ICT Impact on Greenhouse Gas Emissions in Energy-Intensive Industries

Sectoral e-Business Watch
Study Report No. 01/2009

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ICT Impact on Greenhouse Gas Emissions in Energy-Intensive Industries

A Sectoral e-Business Watch study by

DIW Econ

Final Report

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This report was prepared by DIW econ on behalf of the European Commission, Enterprise and 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 DIW Berlin, IDC EMEA, Ipsos and GOPA-Cartermill based on a service contract with the European Commission.

About the Sectoral e-Business Watch and this Report

The European Commission, Enterprise and 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 at the SeBW website (www.ebusiness-watch.org).

This is the final report of a study focusing on ICT impacts on greenhouse gas emissions in energy-intensive industries. The study describes how companies in these industries use ICT for reducing greenhouse gas emissions and assesses implications thereof for the industry as a whole. The findings are based on econometric analyses of the relationship between ICT capital and various measures of greenhouse gas emissions and efficiency in the sectors considered as well as case studies, surveys, and literature evaluation.

Disclaimer

Acknowledgements

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The study team would like to thank Enrico Gibellieri, Pietro Evangelista, Graham Vickery, Martin Woerter and Willy Spreutels, who are members of the Advisory Board in 2009, for their valued feed-back, comments and contributions to this study.

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Executive summary

About this study

There is much hope that information and communications technology (ICT) has a high potential to increase energy efficiency and reduce greenhouse gas (GHG) emissions. This study provides the first comprehensive empirical analysis of the relationship between ICT on GHG emissions in European energy-intensive industries, analysing the following five sectors:

- Basic metal and fabricated metal
- Pulp, paper, printing and paper products
- Chemicals, rubber, plastics and coke
- Glass, ceramics and cement
- Transport and storage

Structure of the analysis

In order to explore the variety of possible relationships between ICT and GHG emissions, this study employs three central investigative methods:

- an econometric analysis
- case studies
- surveys of current industry trends and expert views.

The empirical analysis is comprised of a descriptive discussion of relevant data trends, a **parametric regression analysis** that estimates the form and magnitude of the impact of ICT on GHG emissions per output in each sector, and a **semi-parametric analysis** of the impact of ICT on industry efficiency through an input-output production framework.

Eight **case studies** on representative firms from European energy-intensive industries provide explicit examples of ICT use for GHG emissions reductions in industry that anchor the econometric results in the present business and market climate.

Finally, a pilot survey of the glass, cement and ceramic sector and a Delphi-style **survey of industry experts** track ICT adoption for sustainability purposes and report current industry opinion on the potential of ICT to counteract climate change.

Varying trends in GHG emissions and ICT capital, as well as structural differences among sectors, support a **sectoral approach** to analysis. We first focus our analytical methods on each sector independently, using these results to derive the most relevant cross-sector conclusions regarding the relationship between ICT and greenhouse gas emissions in European energy-intensive industries.

This report investigates the following areas:

1. **ICT impact on GHG emissions:** We test for a statistically-robust impact of ICT on GHG emissions and sustainable production, quantifying this impact at the sector level and analysing the implications for the future climate impact of each sector.
2. **ICT uses and development status:** We illuminate the specific means by which firms in energy-intensive industries utilise ICT to improve efficiency and sustainability, the progress made in ICT systems development, the potential for further innovation to improve the climate-change impact of ICT, and the interaction between current EU emissions policy and ICT development.
3. **ICT diffusion and adoption barriers:** We report the extent to which ICT that can reduce greenhouse gas emissions has been adopted in energy-intensive Industries for emissions-reductions purposes, the incentives and barriers to ICT adoption, and the particular influence of European emissions regulation on the decision to use ICT to counteract climate impact by these industries.

Econometric results

First and foremost, we find highly significant structural differences and structural change, both among and within sectors, which limits the scope of meaningful results from available data and impedes analysis of the paper sector alltogether. We also find significant differences in the relationship between ICT and GHG emissions among the sample European countries, even within a sector, which suggests that new Eastern European member states are employing ICT with less focus on sustainability. Nevertheless, the significant conclusions derived through econometric analysis confirm a limited but acute impact of ICT on the GHG emissions and sustainability of European energy-intensive industries.

Excluding the paper sector, we find that increased ICT share in total capital significantly **improves industry sustainability**, so that a change in production volumes does not require a corresponding increase in GHG emissions. We also find significant evidence of a **non-linear impact of ICT** across all sectors. In the metal and transport sector in particular, we find that increased ICT capital relative to gross output has improved the emissions per output of the industry at a diminishing rate.

Furthermore, we find that achieving reductions in GHG emissions using ICT is expensive relative to other abatement technologies. These results suggest that future investments in ICT must be carefully vetted for cost and an ability to reduce emissions in order to efficiently improve the climate impact of energy-intensive sectors in the long run.

Contextualising empirical results: case studies and opinion surveys

We conducted eight case studies about the use of ICT for production engineering, energy use optimisation, and emissions monitoring. The results confirm, by and large, the **important role for ICT** in increasing sector sustainability, particularly through the use of ICT-based production optimisation, energy management, and emissions management systems.

The industry and expert surveys conducted for this study further show a **recent increase in adoption** of these systems (and persistently weak market incentives for adoption of emissions-management systems, in particular). This provides an optimistic context for the econometric results.

While historical impact of ICT on industry emissions is distinct but limited, increased adoption and awareness sector-wide suggest that empirical evidence for the role of ICT in sector sustainability will improve in the future.

Policy recommendations

Above all else, we advise that the best way to reduce GHG emissions in energy-intensive industries is to allow the market to determine the most efficient technology – whether it is ICT-based or not – through a **sufficiently high price for carbon** (sufficiently low carbon caps) in the framework of the European Union Emissions Trading System (EU ETS).

However, our analysis also indicates need for indirect policy support to **foster the development and wider adoption of ICT** that supports energy management and emissions management systems. Documentation and publication of best practises, financing support for research and development, encouragement of cross-sector cooperation for ICT development and cultivation of a greater awareness of climate change concerns will all incentivise the needed development and adoption of these ICT-based systems.

Furthermore, we suggest a particular **attention to new Eastern European member states and the transport sector**, where emissions reductions are most needed but ICT has not yet been proven to be emissions-reducing.

Finally, we emphasise the need for **standardised emissions accounting and reporting systems** in order to increase the credibility and competitiveness of European energy-intensive firms and to facilitate further useful analysis that builds on this report's conclusions.

1 Introduction

1.1 About this report

Objectives, sources and deliverables

This study focuses on the role of information and communications technology (ICT) use for reducing greenhouse gas (GHG) emissions in energy-intensive industries. It provides empirical evidence on the role that ICT plays in sustainable production technologies that minimise GHG emissions. It also describes how companies in these sectors use ICT for reducing greenhouse gas emissions, and points at possible implications for policy. The analysis is based on economic literature and own empirical analysis. Results are further illustrated by company case studies as well as by the findings from two surveys: a telephone survey among decision-makers in European enterprises from the glass, ceramic and cement industry, which has been conducted in the frame of a separate study, and a telephone and online survey among corporate managers and industry experts from Europe's energy-intensive industries.

Combining descriptive and analytical approaches

The study approach is exploratory, descriptive and explanatory, applying a collection of investigative approaches: An **empirical econometric analysis** on the impact of ICT on greenhouse gas emissions and efficiency and will be combined with **qualitative** case studies and **quantitative** survey data. This threefold approach is meant to produce an in-depth understanding of current ICT use in European energy-intensive industries with regard to GHG emissions. The results from these different approaches are self-sustained pieces of research, and are intertwined and cross-referenced for better understanding.

Study structure

This final report contains six chapters. **Chapter 1** explains the background and context for this study, introducting the Sectoral e-Business Watch programme of the European Commission, a conceptual framework for the analysis of e-business, and the specific focus and investigative approach used in this study. It also provides general information on greenhouse gas emissions in European industry and the European Commission (EC)'s policy towards reducing greenhouse gas emissions.

Chapter 2 sets the stage for the proposed empirical analysis. We define and characterise the five industries that will be analysed, describe the available data and discuss observed patterns in relevant emissions and capital stock metrics. The chapter reviews relevant literature and discusses its influence on the choice of methodologies for the central empirical analysis. **Chapter 3** explains the two specific econometric methodologies employed, the results of the analysis for each of the five sectors, and a summary of key findings. **Chapter 4** presents eight case studies of specific firms from the analysed sectors. The results of two opinion surveys on the use of ICT for reducing GHG emissions are provided in **Chapter 5**. The first survey investigates the European glass, cement and ceramic sector in depth and the second is a Delphi-style survey of decision-makers and experts in the five analysed sectors. Finally, **Chapter 6** integrates findings from the econometric analysis, case studies, and surveys and presents policy recommendations.

1.2 About the Sectoral e-Business Watch

Mission and objectives

The "Sectoral e-Business Watch" (SeBW) studies the adoption and impact of ICT and electronic business practices in different sectors of the economy. It continues activities of the preceding "*e-Business W@tch*" which was launched by the European Commission, DG Enterprise and Industry, in late 2001, to support policy in the fields of ICT and e-business. The SeBW is based on a Framework Contract and Specific Contract between DG Enterprise and Industry and empirica GmbH.

Within the European Commission, DG Enterprise and Industry has the mission to help improve Europe's economic standing by ensuring that businesses are competitive and that they can compete openly and fairly. In ICT-related fields, DG Enterprise and Industry targets six policy fields: competitiveness of the ICT producing sector, ICT uptake in ICT using sectors, legal issues related to ICT uptake, ICT standardisation, e-skills and disruptive ICT.[1]

The services of the SeBW are expected to contribute to policies in these fields. The SeBW's mission can be broken down into the following main objectives:

- to assess the **impact of ICT** on enterprises, industries and the economy in general, including the impacts on productivity and growth, and the role of ICT for innovation and organisational changes;
- to highlight **barriers for ICT uptake**, i.e. issues that are hindering a faster and/or more effective use of ICT by enterprises in Europe;
- to identify and discuss **policy challenges** stemming from the observed developments, notably at the European level;
- to engage in **dialogue with stakeholders** from industry and policy institutions, providing a forum for debating relevant issues.

