and treats range; ‘Fruitfield’ and ‘The Real Irish Food Company’ in the jams and preserves range; and ‘Chef’ in the sauces and pickles range. The company’s target market is the fast moving consumer goods market. Its main customers are Tesco, Dunnes, Superquinn, Supervalu, Londis, and Musgrave’s. The challenges faced by the company in maintaining and expanding its existing market share come from both its competitors (United Biscuits, Foxes, and Heinz) and an increasing manufacturing cost base – mainly due to increasing raw material and energy costs.

e-Business plays an important role in the running of the food group. Various applications are employed throughout the business such as EDI (Electronic Data Interchange) used by the Customer Service department for the receipt of orders from the various customers and sales representatives, and EPOS (Electronic Point of Sales) data by the Marketing department for development of marketing strategies. Furthermore, Jacob Fruitfield Food Group has adopted an energy focus system which measures and monitors energy consumption at its manufacturing facilities. The focus in this study is on the organisational assimilation of this solution at the Tallaght production site, illustrating how energy monitoring has become an integral part of Jacob Fruitfield Food Group's activities. The production facility at Tallaght comprises of one large production building, an adjoining warehouse, an office block and a free standing compressor room. The total area of the premises is approximately 42,140 m^2. Two main sources of energy are used on site: electricity - used for lighting, motive power for production machinery, compressors, refrigeration, ventilation / extraction, battery chargers and miscellaneous use; and natural gas – used for baking ovens, raising steam for process and washing purposes, space heating for the factory, warehouse and offices and for raising domestic hot water.

3.2.2 e-Business activities

The energy monitoring solution, which was supplied and installed by EFT Control Systems Ltd in 2004, primarily shows how much gas and electricity is consumed on the manufacturing site. The application is connected to a set of 3 primary meters and 34 sub-meters across the facility. The three primary meters are a gas meter, an electricity meter and a water meter. Sub-metering for the gas cycle include a baking meter and a heating meter. The heating meter is subdivided into metering for steam boilers, factory air handling units, offices and changing rooms. The electricity meters are installed at the onsite sub-stations and at the air compressor room. The Group produces its own compressed air which is one of its most electricity intensive processes: the conversion rate from electricity to compressed air is only about 15%. The readings collected from the gas and electricity metering system are transferred to the computer application on a 15 minute basis. This application enables the user to gather readings at various times by 'clicking in and out' of the various meters. In terms of electricity the company has established that 300 kilowatt is the base load level. This level rises to well over 1000 kilowatt during the day, going down to approximately 750 kilowatt during the evening shift.

The energy information system process at Jacob Fruitfield Food Group rests upon the following components: the meters, the application, the data generated by the application (primarily in meter readings and Excel reports), the information derived from the data generated, the transformation of the information into a form meaningful and useful to human beings and finally activities of human beings that result in reduced energy consumption. Figure 21 illustrates these elements and the sequence thereof.

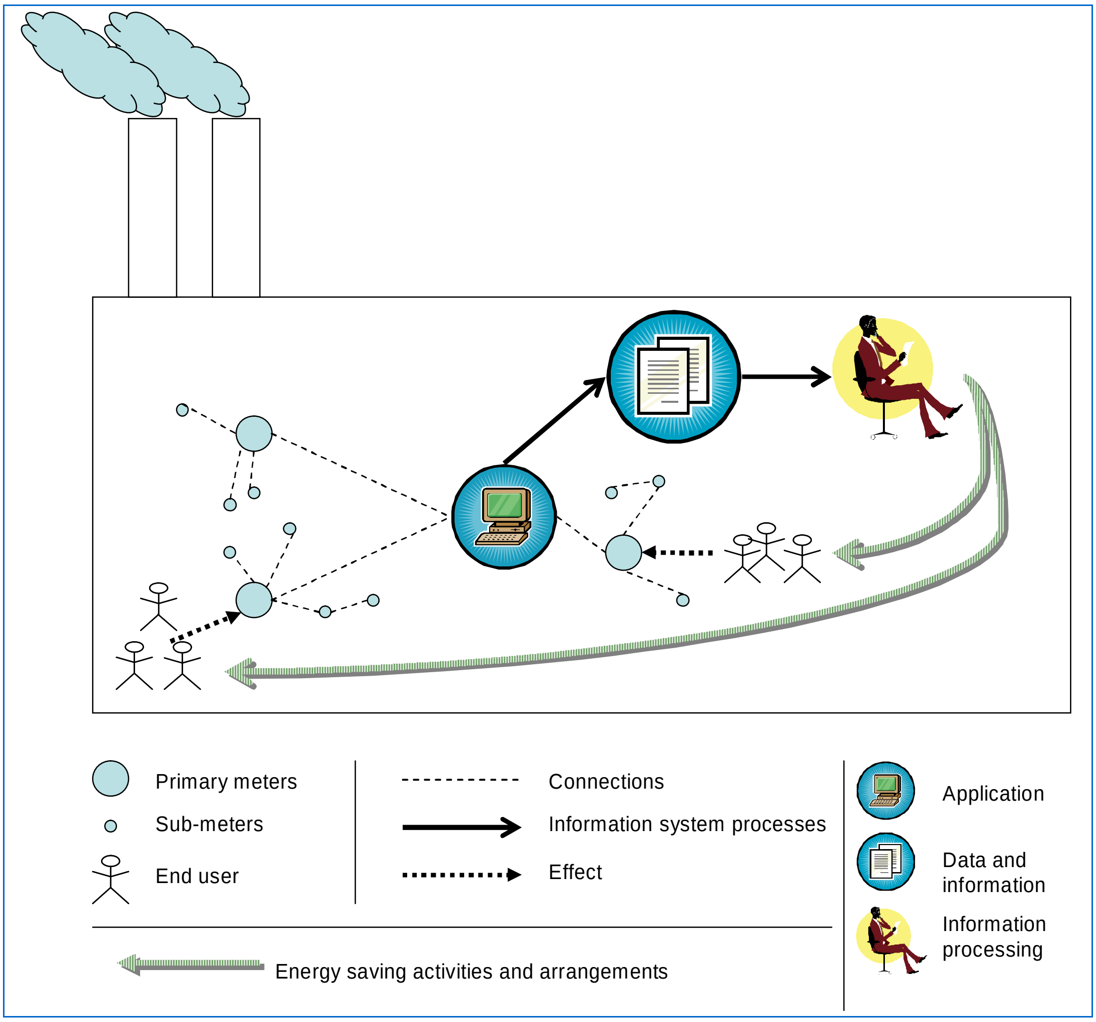


Figure 21: Energy information system process at Jacob Fruitfield Food Group

The energy information system process rests upon an initial step initiated by the company in 2005: an energy audit. The first key stage of this audit was to collect all relevant information. This included an evaluation of bills (electricity, gas, water, effluent etc.) and an analysis of where energy is being consumed at and at what loads. The second key stage was to inform stakeholders and people working for Jacob Fruitfield Food Group about the findings from the first stage. This second stage revealed a strong need for educating people about energy issues. The first two steps showed the need to examine energy consumption patterns in detail. This resulted in the third step which was to analyse and investigate consumption patterns. The final step was to act upon the findings of the analysis and investigation process. The following example illustrates one of the processes of the energy audit:

The evaluation of the gas consumption started with identifying the amount of gas used and where. The energy monitoring application revealed that the majority of gas was used on baking and heating. Baking is a core activity at the factory. The expectation was this would have the greater gas usage. The analysis however revelad that 48% of gas was used on heating. Heating is broken down into steam boilers, air handling, and heating of offices and canteen. On further investigation the company discovered that two processes within the heating system of the factory were working against each other. Extract fans were discharging warm air fed in by the heating system. This insight led (a) to an evaluation why extract fans were used at certain locations within the factory - upon which it was decided to switch off all the extract fans that are not situated at the end / entrance of the ovens; and (b) to a decision to drop the heating temperature in the factory and use the natural heating regime - heating generated during the production process. The outcome of this gas-heating audit was first, a significant reduction in gas consumption (1.13 million kilo watt hours), second, making use of a production by-product (heating), and third, raised energy awareness among staff who are asked to come forward if they desire temperature adjustments within the factory.

3.2.3 Impact

The assimilation of the energy monitoring solution into the Food Group's ongoing activities is having significant effects on the company. First and foremost it has led to a reduction in the use and consumption of gas and electricity. With the focus on the factory at Tallaght in the first year, the company has managed to reduce gas consumption by 9% per annum. This reduction was mainly achieved by monitoring usage and changing practices at the factory. The next step planned is to focus on water and effluent consumption and other energy consuming sources. The absorption of the energy montoring application into the company has also led to changes in work processes and the acquisition of new, more energy efficient equipment.

The energy monitoring application enables the analysis and classification of energy patterns: managers can identify hourly, daily, weekly, monthly and yearly energy consumption and act upon changes to these patterns. Furthermore, this data gives the company tangible energy performance indicators. For example, in cases where heating degree days are roughly the same in year x and in year y, then heating consumption should roughly be the same in both years unless performance at the factory was different and there are significant factors unaccounted for. The understandings generated about energy consumption patterns do result in energy saving exercises: one weekend the management team went to the factory and switched off all unnecessary equipment including the lights. The meter readings revealed that the total lighting load at the factory is 84 kilowatt. Considering that at night the average electricity load is 300 kilowatt, the managers realised that just through switching off the lights at night in specific areas the average night-time electricity load can be reduced significantly.

The use of the energy monitoring solution has taught Jacob Fruitfiled Food Group that energy savings can mainly be achieved through educating people and getting them involved in the processes. The level of energy savings will notably increase with the adequate involvement of people. While energy habits are hard to establish, once the process of education has started, education is generally fruitful. The group has learned that the best way to educate end-users is threefold: first, to explain what energy is all about; second, to inform them about energy consumption at the company and beyond; and third, to show them what can be done to reduce energy consumption using real-life examples. The energy manager makes use of various tools to educate staff including, the use of energy notice boards – showing monthly, weekly and weekend usage levels for the various areas / utilities throughout the factory, running energy awareness weeks, putting bright informative posters up around the factory, talking to end-users and trying to form habits in people, giving presentations to supervisors, and emailing all employees about energy issues. This energy education goes beyond organisational boundaries, which the following example illustrates nicely: one of the employees was complaining about floodlights being switched on during a daylight football match referencing energy measures at his workplace. While energy education is a slow process, the Food Group recognises that it is one of the most important methods to reduce energy consumption. This understanding combined with future energy saving activities such as expanding the audit to other energy consuming matters, enables the company to expand on its energy policy and make significant further savings in the future. The energy monitoring application will remain a core element of the energy saving process at Jacob Fruitfield Food Group.

3.2.4 Lessons learned

The energy monitoring application has become fully incorporated into the regular activities at the production facilities of Jacob Fruitfield Food Group. What this case study shows is that energy savings can best be achieved when computer applications are fully absorbed into ongoing organisational activities. There are many processes that lead to the conservation of energy at a production plant and it is a long and hurdle-some way to identify these and implement changes that lead to energy savings. Core elements of energy saving processes are computer and technical applications that provide accurate data and people dedicated to change work processes based on information generated from the applications. One key instrument in the energy saving approach at the Jacob Fruitfield Food Group is the use of energy audits. Commonly these audits consist of energy pattern analyses, identification of energy intensive matters and searches for most suitable solutions. Yet all these activities are based on effective human involvement illustrating that the success of energy computer applications depends significantly on what people do with the data and information produced by the applications. While organisations can define formal energy processes that incorporate applications, the end user who switches off a piece of equipment when it is no longer needed is at the heart of the energy saving measure.

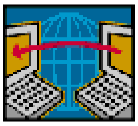
3.2.5 References

Research for this case study was conducted by Maria Woerndl, empirica on behalf of the Sectoral e-Business Watch. Sources and references used:

- Interview with Natasha Whyte (Fitzgerald), Energy Manager & Total Productive Maintenance Controller, Jacob Fruitfield Food Group, July 10th, 2007, in Bonn/Germany
- Internal documents
- Websites:
  - Jacob Fruitfield Food group, http://www.jacobfruitfield.com
  - EFT Control Systems Ltd, http://www.eft.ie.

3.3 Coop supermarket retail company, Switzerland

Abstract



Coop Switzerland is the second-largest retail company in Switzerland. In reaction to climate policy of the Swiss government, which allows for voluntary agreements as a substitute for a CO_2 levy, it has adopted a range of measures to reduce energy needs and CO_2 emissions, thus markedly raising energy productivity. Among other measures, Coop refurbishes its retail outlets and implements an ICT-based facility management system that includes target values for energy consumption and exact controlling of energy and water flows. Moreover, Coop has installed a standardised energy data recovery and evaluation system in all new and refurbished retail outlets. Finally, we also report on three e-Business activities: Internet shopping, Customer loyalty programme, and a pilot self-scanning system for retail customers.