By delivering evidence on ICT uptake and impact, the SeBW also supports informed policy-making in domains beyond ICT including innovation, competition and industrial policy.

Policy context

The initial *e-Business W@tch* programme was rooted in the **eEurope Action Plans** of 2002 and 2005. The eEurope 2005 Action Plan had defined the goal "*to promote take-up of e-business with the aim of increasing the competitiveness of European enterprises and raising productivity and growth*".[2] The **i2010 policy**[3], a follow-up to eEurope launched in 2005, also stresses the critical role of ICT for productivity and innovation, stating that "*the adoption and skilful application of ICT is one of the largest contributors to productivity and growth throughout the economy, leading to business innovations in key sectors*" (p. 6). This policy rationale for the Sectoral e-Business Watch is still valid.

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1 See http://ec.europa.eu/enterprise/ict/index_en.htm#policy for more details.

2 "eEurope 2005: An information society for all". Communication from the Commission, COM(2002) 263 final, 28 May 2002, chapter 3.1.2.

3 "i2010 – A European Information Society for growth and employment." Communication from the Commission, COM(2005) 229 final.

Also in 2005, in consideration of globalisation and intense international competition, the European Commission launched a **new industrial policy**[4] to create better framework conditions for manufacturing industries in the coming years. Some of the policy strands described have direct links to ICT usage, recognising the importance of ICT for innovation, competitiveness and growth. In a **mid-term review** of the new industrial policy in 2007, the EC identified three particular challenges: intensified globalisation and technical change as well as climate change. In 2009, the EC will issue a Communication related to the role of high technology and industrial policy in the **economic crisis**.

The SeBW is one of several policy instruments used by DG Enterprise and Industry in this context. Other key instruments include the following:

- the e-Business Support Network (**eBSN**), a European network of e-business policy makers and business support organisations,
- the **eSkills Forum**, a task force established in 2003 to assess the demand and supply of ICT and e-business skills and to develop policy recommendations,
- activities in the areas of **ICT standardisation**, as part of the general standardisation activities of the Commission.[5]

In parallel to the work of the SeBW, the "**Sectoral Innovation Watch**" (see www.europe-innova.org) analyses sectoral innovation performance and challenges across the EU from an economic perspective.

Scope of the programme

Since 2001, the SeBW and its predecessor "e-Business W@tch" have published e-business studies on about **30 sectors** of the European economy, annual comprehensive synthesis reports about the state-of-play in e-business in the European Union, statistical pocketbooks and studies on specific cross-industry ICT issues. All publications can be downloaded from the programme's website at www.ebusiness-watch.org. In 2009, the main studies of the SeBW focus on the following five sectors and specific topics:

No.	Type of study and leader	Sector / topic
1	Sector study (NACE Rev.2 Division 35)	ICT and e-business impacts in the **energy supply** industry
2	Sector study (NACE Rev. 2 Division 23.1-6)	ICT and e-business impacts in the **glass, cement and ceramic** industry
3	Thematic study (cross-sector)	**ICT impacts on greenhouse gas emissions** in energy-intensive industries
4	Thematic study (cross-sector)	An economic assessment of **ICT-related industrial policy**
5	Thematic study (cross-sector)	**e-Skills** demand developments and challenges in manufacturing industries

ICT and e-business use in companies as well as related policy approaches have become increasingly sophisticated in recent years. For the SeBW this implies that there is also a

4 See European Commission (2005a).

5 Larger recent activities include a workshop on "IPR in ICT standardisation" in November 2008, and a conference on "European ICT standardisation policy at a crossroads" in February 2008. See http://ec.europa.eu/enterprise/ict/policy/standards/ict_index_en.htm for details.

need for **increasingly specific analyses**, conclusions and policy implications. The methodological framework of the SeBW builds upon the methodology established for the preceding "e-Business W@tch" programme, adapting the focus from monitoring "e-readiness" and "e-activity" to the evidence-based **analysis of "e-impact"**.

1.3 ICT and e-business: key terms and concepts

A definition of ICT

Information and communication technology (ICT) is an umbrella term that encompasses a wide array of hardware, software and services used for data processing (the information part of ICT) as well as telecommunications (the communication part). The European Information Technology Observatory (2009) structures the ICT market into three broad segments with an estimated total market value of about € 718 billion in 2009 (Table 1). Compared to 2008, the European ICT market has experienced a decrease of minus 2.2%. For 2010, EITO expects the ICT market to stabilise and to decrease by only 0.5% to 714 billion €.

Table 1: European ICT market (sales volume) in 2009

Market segment	Products / services included	EU market value estimates (2009)	Development to 2008
Information Technology (IT)	IT hardware, software, services	€ 299 billion	-2.6%
Telecommunications (TC)	TC end-user equipment, carrier services, network equipment	€ 361 billion	-0.7%
Consumer electronics	Examples: flat-screen TVs, digital cameras and navigation systems	€ 58.5	-8%
Total ICT market		*€ 718 billion*	*-2.2%*

Source: EITO 2009

ICT is a technology with special and far-reaching properties. As a so-called **general purpose technology** (GPT), it has three basic characteristics:[6] First, it is pervasive, i.e. it spreads to all sectors. Second, it improves over time and hence keeps lowering the costs for users. Third, it spawns innovation, i.e. it facilitates research, development and market introduction of new products, services or processes. One may argue that only electricity has been of similar importance as a GPT in modern economic development.

Companies in all sectors use ICT, but they do so in different ways. This calls for a **sectoral approach** in studies of ICT usage and impact. The following section introduces a framework for the discussion of ICT that has been applied in most studies of the Sectoral e-Business Watch.

A definition of e-business

In a maturing process in the past 15 years, electronic business has progressed from a specific to a broad topic. A central element is in any case the use of ICT to accomplish **business transactions**. This means exchanges of goods – or, in economic terms: property rights – between a company and its suppliers or customers.

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6 Cf. Bresnahan/Traijtenberg (1996) and Jovanovic/Rousseau (2005).

Electronic transactions, i.e. electronic procurement or sales, constitute **e-commerce**. The suppliers or customers can be other companies ("B2B" – business-to-business), consumers ("B2C" – business-to-consumers), or governments and their public administration ("B2G" – business-to-government).

The OECD Working Party on Indicators for the Information Society proposes a definition of **e-business** as "*automated business processes (both intra-and inter-firm) over computer mediated networks*" (OECD, 2004, p. 6). Using this definition, e-commerce is a key component of e-business but not the only one. This wider focus oriented on business processes has been widely recognised: e-business also covers the digitisation of **internal and external business processes** that are not necessarily transaction-focused. Internal business processes include for example functions such as research and development, finance, controlling, logistics and human resources management. An example of external cooperative or collaborative processes between companies is industrial engineers collaborating on a design in an online environment.

The importance of e-skills and company organisation

It is widely acknowledged that the optimisation of value systems with ICT requires employees endowed with particular skills. ICT skills or "e-skills" comprise ICT practitioner skills, ICT user skills and e-business management skills. Furthermore, there are indications that the successful use of ICT is not only a matter of implementing technology but also of adapting the companies' organisation to the specific needs of electronic value systems. Organisational changes may for example relate to a rearrangement of strategies, functions, and departments. Studies of the impact of ICT on firm-level productivity have shown that only if ICT capital is combined with complementary investment in working practices, human capital and firm restructuring it will have an impact on performance.[7] Since these complementary investments and organisational changes are highly firm-specific, returns to ICT capital vary strongly across companies.[8] Hence, e-skills and organisational issues play an important role in SeBW analyses.

Affected by the economic crisis after a phase of gaining momentum

While e-business had regained momentum as a topic for enterprise strategy in recent years, the situation and outlook of ICT investment has turned much less favourable with the economic crisis since mid-2008. In its Information Technology Outlook, the OECD states that in 2009 "*ICT growth is likely to be below zero for the OECD with considerable turbulence as the financial services sector restructures and the real economy experiences a deep economic downturn.*"[9]

However, the economic crisis does not affect all ICT in the same way. The OECD expects that "*IT services and software will generally grow, along with new Internet and communications-related products and infrastructure as they are an essential part of spending and partly recession-proof*".[10] The OECD also expects that growth of the ICT industry is unlikely to collapse as it did in 2001 when the bubble of the "new economy" burst.[11] Furthermore, the development of ICT capital differs by industry. Industries

7 See Bresnahan, Brynjolfsson and Hitt (2000).

8 See Pilat (2005).

9 OECD (2008), p. 15.

10 OECD (2008), p. 15.

11 OECD (2008), p. 23.

exposed to deep demand cuts such as automotive may have to reduce their ICT investment, while industries with rather stable demand such as energy supply may sustain their ICT investment. In any case, the evolutionary development of e-business has certainly not come to an end with the economic crisis. It is widely recognised that "e"-elements have become an essential component of modern business and the implications of trends such as "cloud computing" and "Web 2.0" are widely discussed.

Increasing competitive pressure on companies, many of which operate in a global economy, has been a strong driver for ICT adoption. Companies use e-business mainly for three purposes: to **reduce costs**, to **increase revenues** and to **improve customer service**. In essence, all e-business projects in companies explicitly or implicitly address one or several of these objectives. Recently, the use of ICT to **save energy** and **reduce greenhouse gas emissions** emerged as a specific issue of cost reduction, one with wide impacts for the economy and society as a whole.

While cutting costs continues to be a key motivation for e-business activity particularly in the economic crisis, anticipatory firms exploit the **innovation** potential of ICT for key business objectives. They have integrated ICT in their production processes, quality management, marketing, logistics and customer services. These functions are considered key to improve competitiveness of European economies. Competing in mature markets requires not only optimised cost as well as products or services of excellent quality but also the effective communication and cooperation with business partners. Companies that exploit the innovative potential of ICT even in times of economic crisis could leave the crisis stronger and more competitive.