Case study fact sheet

Full name of the company:	*Coop*
Location (HQ / main branches):	*Basel, Switzerland*
Main business activity:	*Supermarket retailer*
Year of foundation:	*1840 (originally established as a number of local cooperative societies)*
Number of employees:	*> 45,000 (third-largest employer in Switzerland)*
Turnover in last financial year:	*CHF 14.7 billion (about € 9 billion)*
Primary customers:	*Private households*
Most significant geographic market:	*Switzerland (mostly eastern part of the country)*
Main e-business applications studied:	*Internet shopping, Customer loyalty programme, Self-scanning system*

3.3.1 Background and objectives

Coop is the second-largest retail group in Switzerland. It is organized in five sales regions, operates over 1500 stores, and has a workforce of more than 45,000. Its focus is on the long-term trends of zest for life, freshness, health, convenience, and dynamism. As an enterprise organised along cooperative lines, Coop says its primary commitment is to its more than two million member households. This commitment would be reflected in Coop's corporate profile: "We are close to our customers".

Coop has also become an internationally recognised pioneer in innovative energy management of production facilities and supermarkets. Energy consumption is a relevant cost factor. Electricity spending alone amounts to 80 Swiss francs (about 50 euros) per square meter, or around 60 million Swiss francs per annum for all 950 stores.

Finally, Coop aims at sustainable development. The present case study was undertaken with the help of its sustainability manager, and in 2006 Coop has formulated 14 sustainability guidelines.

Energy savings triggered by Swiss climate policy

In 2000, when the fifteen Coop cooperatives were merged into one company, a new concept for buildings and building services was implemented that also comprises target values for energy consumption and exact controlling of energy and water flows.

In 2004, Coop and the Swiss Federal Government (represented by the Swiss Agency of the Economy, EnAW, see below) agreed upon CO_2 mitigation targets for Coop's sales outlets, distribution centres, and manufacturing companies. In particular, by 2010 CO_2 emissions are to be lowered by 30% at its sales outlets and by 16% at its distribution centres and manufacturing companies, compared to 1990 levels. Coop agreed to this deal in face of the Swiss CO_2 Act, which foresees a CO_2 emission levy (the exact level and date of introduction which was decided upon at the end of 2006), from which companies with voluntary agreement can be exempted from.

CO_2 audits undertaken by EnAW account for all sources of energy used, including oil, natural gas and district heating. Over the last years, with the help of external experts, Coop has managed to improve data collection methods markedly, and now has reliable data on a rapidly increasing number of its new or modernised supermarkets, which have been equipped with a standardised system for evaluating energy data. Specific heat consumption of new and refurbished supermarkets has been cut by 50% of the average consumption of all supermarkets (despite higher comfort levels and the more intensive use of refrigeration units and finishing ovens). At the same time electricity consumption has decreased by 7%, compared to the average consumption of all supermarkets.

Every year, Coop refurbishes about 100 of its total 900 retail outlets / supermarkets (excluding DIY stores). A facility management company (B+B Engineering, a subsidiary of the Reuss Group Holding, Gisikon, Canton Lucerne; hfm Hälg Facility Management) has been commissioned to supervise the technical infrastructure (presently of about 100 Coop supermarkets), and is involved in the planning of new buildings and refurbishments.

A significant share of the supermarkets equipped with the new data collection system has an annual specific heat consumption of less than 40 kWh per square metre. Coop's engagement has even led to a reduction in the requirements for sales outlets imposed by 'Minergie', an energy efficiency standard / label for buildings (www.minergie.ch).

Increasing competitive pressure (mainly from Migros, Denner, Aldi, Lidl, among others) has been a main driver for continued efforts to rationalise and economise.

Cooperation with Energy Agency of the Economy (EnAW)

Coop collaborates intensively with the Energy Agency of the Economy (Energieagentur der Wirtschaft – EnAW; www.enaw.ch), which, on behalf of the Federal Government (Bund), coordinates and advises some 1000 Swiss firms clustered in 68 groups of the "industry and services" sector regarding federal energy and climate policies goals and tasks. In 2003, a range of energy-saving measures were developed and defined for an energy audit of Coop. The actual audit was done in 2004 and successfully completed. The action taken in preparation for the audit led to a decreasing trend in Coop's energy consumption. More specifically, heat demand in absolute terms could be reduced by 16% so far, and from 2002 to 2003 alone by 2.3%. The trend change was all the more remarkable since the increasing demand for fresh convenience products (that need to be cooled) has increased energy requirements, as did the supply and demand for bread finally baked at the retail outlets. Besides, total sales area has increased.

Transport and logistics

One third of all transports from the national distribution centres of the Coop Group is conducted by railway. In 2006, 30 new lorries were purchased. A more intensive concentration of distribution centres led to a reduction in CO_2 emissions from transport by 20% and of electricity consumption by 8%. The new lorries are larger in size, and drivers are educated in Eco-Driving (which has proven to enable fuel savings of between 10-15%).

In 2006, SAP and WAMAS supply chain and warehouse management software replaced all existing software systems, resulting in higher efficiency and reliability of many processes. The system change affected not only logistics, but also category management, purchasing, stock management, sales, finance, and controlling.

At the same time, a “pick-by-voice” system was tested, which is currently being implemented: order pickers receive their orders from an electronic voice and confirm execution over a microphone (so that they have both hands free). Moreover, Coop introduced sales-based ordering (SBO) on selected product segments, and plans to eventually extend it to the entire product range. The automated re-ordering proposals support the staff and improve the efficiency of product-range management and the maintenance of the optimum stock levels.

The specific role of ICT for energy saving and energy contracting

ICT plays important roles for Coop in various different ways. For instance, Coop has begun to install a standardised energy data recovery and evaluation system in all new and refurbished retail outlets. Moreover, multi-site contracts with facility management companies enable detailed recording of electricity needs in older retail outlets. By 2004, the standardised new energy management system was already used in 180 retail outlets. In order to minimise cooling losses, jalousies automatically close chest freezers after shop closure (i.e. when the lights are switched off). Air conditioning (AC) systems are not necessary, since cold air is sucked off, thus avoiding excessive concentrations of cold air in the shops. Cooling needs in summer are satisfied by recovering and reusing the cold released from the freezer units.

A path-breaking and pioneering integrated building management system called “Tet” (also referred to as ‘MESA’ – ‘Management für Energie, Sicherheit und Automation’) was co-developed by Coop and B+B Engineering, which in the meantime being offered commercially in its third generation. The Tet-system is based on black-boxes (measurement points) that collect all relevant data. Sensors provide data for cooling, heating, lighting, and water flows. Coop has defined set target values for room temperatures and the consumption of electricity, fossil fuel, and water. If the actual values diverge from the set values, a technician is alarmed electronically. The technician can make some remote adjustments online, while for others the manager of the retail outlet or the group of technicians assigned to the region where the outlet is located are responsible. Remote diagnostics allow for the checking of a host of operating data.