1.4 Study focus and investigative approaches

Focus

The focus of the study is threefold. First, we evaluate how ICT has contributed to reducing greenhouse gas emissions in energy intensive industries. Second, we investigate how can ICT potentially contribute to this goal, and third, we provide policy recommenddations in order to further the realisation of discovered potential. The following topics and questions are treated in detail in this study:

- **ICT impact on emissions and sustainability**: To what extent does ICT enable firms in energy-intensive sectors to reduce the greenhouse gas emissions emitted by their industries? What direct and indirect effects may ICT have in this respect? How can the magnitude of this impact be quantified and how does it differ across sectors?
- **ICT uses and development status**: How important is ICT for reducing greenhouse gas emissions relative to other technologies? What specific ICT is currently available to reduce greenhouse gas emissions, and what other technologies are being developed for prospective future use? To what extent can the use of ICT help firms to mitigate possible consequences of the EU-emissions trading scheme (EU ETS)? To what extent does ICT help firms to better plan their response to emissions regulation?
- **ICT diffusion and adoption barriers:** How far has ICT that can reduce greenhouse gas emissions been diffused in the industries considered? What are the barriers to adopting them or to using them more effectively? Has emissions

regulation such as the EU ETS stimulated adoption of ICT in order to reduce greenhouse gas emissions?

- **Policy implications:** How can public policy best promote the effective use of ICT to reduce greenhouse gas emissions in energy-intensive industries? Are there any implications of ICT use for the EU ETS and its further development? Can policy contribute to developing relevant ICT?

Data collection and analysis

The study is based on a selected set of data sources and investigative approaches, including analysis of available statistics, primary data collection through surveys, case studies, and literature or desk research. Information was collected from the following sources:

Applied econometric analysis: Econometric methods were used to evaluate historical data for a statistically-significant impact of ICT capital growth on GHG emissions. The detailed structure of this economic analysis is presented in chapter 3.

Pilot survey: The glass, cement and ceramic sector is one of two sectors covered by the SeBW Survey 2009. The SeBW Survey is an additional source for analysing ICT impact on greenhouse gas emissions.

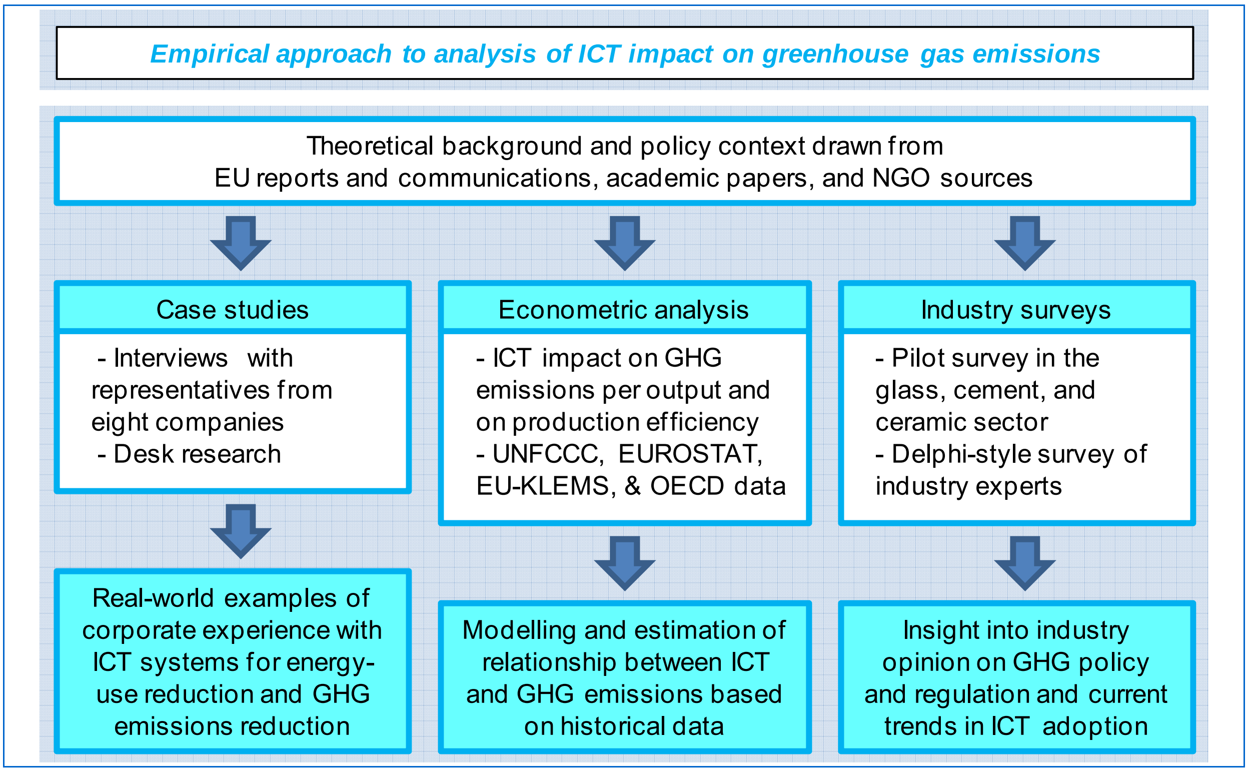
Delphi-style survey: An online and telephone-based Delphi style survey was conducted among selected industry experts, including company managers and experts from industry organisations. Two rounds of the survey were performed with the same experts. In the second round, participants were asked to evaluate their responses in light of survey results from the first round.

Case studies: Eight case studies describing the ICT and e-business strategy of companies from European energy-intensive industries were conducted. The companies were selected to match the focus of this study, seeking a balanced coverage of countries, business activities (sub-sectors) and company size-bands.

Interviews: Interviews were conducted with firm representatives as part of the case study work. In addition, further in-depth interviews with company representatives and industry experts, including the Advisory Board members, were conducted for this report.

NGO sources: Reports and position papers from the following sources are used:

- **www.smart2020.org**, which offers a comprehensive report on how ICT can help to reduce greenhouse gas emissions;
- **www.risoe.dk**, the national laboratory for sustainable energy at the Technical University of Denmark, offers reports on global, regional and national perspectives on current and future energy issues;
- **www.cdproject.net**, the carbon disclosure project, aims at collecting and distributing high quality information that motivates investors, corporations and governments to take action to prevent dangerous climate change.



Validation of results – the advisory board

The study was conducted in close consultation with an Advisory Board, consisting of the following experts (in alphabetical order by last name):

- Pietro Evangelista, National Research Council, Italy;
- Enrico Gibellieri, European Steel Technology Platform, Deputy Vice President;
- Willy Spreutels, Brussels;
- Graham Vickery, OECD;
- Martin Wörter, KOF Swiss Economic Institute, ETH Zürich.

Three meetings of the Advisory Board will be held, in addition to interim informal exchanges between the members and authors of this report with regard to specific sections of the study. The first meeting took place on May 12, 2008 in Berlin. At this meeting, the draft interim report was reviewed. At the second meeting the final results will be discussed. The third meeting is planned to take place in the context of the e-Business Conference 2009 to draw conclusions for future research.

1.5 Environmental and policy context

Greenhouse gas emissions in industry

Human activity – in particular the burning of fossil fuels – has thickened the blanket of greenhouse gases (GHGs) around the earth. The resulting increase in global temperatures is commonly referred to as *global warming*. In 1994, the international community started to consider options to reduce global warming and established the United Nations Framework Convention on Climate Change (UNFCCC). Industrial activities, which account for more than half of global GHG emissions, are a major focus of related measures.

Most importantly, 184 countries have committed themselves to the targets and mechanisms of the UNFCCC's Kyoto Protocol which foresees binding emission caps for almost all developed economies. However, despite such efforts, global GHG emissions are still expected to increase in upcoming years. For example, the SMART 2020 report by The Climate Group (Climate Group, 2008) predicts an increase of the amount of emissions per year to roughly twice the pre-industrial levels.

The main concerns preventing more ambitious and drastic steps to reduce GHG emissions caused by commercial activities are economic concerns, such as concerns about additional costs to energy-intensive industries. However, while reducing GHG emissions is costly, Stern (2007) argues that ignoring this increase is even more expensive, as the resulting climate change will damage future economic growth. According to the well-known Stern Review, a lack of reduction efforts will result in costs and risks that will be equivalent to 5% of global gross domestic product (GDP) each year. In contrast, the costs of taking actions to reduce GHG emissions and to avoid the worst impacts of climate change could be limited to 1% of global GDP each year.

The perceived potential of ICT for reducing GHG emissions

In general, there are high expectations for the impact that ICT can have on reducing GHG emission levels. For instance, the Smart2020 report states that "w*hile the* [ICT] *sector plans to significantly step up the energy efficiency of its products and services, ICT's largest influence will be by enabling energy efficiencies in other sectors, an opportunity that could deliver carbon savings five times larger than the total emissions from the entire ICT sector in 2020.*" Areas where ICT is expected to have the biggest impact are transportation, logistics, buildings, energy supply and grids, with up to 17% energy savings expected in buildings in the EU and a carbon emissions reduction of up to 27% expected to be achievable in transport logistics.

ICT is similarly lauded by the EC for its "economy-wide capacity for energy-saving" and for its "potential to effect rapid and propound change" (COM (2009) 111). The EC cites the Smart2020 report, as well as another study that predicts energy use reductions of 10% by consumers through the use of ICT, in support of its convictions.[12]

In particular, COM (2009) 111 identifies two roles for ICT in reducing GHG emissions through energy-efficiency:

- An **"enabling role":** ICT enables energy efficiency improvements by reducing the amount of energy required to deliver a given service.
- A **"quantifying role":** ICT provides the quantitative basis on which energy-efficient strategies can be devised, implemented, and evaluated.

In support of these two roles for ICT, the EC cites ICT's use in energy monitoring and management systems (which is especially important in energy-intensive industries); smart metering for consumers of energy; and new technologies in lighting, grid computing and virtualisation. In COM (2009) 111, the EC specifically observes the applicability of

[12] See European Commission (2008) Final Report on the Impacts of Information and Communication Technologies on Energy Efficiency or the ESMA (March 2008) Report on Methodology for Estimating Energy Savings.

ICT systems such as Intelligent Transport Systems in rationalising energy-use and reduction corresponding carbon emissions in transport activities.

The perceived potential for ICT to help reduce carbon emissions is high, but this potential is not always free to be realised. The EC identifies key barriers to the effectiveness of ICT use to combat climate change through energy-efficiency gains (COM (2009) 111), including:

- The lack of easily accessible means for consumers (individuals, businesses, and public administration) to compare potential energy-saving ICT innovations.
- The lack of a common set of commitments, targets, and methodology for measuring energy performance.

Furthermore, ICT is not without its own carbon impact. The use of ICT equipment in the delivery of services comprises approximately 1.75% of carbon emissions in Europe (COM (2009) 111). Nevertheless, the EC asserts that overall potential of ICT to improve energy efficiency is "**generally accepted**". This assertion is based on verbiage in previous communications, opinions delivered by the European Economic and Social Committee and the Committee of the Regions, and Resolutions adopted by the European Parliament (COM (2008) 241 and (2009) 111).

Climate change policy in the EU and the integration of ICT

Up until 2005, there was no binding restriction on GHG emissions of commercial activities in place in almost any EU member state. Notable exceptions are Sweden, Denmark and Finland, where carbon taxes were introduced in the early 1990s,[13] and the UK, where such a tax was introduced in 2001.

In 2005, the European Union introduced the EU Emissions Trading System (EU ETS), the first GHG emissions trading system in the world. It covers the nine most-polluting industrial sectors with currently more than 10,000 installations. Together, these sectors account for 40% of the EU's total GHG emissions (Wikipedia). Under the EU ETS, each country determines a binding cap for its national GHG emissions and allocates tradable emission allowances in the same amount to all affected installations. In this way, operators of installations can choose to either use the allowances to back up their own emissions or to sell the allowances on an EU-wide market and to reduce their own emissions by the same amount. In this way, the costs of reducing EU-wide GHG emissions are minimised at given national emission caps.

In the last few years, the EU has repeatedly confirmed its commitment to meeting energy savings and carbon emission reduction goals of 20% by 2020.[14] The EU holds energy efficiency as the core solution to climate change (COM (2006) 545 and COM (2008) 30).

Attention to ICT in policy has increased strongly in the last two years, with the EC's COM (2008) 30 and COM (2009) 111 displaying a clear conviction that ICT should be integral to climate change policies. In COM (2009) 111, the EC strongly supports policy focus on both the ICT sector and on "exploiting the enabling capacity of ICTs in all sectors" in order to integrate ICT into the struggle against climate change. The corresponding Recommendation to "pave the way for ICTs to contribute to energy efficiency gains and

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[13] Finland (1990), Sweden (1991) and Denmark (1992) were the first countries worldwide to tax carbon emissions.

[14] See EU Council Presidency Conclusions 7224/1/07 and 17271/08.

emissions reductions...in a measurable and verifiable way" is organised around new targets and collective agreement in the ICT sector, working partnerships between the ICT sector and other energy-using sectors for the development and delivery of energy and emissions assessment tools, and the assistance of Member States in enabling an EU-wide roll-out of energy-optimising ICT.

Of particular relevance to this study is the EC's specific policy attention to ICT-based energy use and carbon emissions reductions in transport activities. Various EC Action Plans support the deployment of Intelligent Transport Systems (COM (2007) 607), the launching of public-private partnerships for the development of ICT-based smart energy systems for transport (COM (2008) 886), and the provision of more complete and meaningful information on energy consumption and carbon emissions in freight transport by the end of 2012 (COM (2009) 111). The 7th Framework Programme for Research and Technological Development (FP7) also specifically supports R&D for energy-efficient ICT in transport (COM (2009) 111).

Another particularly relevant component of the EC's integration of ICT into climate change policy encourages behavioural changes. The EC calls for an overall "enduring shift in the behaviour of consumers, businesses, and communities" to reduce energy end-use as a compliment to savings achieved by ICT-enabled efficiencies (COM (2009) 111). This shift should be supported by Member States through "procurement to create demand...innovation programmes...and support [for] pilots and best practice" (COM, 2009). For its part, the EC is exploring setting up a web portal for sharing of best practices and data, providing a guide for regional and local authorities on the use of ICT for energy efficiency, and facilitating the ICT21EE initiative to support cities and municipalities in using ICT to reduce emissions by the end of 2010 (COM (2009) 111).

Finally, the latest EC policy regarding ICT use for energy-efficiency and carbon emission reductions highlights the importance or harmonised regulations and standards. In COM (2009) 111, for example, the EC implores Member States to agree on EU-wide minimum functional specifications for smart meters by the end of 2012. This last point signals a growing recognition of the necessity of EU-wide standards in order to enable operators, suppliers, and consumers to effectively use ICT for energy-management and achieve GHG emissions reductions.

Despite the EC's constant confirmations of ICT's ability to achieve energy savings and its increasing reliance on ICT as an integral component of climate change policy, empirical evidence that supports these convictions is relatively scare. The impact of ICT on energy efficiency is estimated to be highly positive by several studies and reports frequently cited by the EC, as mentioned previously. Strictly econometric analyses, in which the impact of ICT is analysed using historical data, find more modest evidence that ICT has so far enabled large energy savings (see section 3.4 for a more detailed assessment of this econometric literature). The conclusions of these analyses in general also suffer from significant data limitations and –in part– the lack of a well-defined theoretical background. Most importantly, to our knowledge, the direct impact of ICT on GHG emissions has not yet been comprehensively investigated.

All in all, there is a significant need for a comprehensive empirical assessment of the past and present contributions of ICT to reductions in GHG emissions. In the following chapter, we lay out the structure of the empirical analysis used in this study to quantify the role of ICT in reducing GHG emissions and in increasing the sustainability of energy-intensive industries.

2 Empirical background

The empirical background provided in this chapter provides essential context for understanding this report's econometric analysis, which forms the core of the research work presented in this Final Report. The chapter begins with an exact definition of the energy-intensive sectors analysed and a description of the data that will be used. We then provide a descriptive analysis of this data, which discusses the trends in ICT capital growth and greenhouse gas emissions in European countries and industries that drive the econometric results. The descriptive analysis is followed by a literature review, which summarises the current state of analysis on ICT and emissions in energy-intensive industries, setting the stage for chapter 3's explanation of the particular econometric methods employed.

2.1 Sectoral focus

Need for sector-level analysis

The impact of ICT on a specific firm is linked to several relevant factors, including the extent to which different ICT applications have spread across different industries. 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 firm may lead to positive externalities at the sectoral level. In the latter sense, ICT is a network technology (i.e. the more entities use ICT, the larger the accruing benefits tend to be). Clearly, a firm-level analysis would be appropriate to examine the impact of ICT on greenhouse gas (GHG) emissions. However, the required dataset is not available. Moreover, 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. For example, energy-intensive industries can be expected to enjoy larger benefits from adopting ICT to better manage energy use and GHG emissions than a non-energy intensive industry would. Consequently, sectoral characteristics influence not only the intensity of ICT use, but also the intensity of GHG emitted in production. Sector differences clearly call for a disaggregated sectoral level of analysis, as it is envisaged in the Sectoral e-Business Watch project.

Business activities covered

This cross-sector study of the impact of ICT use on greenhouse gas emissions will focus on the following five European energy-intensive industries:[15]

- Basic metal and fabricated metal (NACE Rev. 1.1, Divisions 27 and 28).
- Chemicals, rubber, plastics and coke (NACE Rev. 1.1, Divisions 23 to 25);
- Pulp, paper, printing and paper products (NACE Rev. 1.1, Divisions 21 and 22);
- Glass, cement and ceramic (NACE Rev. 1.1, Division 26);
- Transport and storage services (NACE Rev. 1.1, Divisions 60 to 63);

[15] The sectoral classification is based on NACE 1.1, which is also the basis for a main data source EU-KLEMS) for the empirical analysis (see section 2.2).

Most of these sectors have been almost free to emit GHG without specific regulations. In fact, emissions in these sectors have been mainly reduced in the light of increasing energy prices, since a major part of GHG emissions stems directly from fuel combustion. In addition, in Finland, Sweden, Denmark (all since the early 1990s) and in the UK (since 2001) there have been taxes imposed on GHG emissions. Since 2005, the GHG emissions of three of these industries (paper, basic metal, and glass-cement-ceramic) are subject to the EU ETS. For these industries, greenhouse gas emissions are costly and add to regular fuel and energy costs. In contrast, firms in the chemicals, rubber and plastic sector as well as transport firms face only the direct costs of energy consumption and have thus no incentive to reduce GHG emissions other than to save energy costs.

2.2 Data sources

This study utilizes a variety of data sources, as described below.

EU KLEMS is an extensive database provided by the Groning Growth Development Center (GGDC). The EU KLEMS research project provides a database of measures of economic growth, productivity, employment creation, capital formation and technological change at the industry level for all EU member states from 1970 onwards (EU KLEMS, 2008).

EUROSTAT is the statistical office of the European Communities and collects data from national statistical institutes and other competent bodies to harmonise them according to a single methodology. Information is available on regional and country level for the enlarged Union, the Candidate Countries and the EFTA countries (EUROSTAT, 2008).

The United Nations Framework Convention on Climate Change (**UNFCCC**) is an international environmental treaty produced at the United Nations Conference on Environment and Development (UNCED). The treaty was created with the aim of stabilising greenhouse gases that contribute to climate change. To supplement the treaty and further the work done by the convention, the UNFCCC secretariat compiles an international database of GHG emissions for participating countries and releases numerous publications on the topic of climate change (UNFCCC, 2008).

The **OECD** is an international organisation of 30 countries dedicated to the ideals of democracy and the market economy. A significant part of their focus is to provide a forum for policy comparisons as well as coordinating international and domestic policy. To supplement this goal and enable a meaningful comparison of different social and economic indicators, the OECD collects harmonised data from member countries in addition to select non-member countries on a variety of relevant topics (OECD, 2008).