Usually, after two years of guarantee Coop takes over the management of the facilities from the facility management provider. Since Coop considers itself as a retailer, and not a technology company, more intensive outsourcing of energy / facility management in the form of long-term service contracts is currently debated within the company. Such contracts, which involve guaranteed minimum energy consumption levels and specific services, already exist with the suppliers of cooling devices.

Lighting and room temperature are controlled from a central control unit at the headquarters of the Coop Group in Basel. Waste heat from lighting is also integrated into the energy management system. Finally, escalators stop when they are not in use and rain water is collected for toilet flushing and the watering of plants. Coop has so far collected water consumption data only for its new and modernised sales outlets. With 0.79 m^3/m^2 of floor area, annual water consumption at the 136 sales outlets where the system was installed was slightly lower in 2006 than in the year before. Water consumption at Coop's manufacturing companies and distribution centres has been measured collectively for a long time. Water consumption at the manufacturing companies increased by only 1% in 2006, despite higher output in some cases. Last but not least, standardisation yields manifold advantages, including energy and cost savings.

3.3.2 e-Business activities

For several years now, Coop has significantly intensified its e-Business activities. In the following, the three activity areas coop@home online shopping, the customer loyalty programme "Coop Supercard", and the self-scanning system "passabene" are briefly described.

Internet shopping (coop@home)

In August 2006, Coop launched the Internet shopping platform "coop@home" by merging the "Online Supermarket" and the Internet-based "Coop Wineshop". The product range increased from 4000 to more than 10,000 products, and Coop now offers the largest range of items in Switzerland that shoppers can order online via the Internet or by telephone or fax. Prices are the same as in sales outlets, and customers can also order fresh produce, deep-frozen food, and more than 1000 different wines from all over the world. In 2006, the Coop coop@home had an annual turnover of 45 million Swiss francs, which is an increase by 38% compared to 2005.

Customer loyalty programme (Coop Supercard)

With more than 2.3 million users, Coop Supercard (www.supercard.ch) is the largest customer loyalty programme in Switzerland. In 2006, customers claimed some two million bonus gifts (worth about 120 million Swiss francs), which represented a 3% increase on an annual basis. Since September 2006, Supercard holders can also gain points with their cards at Coop petrol stations.

Self-scanning system (passabene)

Since 2003, Coop has introduced many technical and organisational improvements to facilitate the check-out procedure for customers, including the installation of fast scanners and card terminals, and improvements in the staff shift scheduling in line with precise customer frequency analysis and the training of check-out staff. In 2006, Coop introduced the self-scanning system 'passabene' as a pilot project in a number of supermarkets. Passabene is expected to radically change shopping behaviour. Customers can scan their purchases with a hand-held scanner, which is handed in at the check-out desk after completing shopping, where the cashier then initiates the payment procedure. Purchased items no longer need to be put on the conveyor belt, thus simplifying and shortening the check-out procedure. The running total is always displayed on the hand-held scanner, thus improving price information for shoppers. It should be noted that Coop deliberately opted against an unmanned self-check-out system, because the currently implemented system still allows contact with the check-out staff.

3.3.3 Impact of ICT on energy use

The restructuring and modernisation of Coop distribution centres and retail outlets has led to dramatic changes in energy consumption. The measures taken are manifold, and some are directly related to the use of ICT.

- So far 10 retail outlets have been optimised in a way that they no longer need any external energy for heating purposes (as of March 2007), but are heated completely with a waste heat recycling system;
- Heat energy demand for room heating and on-demand baking ovens in new and refurbished retail outlets has been reduced by 60% due to energy recovery from the cooling system;
- Freezer units are being fitted with glass doors and sliding glass lids, while chest freezers are being fitted with glass aprons to trap the cold air;
- The new energy concept has also been implemented at a significant number of the Coop DIY stores, and specific heat consumption is now barely half as much as that of the not-yet-modernised DIY centres;
- Heat energy consumption could be reduced by 18% (while electricity demand has increased by 2.9%) (as of 2003);
- Swissmill, the grain mill of Coop, uses a greater diameter of pressurised air pipes, which saves around 25,000 kWh of electricity per annum;

Finally, it is worth mentioning that infrastructure costs could be substantially lowered due to the streamlining of outlets and the optimisation of processes.

3.3.4 Lessons learned

Driven by Swiss climate policy (CO_2 Act, CO_2 levy), Coop has implemented a voluntary agreement programme in cooperation with the Energy Agency of the Economy that manages (and certifies) the voluntary agreement scheme on behalf of the Swiss government.

By taking decisive energy efficiency and energy management measures, the upward trend in electricity consumption could be slowed down, while that of heat demand has actually been reversed. Moreover, significant CO_2 reductions could be achieved e.g. through the investment in more economical lorries, and a higher concentration of the distribution centres.

The energy management system adopted consists of a variety of organisational and equipment changes within the modernised retail outlets. All relevant data (such as on water, energy, electricity consumption and temperature level of freezers) are recorded via ICT. An important part of the energy management is the standardisation of the buildings that also complies with Minergie, a Swiss energy efficiency standard / label for buildings. Furthermore, the time-of-use management system controls lighting and temperature. Using the waste heat of freezers leads to further energy savings. Through the permanent comparison of data the energy management system safeguards that deviations are immediately detected and followed up by the staff in charge (cf. “Energiemanagement hinter den Kulissen”, Food & Near-Food 02/06, 12-13).

3.3.5 References

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- www.minergie.ch (MINERGIE energy label).

4 Conclusions

In this section we summarise the key findings, provide an outlook for future research needs, and derive some policy recommendations.

4.1 Key findings

4.1.1 Desk research

While there have been countless studies on the links between ICT and growth or between energy consumption and growth, the relationship between ICT and energy consumption remains largely unexplored, at least from an economic point of view. Three relevant economic studies have approached the topic from different angles. A French study for the service sector (Collard et al., 2005) suggests that information technology tends to increase electricity intensity of production, while communications technology in general reduces intensity. The "CT" impact is greater than the "IT" impact. A Japanese study (Takase and Murota, 2004) concludes that increasing IT lowers CO_2 intensity, but energy consumption may go up or down, depending on whether the income effect or the substitution effect dominates. A South Korean study (Cho et al., 2007) found that ICT investment promotes substitution away from labour and towards electricity. The outcome differs from sector to sector, with energy consumption going down in manufacturing, but going up in the services sector.