Based on data from these sources, a **pooled data set** is constructed. Altogether, it includes all required information for all five sectors over a period from 1995 to 2005 for the following eleven EU member states: Czech Republic (CZ), Denmark (DK), Germany (DE), Italy (IT), Netherlands (NL), Austria (AT), Portugal (PT), Slovenia (SI), Finland (FI), Sweden (SE) and the United Kingdom (UK). These countries are highlighted in all subsequent tables on data availability.

GHG emissions data

Data on GHG emissions was taken from EUROSTAT and – where necessary – complemented by information provided by the UNFCCC. Altogether, data on GHG emission levels is available for the years 1990 to 2006 as shown in Table 2.

Methodologically, the GHG emissions data provided by EUROSTAT and the UNFCCC are compiled according to the standards as defined by the Intergovernmental Panel on Climate Change (IPCC 2006). This GHG inventory methodology accounts for the amount of GHG that is emitted to or removed from the atmosphere. It also provides information on the activities that cause emissions and removals. These activities are divided into the following main groups:

- Energy,
- Industrial processes and product use,
- Agriculture, forestry and other land use,
- Waste and
- Other.

All energy-intensive industries which are analysed in this study emit GHGs by combusting primary energy fuels (*Energy consumption*). In addition, some also release GHGs as by-product of specific industrial processes (*Industrial processes*). For example, in the chemical industry CO_2 is released in the production of ammonia, titanium dioxide or soda ash. The total amount of emissions in the five industries is calculated by adding both values. Table 1 shows the combination of IPCC categories that adds up to the total emissions of the analysed sectors.

For the glass, ceramic and cement industry, industrial processes are directly reported in the data while emissions from fuel combustion are included in an “other manufacturing” aggregate. Hence, the energy-based emissions that can be attributed to the glass, cement and ceramic industry were estimated based on the share of the industry’s energy inputs in that of “other manufacturing”.

Table 1: IPCC emission categories for the analysed sectors

	IPCC 2006	
	Energy consumption	**Industrial processes**
Pulp, paper, printing and paper products	**GHG ➚**	
Transport and storage services	**GHG ➚**	
Chemicals, rubber, plastics and coke	**GHG ➚**	**GHG ➚**
Basic metals and fabricated metal	**GHG ➚**	**GHG ➚**
Glass, cement, and ceramic	**GHG ➚**	**GHG ➚**

Source: DIW econ, 2009.

Table 2: Availability of data on greenhouse gas emissions from EUROSTAT and UNFCCC combined in analysed sectors

Country	All industries	Paper	Transport	Chemicals	Metal	Glass, ceramic, cement
EU 27	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	x
EU 25	x	x	x	X	x	x
EU 15	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	x
Euro Area	x	x	x	X	x	x
BE	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	1990-2005
CZ	1990-2006	2003-2006	1990-2006	1990-2006	1990-2006	1990-2005
DK	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	1990-2005
DE	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	1990-2005
EE	1990-2006	1990-2006	1990-2006	1990-2006	x	1990-2005
IE	1990-2006	1990-2006	1990-2006	1990-2006	1990-2002	1990-2005
EL	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	1990-2005
ES	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	1990-2005
FR	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	1990-2005
IT	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	1990-2005
CY	1990-2006	1990-2006	1990-2006	1990-2006	x	x
LV	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	1990-2005
LT	1990-2006	1990-2006	1990-2006	1990-2006	x	x
LU	1990-2006	x	1990-2006	x	1990-2006	1990-2005
HU	1990-2006	1990-2006	1990-2006	1990-2006	x	1990-2005
MT	1990-2006	x	1990-2006	x	x	x
NL	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	1990-2005
AT	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	1990-2005
PL	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	1990-2005
PT	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	1990-2005
SI	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	1990-2005
SK	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	1990-2005
FI	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	1990-2005
SE	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	1990-2005
UK	1990-2006	x	1990-2006	1990-2006	1990-2006	1990-2005
US	1990-2006	x	1990-2006	x	x	x
JP	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	1990-2005
KR	x	x	x	x	x	x
AU	1990-2006	1990-2006	1990-2006	1990-2006	1990-2006	1990-2005

Source: EUROSTAT, UNFCCC

Table 3: EU KLEMS data availability for the basic metal and fabricated metal sector[16]

Country	Gross output (GO)	Total hours worked (H_EMP)	Fixed ICT capital stock, real (K_ICT)	Fixed non-ICT capital stock, real (K_NICT)
EU 25	1995-2005	1995-2005	x	x
EU 15	1970-2005	1970-2005	x	x
Euro Area	1970-2005	1970-2005	x	x
BE	1970-2005	1970-2005	x	x
CZ	1995-2005	1995-2005	1995-2005	1995-2005
DK	1970-2005	1970-2005	1970-2005	1970-2005
DE	1970-2005	1970-2005	1991-2005	1991-2005
EE	1995-2005	1995-2005	x	x
IE	1970-2005	1970-2005	x	x
EL	1970-2005	1970-2005	x	x
ES	1970-2005	1970-2005	x	x
FR	1970-2005	1970-2005	x	x
IT	1970-2005	1970-2005	1970-2005	1970-2005
CY	1995-2005	1995-2005	x	x
LV	1995-2005	1995-2005	x	x
LT	1995-2005	1995-2005	x	x
LU	1970-2005	1970-2005	x	x
HU	1991-2005	1992-2005	x	x
MT	1995-2005	1994-2005	x	x
ML	1970-2005	1970-2005	1970-2005	1970-2005
AT	1970-2005	1970-2005	1976-2005	1976-2005
PL	1995-2005	1995-2005	x	x
PT	1970-2005	1970-2005	1995-2005	1995-2005
SI	1995-2005	1995-2005	1995-2005	1995-2005
SK	1995-2005	1995-2005	x	x
FI	1970-2005	1970-2005	1970-2005	1970-2005
SE	1970-2005	1970-2005	1993-2005	1993-2005
UK	1970-2005	1970-2005	1970-2005	1970-2005
US	1977-2005	1977-2005	1977-2005	1977-2005
JP	1973-2005	1970-2005	1973-2005	1973-2005
KR	1970-2005	1970-2005	1977-2005	1977-2005
AU	1970-2005	1970-2005	1970-2005	1970-2005

■ * NACE Rev. 1.1: 27 and 28

■ Source: EU KLEMS

[16] This table is only included for the basic metal and fabricated metal sector because the distribution of data available is the same for the other four sectors analysed in this study.

Input and output data

The EU KLEMS database uses a 63-industry breakdown based on the NACE classification Revision 1.1 for the major EU-25 member states as well as for the U.S., Japan and Australia (EU KLEMS, 2008). The data from EU KLEMS used in this study is comprised of gross output (GO), total hours worked (H_EMP) as well as ICT and non-ICT capital stock (K_ICT and K_NICT respectively)[17]. Depending on the sectoral level and the country concerned, the length of the available time series varies. Table 3 illustrates the data availability based on the EU KLEMS database for the five industries on which this study focuses. For the period from 1990 to 2005, the required data is fully available in nine countries (DK, DE, IT, NL, AT, PT, FI, SE, UK)[18]. For two more countries (CZ and SI), all required information is available for 1995 to 2005. Together, these eleven countries are highlighted in Table 3. EU KLEMS data is converted from current prices to 1995 prices using EU KLEMS quantity indices for the purpose of this report's econometric analysis.

Complementary information

Data on nominal energy prices (NRG_P) are taken from EUROSTAT and converted into real values based on the producer price index provided by OECD.

■

17 ICT capital is defined as software, hardware and communication devices.

18 For the United Kingdom and Czech Republic data is not sufficiently available in the paper sector. Therefore this sector analysis is conducted only with nine countries.

2.3 Descriptive analysis

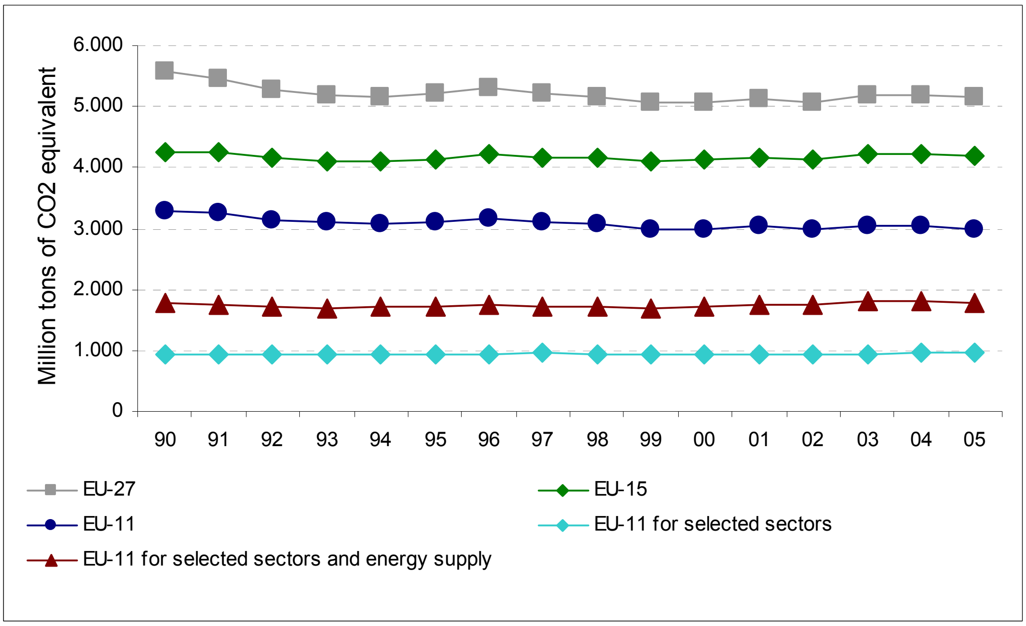
Greenhouse gas emissions

As one of the world's largest economies, the European Union is considered to be the third biggest GHG emitter in the world after the USA and China (Parker and Blodgett, 2008).[19] As depicted in Figure 1, a decrease in the emissions level of the EU-27 can be seen between 1990 and 2005. However, this decrease mainly reflects the economic slowdown in the Eastern European countries in the early 1990s. In the EU-15, which excludes these countries, emission levels remained constant during that period.

Due to a lack of congruence in the available data sources, six countries in the EU-15 could not be reliably analysed for this study. In addition to Luxembourg, Ireland and Belgium, three considerably large emitters in the EU-15 could not be included. These countries are France, Spain and Greece. As a substitute, two other countries not in the EU-15, but for which we had complete data, were added to the analysis – the Czech Republic and Slovenia. In total, the eleven countries[20] analysed in this study emit an amount of GHG equivalent to about 72% of total emissions of the EU-15 in 2005.

The five energy-intensive industries as defined in this study ("selected sectors" in Figure 1) account for almost 32% of total emissions in these eleven selected countries. The supply of electricity, gas and heat ("energy supply" in Figure 1) accounts for a similar share. The remaining third of the total emissions in these countries is caused by other energy activities (mainly oil refinery and the processing of coal), other manufacturing activities, agriculture and waste.

Figure 1: Greenhouse gas emission in Europe



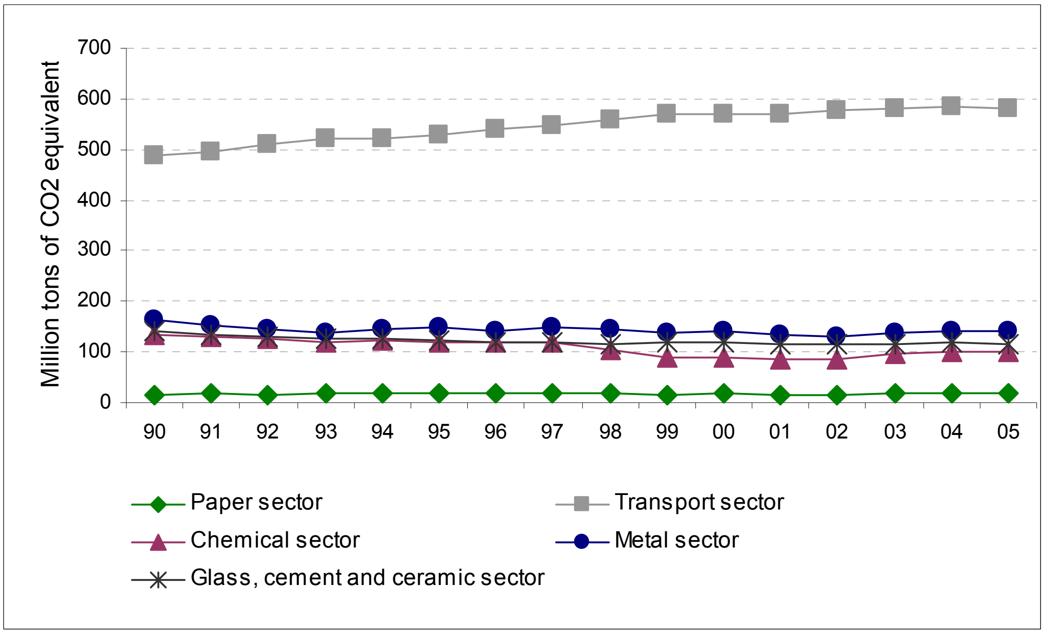
Source: EUROSTAT and DIW econ, 2009.

[19] The International Energy Agency reports emissions of more than 5,600 million tons of CO2 for the USA and China in 2006. The emissions level for the EU is shown in Figure 1.

[20] These countries are the Czech Republic, Denmark, Germany, Italy, the Netherlands, Austria, Portugal, Slovenia, Finland, Sweden and the United Kingdom.

According to Figure 1, total GHG emissions from energy-intensive industries increased by 6% from 1990 to 2005. However, this trend cannot be observed across all five individual sectors. Figure 2 shows the development of GHG emissions by sector over the same period, from 1990 to 2005. From 1990 to 2005 the total amount of emissions increased in the paper and transport industries by 13% and 24% respectively, but decreased in other sectors: the chemical industry by 25%, the metal industry by 14% and the GCC industry by 9%.

Figure 2: GHG emissions of energy intensive industries in the eleven analysed countries[21]



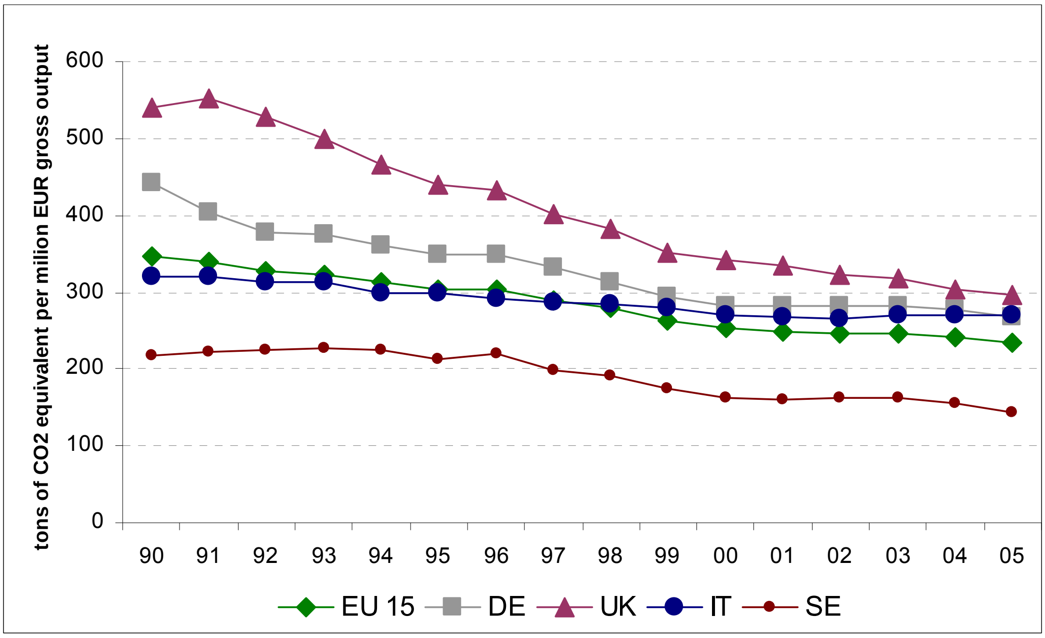
Source: EUROSTAT and DIW econ, 2009.

An increase or decrease in the amount of greenhouse gases emitted by a specific country or sector only gives a biased indication of how successful the efforts to reduce emissions have been. GHG emissions are affected by many factors, such as increases in output or changes in production processes. Indeed, a strong rise in production volumes could offset significant improvements of energy-saving technologies simply due to the emissions-increasing effect of growth.

To eliminate disproportionate effects of output growth on comparisons of emissions levels, we look at emission intensity rather than absolute emissions. Figure 3 shows the emission intensity for the national economies of selected EU member states and the aggregated EU-15, where emission intensity is defined as GHG emissions per unit of gross output. The figure shows a clear trend of decreasing emission intensities in each country, although there are significant differences across countries in the rate of decline. For example, the United Kingdom's emission intensity decreased by 45% between 1990 and 2005, while in Sweden and Italy the reduction was "only" 34% and 16% respectively. However, the latter two countries began with a lower absolute level of emission intensity and have always maintained lower emission intensities than the United Kingdom. Germany (DE) follows the trend of the UK, decreasing emission intensity from an originally higher level.

21 Note that the data on the paper industry does not include the United Kingdom as this data is not available.

Figure 3: Greenhouse gas emission intensity in total economy



Source: EUROSTAT and DIW econ, 2009.

Although the emission intensities have been falling at national levels, individual sectors again show different patterns. Figure 4 gives an overview of the development of emission intensities in the energy intensive sectors. The countries selected for the particular sectors are those with the highest level of GHG emissions in the European Union, as well as some benchmark countries with remarkably low levels of emissions intensity.