Two other economic studies were mentioned. A study by Laitner (2003) suggests that the issue is clouded by the sheer complexity of the information society, and that a focus on direct energy requirements alone may not be the right angle to take. However, he does conclude that small reductions in energy intensity can be brought about by a range of interrelated trends. A Japanese study on projected intensified ICT use in Japan (Ishida and Yanagisawa, 2003) suggests that it would be possible to prevent an increase in energy consumption only if ICT-induced economic growth were capped.

4.1.2 Econometric modelling

The first part of the econometric analysis, which was devoted to measuring the impact of ICT on electricity intensity in the framework of a structural factor demand model (Collard et al., 2005), brought to light two main results: (1) the diffusion of communication technologies has a positive impact on reducing energy intensity while (2) the diffusion of computer & software technologies tends to increase energy intensity. The results obtained are robust in respect to correcting for potential endogeneity of explanatory variables.

The second approach was used to econometrically asses the impact of ICT capital, electricity and various other input factors on productive efficiency. This was done by estimating simple Cobb-Douglas production functions under the assumption of constant returns to scale. We find that output elasticities with respect to the various input factors vary a lot, both across the input factors and also across sectors. Nearly all estimated models showed a significant positive impact of ICT capital on productivity. Hereby, the effect of computers & software exceeds the effect of communication technologies in all industries considered. Further analysis is needed, e.g. with improved data or for additional sectors, in order to check for the robustness and validity of the results, and for identifying common patterns among comparable sectors (e.g. energy-intensive ones in manufacturing). Also, from our investigation of the chemicals and metals industries, we find that the elasticity of ICT capital tends to be considerably lower than for other input factors (e.g. materials, energy, non-ICT capital), indicating that ICT capital is not the most important input for influencing production output.

Overall, it seems that the research conducted here has the potential to deliver an enriched picture about the implications of ICT on energy consumption, modelled by means of production functions, and some interesting new insights and ideas for future research. On the other hand, the modelling approach is very specific, i.e. that many interesting questions related to ICT and energy use cannot be tackled with it, and data limitations at the sectoral level often make it impossible to dig much deeper. Expected future extensions of the available databases (EU KLEMS, Eurostat) will also enable an extension of the analyses that was undertaken in the present study with very limited resources.

4.1.3 Case studies

The results of the three case studies conducted so far, involving companies who had turned to ICT as a means of measuring, understanding, and ultimately cutting their energy use, can be summarised as follows:

- **Erdemir** is Turkey's largest iron and steel producer, and accounts for 1.7% of Turkey's entire energy consumption. The company used IT applications to bring together all its control systems under one switch, and to provide an on-screen Plant Information System as a means of monitoring energy consumption. This has resulted in energy savings of up to 5%, and an early-warning system for any anomalies (e.g. pressurised air leakages) within the production system.
- **Irish food producer Jacob Fruitfield** set up an Energy Monitoring System to tackle deficiencies identified in an energy audit. The system has helped reduce gas consumption by 9%, provided better understanding of consumption patterns, and has instilled greater energy awareness among staff.

Coop, Switzerland's second-largest retailer, set up an Energy Management System in an attempt to reduce electricity and heat consumption, and to meet its commitments under national climate policy. The system combines data collection from its 950 food retail stores with a comprehensive building management system, which makes sure that target values for temperature and consumption of fuel, electricity and water are met. It also oversees the recovery of energy from the cooling system, which has reduced heat energy demand by some 60%.

4.2 Outlook on further developments expected

This project's research on the link between ICT and energy intensity is now drawing conclusions. It has identified some key trends based on the data available. These trends – e.g. electricity intensity of ICT capital services, energy input per unit of ICT capital, input factor development over time – turned out to differ considerably depending on the sector studied.

The sectoral data used is aggregate data from national statistics offices, which can only provide a crude picture. Nevertheless, when using this data, the descriptive analysis undertaken so far shows some interesting trends, and also some unexplained departures from trends (e.g. for Italy and the UK), which require some explanation. The model-based analysis conducted so far shows greatly varying output elasticities with respect to different input factors across the sectors studied so far (metals, chemicals). ICT also brings with it a number of structural changes (e.g. online bookstores) and new behavioural patterns (e.g. online shopping) that make it difficult to assess the overall impact on energy intensity or consumption.

Finally, there is a need to make the main findings and limitations of the research clearer, and to ensure that final conclusions are in an adequate form fed in to policy-makers. It may be that these conclusions are specific to certain industry sectors, rather than relevant across the board, which has to be made explicit.

4.3 Policy implications

The appropriate starting point for considerations concerning policy implications should naturally be the results obtained by the econometric analysis in chapter 2. The latter consisted of two parts: (i) the Collard model, which was used to estimate the impact of the diffusion of disaggregated ICT-capital on energy consumption in distinct industries, and (ii) the Cobb-Douglas model, which aimed at assessing the relative effect of ICT-capital and various other input factors on productive efficiency. Due to limitations on data availability the analysis could be conducted only for a fraction of the originally targeted industries and countries. Still three key industrial sectors, namely the chemicals, metals and transport sector, are sufficient to show that the influence of ICT on energy intensity and productivity varies greatly across industries. Nevertheless, we find enough similarities to derive some insights, thereby allowing us to formulate four key policy implications. Moreover, the implications are based on the assumption that both a reduction of energy intensity and an enhancement of productive efficiency are desirable policy outcomes.

The four policy implications from this study are:

- Nearly all estimations reveal a negative effect of communication technologies on electricity intensity (i.e. lowering electricity intensity) and a positive effect on productivity (i.e. increasing productivity). Hence the promotion of the diffusion of communication technologies seems to be worthwhile regarding electricity intensity of production as well as productivity.

- Computer & software technologies seem to have an ambiguous influence. Concerning energy intensity on the one hand, only in one of the three industries assessed, a statistically significant effect was estimated, revealing a positive impact. On the other hand, the effect on productive efficiency is positive in all considered industries, thereby always exceeding the effect of communication technologies. Due to this trade-off, recommendations concerning the support of computer & software technologies are dependent on the relative preferences of policy makers regarding the reduction of energy intensity and the enhancement of productivity.

- At first glance, the findings from the three case studies conducted seem to contradict the results of the econometric analysis. According to the companies own statements, the implementation of energy management systems (EMS), which among other things mainly rely on computers & software technologies, lead to a lower level of energy intensity. A possible explanation is that the computer & software capital engaged in such systems is only a fragment of the total computer & software capital. Hence, the promotion of EMS could be a way of targeted support for energy-reducing ICT.

- As mentioned, the limitations on data availability and disaggregation proved to be quite a restriction in conducting a broader empirical analysis. Preferably, such analysis should take into account a larger number of EU member countries, and especially new EU member states, and a larger number of economic sectors (industries). Also, in some parts of the analysis only the impact of ICT and non-ICT capital could be distinguished, which makes it impossible to find out more about the relative impact of computers, software and communication technologies. Therefore an improved data basis is needed to be able to undertake further econometric analysis, both in terms of countries covered and disaggregation by sectors and capital input factors. Hence, the provision of additional funds for improved data bases would assure a more reliable and extensive quantification of economic interrelations, which is the basis of every solid and concrete policy consultation.

An important point to be mentioned is that there is a need to look at "embedded" ICT. For instance, an increasing range of goods such as cars have a high ICT content (e.g. micro-processors in the engine system) that does not show up in aggregate data for the ICT capital stock, and that hence cannot be detected by the modelling approach followed here. Furthermore, in order to obtain policy implications that can be better operationalised, the picture needs to be completed further, and the limitations to the methodological approach adopted (and the data available for this kind of research) need to be emphasised clearly for not misguiding policy-makers.

Practical experience shows, confirmed e.g. by Maher Chebbo of SAP (member of the Advisory Board), that the best results can be achieved when technical and production ICT systems are clearly linked to ICT systems for business development. It would therefore be interesting to map company case studies by means of a 'maturity matrix', in order to show how far advanced a company is in its field with respect to the use of ICT. There are advances in ICT systems for managing energy data, and for managing energy use itself. SAP energy applications bring together energy use from across a company to create a portfolio, so that energy use overall can be measured. Here, standardisation of ICT can play an important role – for example, common interfaces can make systems leaner and more automated.

Many utility companies have been leading the way in the use of ICT to pursue energy efficiency. Other operators might not be so motivated, or decision-makers for IT are not necessarily considering investments with an energy-conscious outlook. Perhaps there is a role here for policy-makers to provide the right incentives. Energy service companies (ESCOs) are also playing an increasingly important role here. Overall, there seems to be a need for a mentality change, despite the fact that climate change policy and marginal cost energy pricing seem to be two effective push factors, already driving this change in the right direction.

The study of the relationship between ICT and energy consumption at the aggregate industry level has proven to be an innovative and fruitful area of research from which many new insights can be gained. But support for ICT is just one of many ways of tackling energy efficiency. In general, we should be looking how to separate economic growth from growth in energy consumption as part of the EU's overall move towards the knowledge-based society.

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Tamer Adanir, Superintendent, Erdemir, Turkey, 22 and 30 October 2007, interviews conducted via the telephone (Koray Karaadak, E.ON Energy Research Center/FCN, RWTH Aachen University).

Natasha Whyte (Fitzgerald), Energy Manager & Total Productive Maintenance Controller, Jacob Fruit Field, Dublin, Ireland, 10 July 2007, interview conducted in Bonn, Germany (Maria Woerndl, empirica).

Brigitte Zogg, Sustainability Manager, Coop Group, Basel, Switzerland, 18 October 2007, interview conducted in Basel, Switzerland (Reinhard Madlener, E.ON Energy Research Center/FCN, RWTH Aachen University).

Appendix A – Modelling

Eq. (3) depicts the Cobb-Douglas production function estimated with cross [$\log(E_t) \cdot \log(ICT_t)$] and quadratic [e.g. $\log(E_t) \cdot \log(E_t)$] terms, which are included in order to check for possible cross elasticities and size effects. Estimation results showed that these are not overly important.

$$\begin{aligned}\log(Y_t) = a_0 + b_{E,t}\log(E_t) + b_{M,t}\log(M_t) + b_{S,t}\log(S_t) \\ + b_{ICT,t}\log(ICT_t) + b_{NICT,t}\log(NICT_t) \\ + \log(E_t)\cdot\log(ICT_t) + \log(E_t)\cdot\log(E_t) + \log(ICT_t)\cdot\log(ICT_t) + b_T time \quad (3)\end{aligned}$$

Appendix B – Results

Results reported in the Interim Report (Cobb-Douglas production function)

In the following, for completeness, we report the preliminary results contained in the Interim Report (based on EU-KLEMS release of 3/2007) that were replaced by new and more detailed results documented in Section 2.2. Note that the changes between the old and the new data are also reported there.

Table A.1 Econometric panel data estimation results, Chemicals industry, Cobb-Douglas production function (CRS), selected EU member countries, 1980-2004

Dependent Variable: LGO_QI_WH
Method: Least Squares
Date: 02/05/08 Time: 11:56
Sample: 2 201
Included observations: 200
LGO_QI_WH=C(1) + C(2)*LIIE_QI_WH + C(3)*LIIM_QI_WH + C(4)
*LIIS_QI_WH + C(5)*LCAPIT_QI_WH + C(6)*LCAPNIT_QI_WH + C(7)*TIME

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	1.037757	0.174603	5.943509	0.0000
C(2)	0.110100	0.020095	5.479039	0.0000
C(3)	0.340530	0.031873	10.68391	0.0000
C(4)	0.238203	0.018624	12.79028	0.0000
C(5)	0.070925	0.008135	8.718476	0.0000
C(6)	0.238628	0.041569	5.740470	0.0000
C(7)	0.003758	0.001604	2.342959	0.0201

R-squared	0.998521	Mean dependent var	-0.665223
Adjusted R-squared	0.998475	S.D. dependent var	1.255243
S.E. of regression	0.049022	Akaike info criterion	-3.158714
Sum squared resid	0.463813	Schwarz criterion	-3.043273
Log likelihood	322.8714	Hannan-Quinn criter.	-3.111997
F-statistic	21713.47		
Prob(F-statistic)	0.000000		

Table A.1 presents the equivalent results for the chemicals and chemical products industry. Again, all coefficients have a positive sign and now all of them are statistically significant. The largest impact on gross output is now imposed by intermediate material input, followed by non-ICT capital and intermediate service inputs. In other words, intermediate service inputs are much more important in the Chemicals industry than in the metals industry.