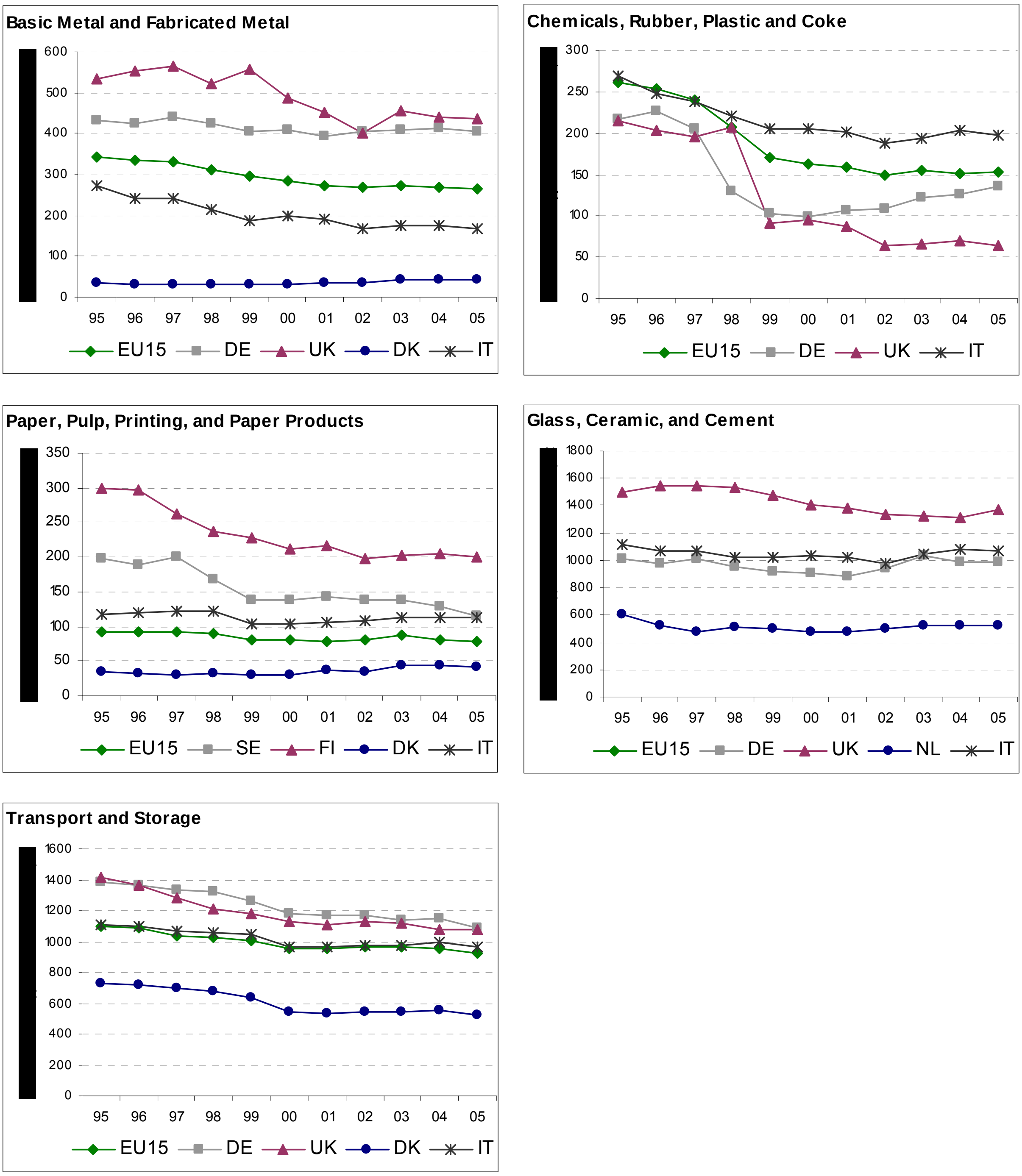
Denmark can be taken as a benchmark country. Denmark's paper industry has always produced on a low level of emission intensity. More importantly, between the years of 1995 and 2005, the Danish paper industry reduced this intensity by almost 20% to only 41 tons of emissions per million euros of paper output. In contrast, the Italian paper industry's emission intensity decreased by only 3% from 117 to 113 tons per million EUR of output. Another interesting pattern can be observed for the chemical industry in the United Kingdom. In 1995, the UK accounted for one of the highest emission intensities in the EU. However, by 2005, the UK had reduced this intensity by almost 70% to one of the lowest emission intensity levels among all European national chemical industries.

Substantial differences among countries can also be observed in the metal industry. For example, the emission intensity of the United Kingdom's metal industry has been reduced by 18% from 1995 to 2005 (from 534 to 436 tons of GHG per unit of output). In contrast, this intensity has remained relatively constant in Denmark, but Denmark's emission intensity in 2005 still amounts to only a quarter of the post-reduction intensity in the UK.

In the transport industry, the relationship between the United Kingdom and Denmark is similar. In 1990, the United Kingdom's transport industry produced one of the highest emission intensity levels in the sector, but it achieved a significant reduction of 40% by 2005. Nevertheless, intensities are still twice as high as in the Danish transportation sector. A similar development can also be found in the glass, ceramics and cement Industry. In 1995, the United Kingdom had the highest emission levels, but managed to reduce them by 9% by 2005. In the same period, countries such as Denmark experienced an increase of 17%. However, since Denmark was among the most efficient, these developments simply led to a convergence of emission intensities.

Altogether, the pattern of GHG emissions as shown in Figure 4 suggests that emission intensities have dropped significantly. However, this observation can – to some extent – simply reflect structural changes, in particular that energy-intensive sub-activities of a specific sector have been transferred to other countries.

Figure 4: Emission intensity as international comparison in the analysed sectors[22]



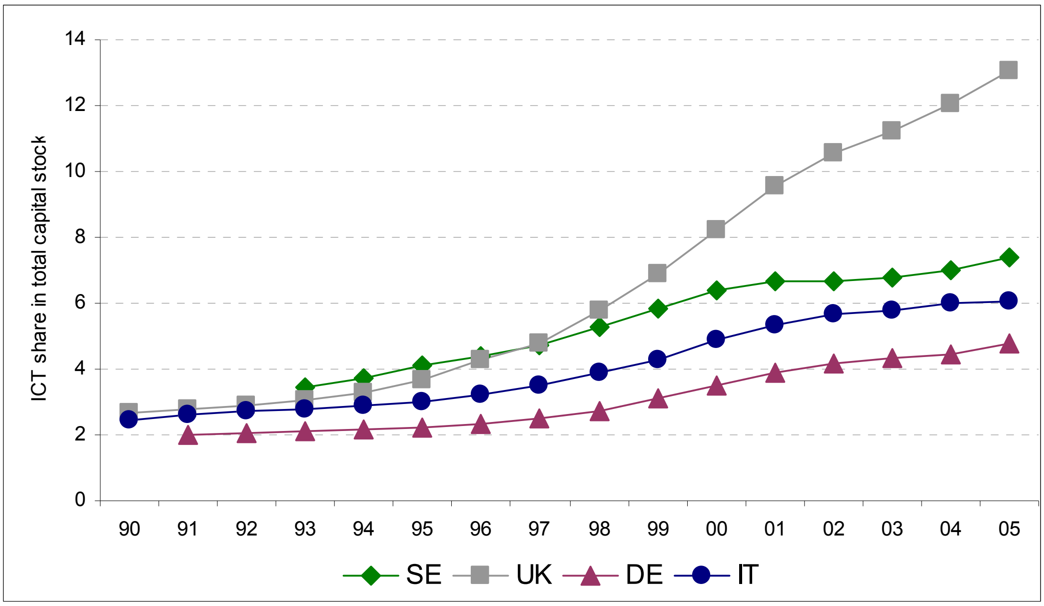
Source: EUROSTAT and DIW econ, 2009.

[22] These countries were selected as representative of the largest emissions in the sector. As noted in section 2.2, emission intensity data for the glass, ceramic, and cement sector was assembled by DIW econ from two data sources. Equivalent data is not available for the EU15 level, so EU15 is not included in the glass, ceramic and cement sector graph in Figure 4.

ICT capital stock

Besides GHG emissions, the second important data variable in this study is ICT capital stock in the selected sectors. At the aggregate level, EU KLEMS data shows that the share of ICT capital (defined as hardware, software and communication equipment) in total fixed capital stock tends to increase over time for all selected sectors (see Figure 5 for selected countries).

Figure 5: ICT capital stock as a share of total capital stock in all industries combined



Source: EU KLEMS and DIW econ, 2009.

This pattern is also reflected at the sector level, as Figure 6 demonstrates. In the paper industry, there was a modest increase in the share of ICT capital in most countries. This was most pronounced in Austria, where the share increased from 6% to 36%. These changes were not uniform, however, as displayed by Sweden, which remained relatively constant at 9%.

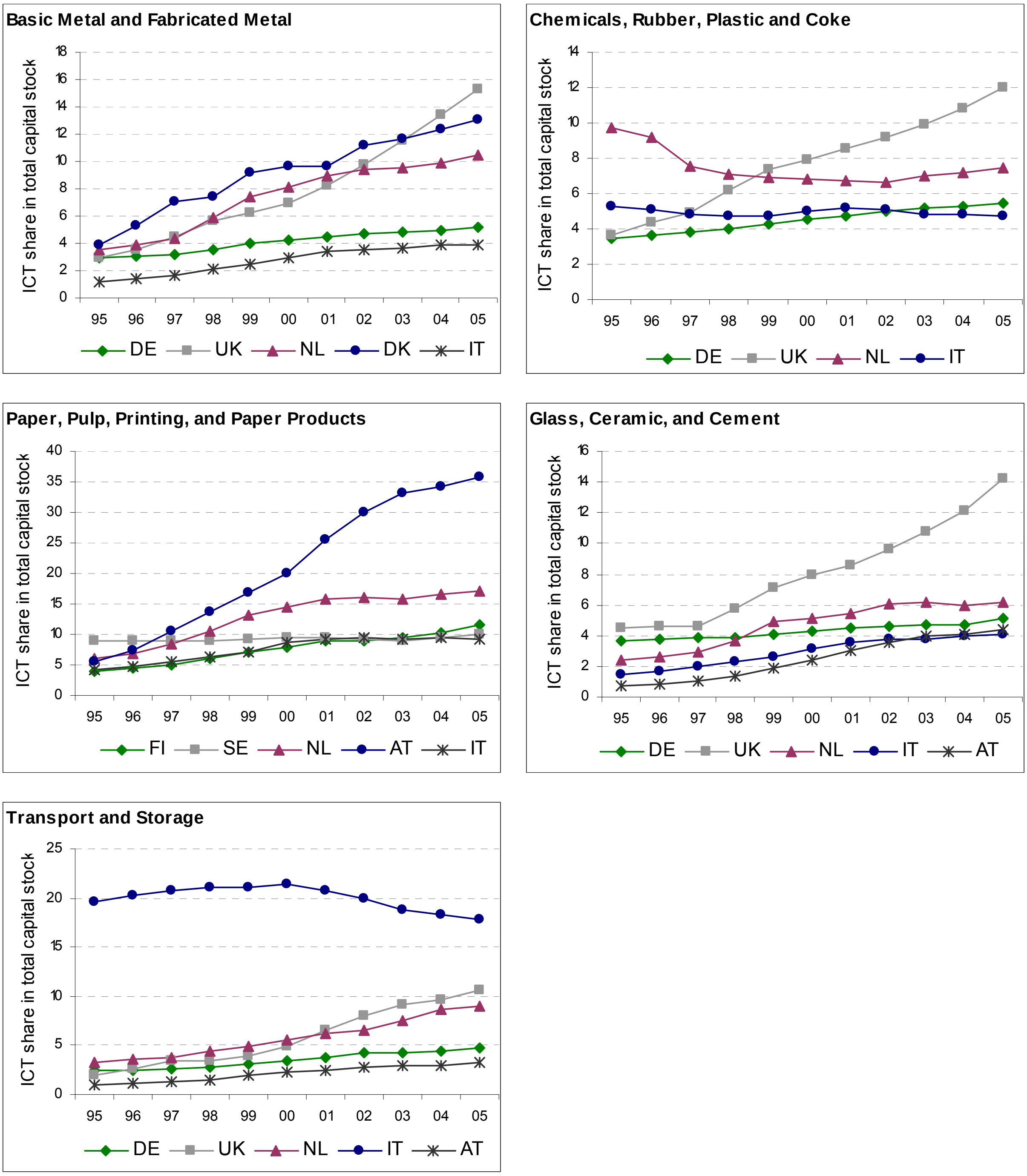
Similarly, in the metal industry, all countries displayed increases, but starting from a lower level than in the paper industry. On average, these increases were moderate, with the United Kingdom displaying the largest increase from 3% to 15%.