Table A.2 Econometric panel data estimation results, metal industries, Cobb-Douglas production function (CRS), selected EU member countries, 1980-2004

Dependent Variable: LGO_QI_WH
Method: Least Squares
Date: 02/05/08   Time: 12:13
Sample: 2 201
Included observations: 200
LGO_QI_WH=C(1) + C(2)*LIIE_QI_WH + C(3)*LIIM_QI_WH + C(4)
*LIIS_QI_WH + C(5)*LCAPIT_QI_WH + C(6)*LCAPNIT_QI_WH + C(7)*TIME

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	0.003117	0.029127	0.107008	0.9149
C(2)	0.235795	0.034582	6.818432	0.0000
C(3)	0.540614	0.037861	14.27878	0.0000
C(4)	0.042228	0.023882	1.768195	0.0786
C(5)	0.027101	0.012825	2.113051	0.0359
C(6)	0.160761	0.042591	3.774497	0.0002
C(7)	0.000559	0.001698	0.329093	0.7424

R-squared	0.995097	Mean dependent var	-1.555569
Adjusted R-squared	0.994944	S.D. dependent var	1.166318
S.E. of regression	0.082931	Akaike info criterion	-2.107250
Sum squared resid	1.327357	Schwarz criterion	-1.991809
Log likelihood	217.7250	Hannan-Quinn criter.	-2.060533
F-statistic	6527.859		
Prob(F-statistic)	0.000000		

The results from the estimation for the basic metals and fabricated metal products industry of the eight EU member countries considered are shown in Table A.2. As can be seen, all coefficients are positive and most of them statistically significant (*t*-statistic > 2 in absolute value). Intermediate material inputs are shown to have the largest impact on gross output (coeff. 0.54), followed by intermediate energy inputs (coeff. 0.24) and non-ICT capital (coeff. 0.16). Hence we can conclude that in the metals industries material inputs matter more than energy inputs, which matter more than non-ICT capital. Changes in ICT capital affect output only modestly (elasticity of 0.03), and both the time trend and service inputs are statistically insignificant (reported for completeness).

Figure A.1 depicts a summary of the above results. The two plots allow for a direct comparison of the output elasticities in the two sectors studied.

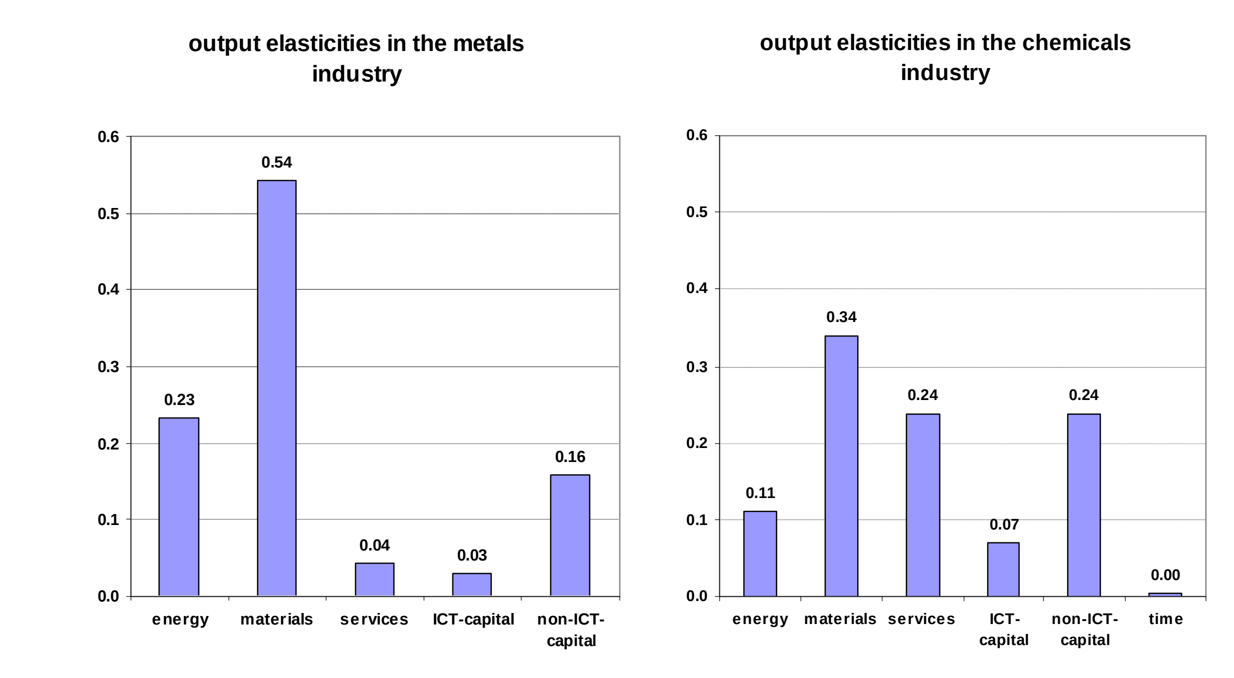

Figure A.1: Output elasticities relative to the various inpt factors, metals versus chemicals industry

The results from this analysis can be summarised as follows:

Chemicals and chemical products industry:

- The output elasticity of material inputs – although lower than for the case of the metals industry – is highest of all (0.34), followed by services and non-ICT capital (0.24);
- The output elasticity of energy inputs (0.11) is much lower than for the metals industry (less than half);
- Output elasticity of ICT capital is lower (less than half) than that for energy inputs, but higher than the one found for the metals industry.

Metals and fabricated metal products industry:

- The output elasticity of material inputs (0.54) is considerably higher than that for energy inputs (0.23);
- The output elasticity of ICT capital is the lowest of all (0.03), and less than a fifth of the output elasticity for non-ICT capital.

Of the five sectors investigated in total, we obtained useful results only for the energy-intensive ones. In the case of banking (financial intermediaries) only materials and energy inputs turned out to be statistically significant, but the latter had a negative sign. In the case of the retail sector, energy inputs and ICT capital was shown to be insignificant, disallowing us to draw any conclusions with respect to the role of these two input factors.

Summary of estimates obtained with the Cobb-Douglas production function

Table A.3 summarises the estimation results for the Cobb-Douglas models in levels for the three sectors studied (metals, chemicals, and transport & logistics) and for variables in values and in volumes (Section 2.2), while Table A.4 presents the corresponding results for the models estimated in differences.

Table A.3 Econometric estimation results in levels, Cobb-Douglas model

	Volumes			Values		
	Chemicals	***Metals***	***Transport***	***Chemicals***	***Metals***	***Transport***
Variables	**Coefficients [t-values]**					
Constant	-0.242 [-7.47]	-0.006 [-1.34]	-0.016 [-4.70]	1.578 [19.46]	1.852 [27.48]	2.062 [20.41]
Energy	0.190 [9.43]	0.114 [4.98]	-	0.061 [6.31]	0.035 [3.37]	0.044 [7.29]
Material	0.389 [12.79]	0.566 [24.52]	0.056 [2.77]	0.369 [15.31]	0.574 [26.65]	0.131 [12.12]
Service	0.083 [5.38]	0.123 [7.13]	0.526 [17.20]	0.301 [17.47]	0.153 [14.75]	0.377 [27.50]
CS	-------------------	-------------------	--------------------	0.051 [6.58]	0.016 [3.17]	0.012 [1.81]
CT	-------------------	------------------	--------------------	0.007 [2.77]	0.007 [2.07]	-
ICT	0.040 [3.37]	0.024 [4.36]	0.056 [6.56]	--------------------	--------------------	--------------------
NON-ICT	-	0.059 [1.61]	0.021 [1.71]	0.165 [5.17]	-	0.101 [5.64]
TIME	0.016 [7.76]	-	-	-	0.003 [3.55]	0.007 [5.15]
Statistics						
R^2 *adj.*	0.967	0.951	0.968	0.992	0.984	0.963
SER	0.062	0.052	0.042	0.038	0.039	0.051
Log likelih	276.958	310.460	335.758	306.438	315.406	271.157
Obs.	200	200	200	164	171	171

Notes: t-values in parenthesis. '-' indicates statistically insignificant and therefore omitted variables

Table A.4 Econometric estimation results in differences, Cobb-Douglas model

	Volumes			Values		
	Chemicals	***Metals***	***Transport***	***Chemicals***	***Metals***	***Transport***
Variables	**Coefficients [t-values]**					
Constant	0.016 [8.38]	-0.001 [-0.40]	0.005 [2.28]	0.013 [6.67]	0.006 [3.61]	0.004 [2.17]
Energy	0.123 [7.78]	0.061 [4.47]	0.067 [5.35]	0.110 [8.62]	0.044 [3.35]	0.079 [6.76]
Material	0.473 [19.43]	0.593 [31.64]	0.060 [3.63]	0.477 [21.99]	0.578 [28.91]	0.060 [4.00]
Service	0.129 [6.49]	0.147 [9.46]	0.430 [15.32]	0.186 [10.82]	0.130 [8.93]	0.412 [15.40]
CS	---------------	------------------	-----------------	-	-	-
CT	---------------	------------------	-----------------	-	-	-
ICT	-	0.032 [2.64]	0.032 [2.06]	------------------	------------------	------------------
NON-ICT	-	-	-	-	0.088 [2.51]	0.246 [4.30]
Statistics						
R^2 *adj.*	0.776	0.876	0.640	0.820	0.860	0.693
SER	0.023	0.017	0.018	0.020	0.016	0.017
Log likelih	457.125	517.272	468.625	395.162	450.036	434.956
Obs.	192	192	192	157	164	164

Notes: t-values in parenthesis. '-' indicates statistically insignificant and therefore omitted variables

Appendix C – Glossary

Term	Explanation
Cobb-Douglas technology	The Cobb-Douglas production function is one of the simplest standard production functions used in economics. It can be specified for a parameter *b*, 0 < *b* < 1, one production output *y* and two input factors x_1 and x_2 as $y(\mathbf{x}) = f(x_1, x_2) = x_1^b x_2^{1-b}$.
Diffusion	The term diffusion describes how the usage of e.g. a new technology for producing a given output or providing a certain service in a market changes over time. It is often observed the rate of diffusion (i.e. the proportion of the output or service produced with the new technology compared to the overall output or service provided) will follow a sigmoid (S-shaped) curve.
Elasticity	Elasticity is the ratio of the percentage change in one variable with respect to change in another variable, such as the responsiveness of the price of a commodity to changes in market demand or visa-versa. In terms of elasticity, a market or good can be described as elastic or inelastic as a means of describing its responsiveness to the change in another quantity.
Energy intensity	Energy intensity is usually defined as the amount of energy needed to produce one unit of GDP. It measures the efficiency of an economy in converting energy into GDP. High energy intensities hence indicate a high share of energy inputs per unit of GDP.
Externality	An externality is an impact (positive or negative) on any party not involved in a given economic activity. The producer of an externality is usually not charged for the costs or compensated for the benefits of the externality. Thus, the externality is produced at a suboptimal level from the societal point of view.
GDP	The Gross Domestic Product (GDP) is the whole market value of all goods and services produced in a country in a year. By contrast, the Gross National Product (GNP) measures the whole market value of all goods and services produced in a country in a year plus income earned by its citizens abroad, minus income earned by foreigners in the country. The key difference between the two is that GDP is the total output of a region, e.g. the U.S., and GNP is the total output of all nationals of a region, e.g. U.S.-Americans.
ICT	ICT stands for Information and Communications Technology and comprises any medium to record and broadcasting information.
Income effect	The income effect deals with how the change of a consumer's consumption budget (e.g due to a change in prices or a rise in the income) affects the consumption of a selected good. The income effect is positive for normal goods (if the purchasing power rises for a certain good, the purchased quantity may rise as well). However, it is negative for inferior goods (these are in general goods which are less preferred than others, usually more expensive, goods with similar properties). The income effect leads to another utility level (see also substitution effect below).
Multiple regression model	Regression analysis is a technique used for the modelling and analysis of numerical data consisting of values of a dependent variable (response variable) and of one or more independent variables (explanatory variables). The dependent variable in the regression equation is modelled as a function of the independent variables, corresponding parameters ("constants"), and an error term. The error term is treated as a random variable. It represents unexplained variation in the dependent variable. The parameters are estimated so as to give a "best fit" of the data. Most commonly the best fit is evaluated by using the least squares method, but other criteria have also been used. In a multiple regression model there are a number of different independent variables or functions of such variables.

Panel data	At a single point in time, an observation can be defined by more than one characteristic. A data set containing observations on multiple phenomena observed over multiple time periods is called panel data.
PID controller	A proportional–integral–derivative controller (PID controller) is a generic control loop feedback mechanism widely used in industrial control systems. A PID controller attempts to correct the error between a measured process variable and a desired setpoint by calculating and then outputting a corrective action that can adjust the process accordingly.
PPP	*Purchasing power parities* permit to convert two and more currencies into a common currency and equalise their purchasing power. These rates eliminate the differences in the price levels between countries and to make them comparable.
Returns to scale	Returns to scale refer to a technical property of production that examines changes in output subsequent to a proportional change in all inputs (where all inputs increase by a constant). If output increases by that same proportional change, then there are *constant returns to scale*, sometimes referred to simply as returns to scale. If output increases by less than that proportional change, there are *decreasing returns to scale*. If output increases by more than that proportion, there are *increasing returns to scale*.
Substitution effect	The substitution effect describes the influence of a change in relative prices on the composition of a consumer’s consumption basket for a given level of utility. According to this effect, if the price of one good rises, a buyer will seek to substitute this good by another good which has become less expensive. The substitution effect is reinforced, or partly off-set, by the income effect (see above). The sum of these two effects is called the price effect.
Volatility	Volatility is the measure of the state of instability. In finance, for example, volatility most frequently refers to the standard deviation of the change in value of a financial instrument with a specific time horizon.