Likewise, the United Kingdom showed similar results in the chemical industry, where it posted an increase from 4% to 12%. Compared to the metal industry, the selected countries' increases were more modest. Most countries increased only a few percentage points, or flat lined during this time frame. In the case of the Italy and the chemical sector, the percentage of ICT capital stock hovered around 5%.

The transport industry displays a more marked difference among countries. While most countries had only 2-3% of ICT capital stock in 1995, Italy had already a much higher percentage, around 20%. However, Italy remained constant at around 20% and merely fluctuating up and then down. The other countries had varied increases; the UK increased from 2% to 11% while Germany increased only from 2% in 1995 to 5% in 2005.

A general increase was also found in the glass ceramic and cement industry. From 1995, most countries considered showed considerable increases, with the United Kingdom leading with a percentage of 4% in 1995 compared to 14% in 2005.

Figure 6: ICT capital stock as share of total capital stock in the analysed sectors

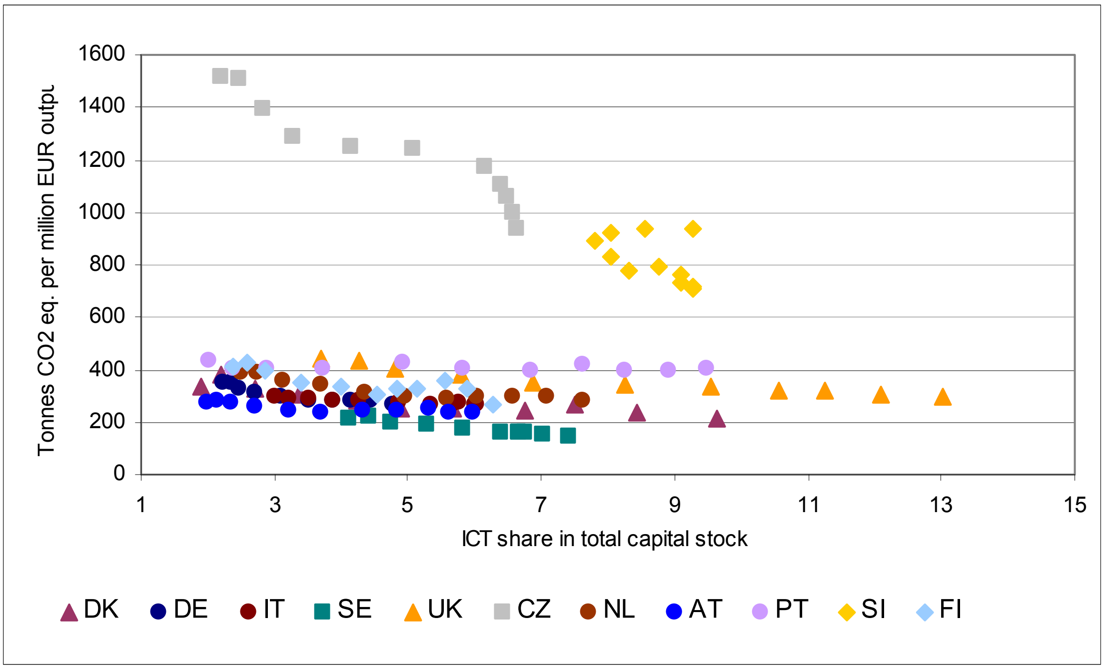


Source: EU KLEMS and DIW econ, 2009.

GHG emission intensity and ICT capital

The central concern of this report is whether a connection can be discovered between the observed reduction in GHG emission intensities and increase in ICT capital shares. As Figure 7 shows, there seems to be a remarkable relationship between these two variables in the total economies of the selected countries. The higher the share of ICT capital, the lower is the emissions intensity in these countries.

Figure 7: ICT share in total capital stock and emissions intensity in the total economy of the eleven selected countries



Source: EUROSTAT and DIW econ, 2009.

However, these observations provide only very first insights into a possible connection between the two variables, since most figures do not show all analysed countries and since changes in GHG emissions can also be caused by other factors. These factors include energy prices or specific policies to reduce GHG emissions, such as the carbon taxes in the Scandinavian countries or in the UK (see section 1.5).

Comparing the development of both variables for different sectors and countries, as displayed in Figure 4 and Figure 6, also reveals preliminary sector-level evidence of a connection between GHG emission intensity and ICT capital share in total capital stock. Emission intensities and ICT capital shares seem to be clearly connected in the **basic metal and fabricated metal** and **chemicals, rubber, plastic and coke** sectors, as well as in the **transport and storage** sector. While the **glass, cement and ceramic** industry of the UK shows clearly decreasing emission intensities with increasing ICT capital shares, there is no clear pattern for other countries. In the **paper, pulp, printing, and paper products** sector, Finland and Denmark show decreasing emission intensities and increasing ICT capital shares. However, average emission intensities across countries have remained rather flat, as the data for the EU-15 demonstrate. In Italy, emission intensities even increase. Overall, there does not seem to be a clear connection between the two variables in this sector.

2.4 Literature review

Several studies have identified solutions to the ecological and economic problem of increasing GHG emissions. Besides an intensive discussion on the usefulness of different policy interventions such as carbon taxes or tradable licenses, the use of new technologies in general – and of ICT in production processes in particular – has been recognised as a promising solution to reduce emission levels through technological progress. Morgenstern (2005) attests to the network characteristics of technology and provides an example of how technology lowers emissions by reducing the cost of more efficient coal plants. A prime example for the usefulness of ICT is the case of "Intelligent Transport Systems" (ITS), which integrate ICT into transport infrastructure to optimise transport routes and ease congestion, decreasing fuel consumption and GHG emissions (ERTICO ITS EUROPE, 2009).

Few surveys document the exact reduction of GHG emissions that can be attributed to ICT programmes, but the ones that do provide promising results. Walls and Nelson (2004) directly measure emissions reductions from a US e-commute program, finding the total emissions reductions to be modest but the potential for greater reductions to be large. Laitner (2000) makes a prediction of the impact of ICT rather than documenting true effects, estimating that IT will cut CO2 emissions 2-3% (cited in Takase and Murota 2004). The first major study to assess the future potential contribution of the ICT industry for creating a low-carbon economy on a global scale is the SMART 2020 report of The Climate Group (2008). It estimates that by 2020, the ICT sector will represent an estimated 2.8% of total global GHG emissions, but that ICT can reduce GHG emissions by 7.8 gigatonnes of CO2 equivalent or 15% of predicted total global GHG emissions. Hence, the emissions reduction potential of ICT is estimated to be about five times larger than ICT's own carbon footprint. According to The Climate Group, the biggest opportunities for ICT are in smart motor systems, logistics (which includes ITS), buildings, grids and dematerialisation (replacing physical objects and activities with electronic or 'virtual' alternatives).

While the potential of ICT for reducing GHG emissions is ubiquitously suggested, economic literature does not provide comparable empirical evidence on this connection. Nevertheless, literature on the connection between ICT and energy consumption or energy intensity (defined as the ratio of energy consumption to an output measure) offers important insights. Literature identifies two theories of how ICT influences the level of energy demand (Cho et al., 2007). On the one hand, increased diffusion of ICT leads to higher levels of electricity consumption (income effect). On the other hand, improved process optimisation to the use of ICT leads to higher energy efficiency ratios and thus lower consumption at given output levels (substitution effect). The net impact of ICT on energy consumption is ex ante theoretically ambiguous and merits empirical analysis.

At an economy-wide level, several studies provide indications for an impact of ICT on energy consumption levels. For example, Laitner (2000) finds that the energy intensity of the US economy has improved considerably during the 1990s, attributing this observation mainly to structural change encouraged by ICT. Similarly, Romm (2002) identifies an increasing decoupling of GDP and energy consumption growth in the US from 1992 till 2000. He attributes this to two main effects: first, structural changes away from heavy manufacturing towards service- and IT-oriented activities, and second, an overall trend of increasing energy efficiency that appears to be connected with use of the Internet.

Other studies address the impact of ICT on energy levels and intensity at a sector or industry level. The results are mixed depending on the sector and type of ICT implemented. Cho et al. (2007) find for South Korea that ICT investment leads to lower electrical intensity of production in the primary metal industry but leads to higher electrical intensity in the service sector and most other manufacturing sectors. Collard et al. (2005) find that electricity intensity in the French service sector increases with the use of computers and software and decreases with the diffusion of communication devices. Overall, however, Collard concludes that a given level of economic growth can be maintained at lower environmental costs by integrating more ICT. Following Collard et al. (2005), in a study for the European Commission Sectoral e-Business W@tch[23], Bernstein and Madlener (2008) find the net effect of diffusion of ICT capital to decrease electrical intensity of production in European energy-intensive industries. Insufficiencies in available data put a limit to the use of sophisticated estimation approaches, however, and the performed analysis does not capture the effects of "embedded" ICT (ICT present in production equipment that is not accounted for in ICT capital data). Finally, Takase and Murota (2004) address the impact of the IT "revolution" on energy use in Japan and the U.S., finding that greater IT capital stocks lower energy intensity of production by 2-4%. ICT is also estimated to have reduced CO2 emissions from energy use. However, the Takase and Murota (2004) assessment is derived from a policy simulation model and can thus not be taken as empirical evidence.

The studies mentioned above establish an indirect link between ICT and GHG emissions through changes in energy consumption. However, fuel combustion is only one channel through which GHG emissions are generated.[24] Emissions are also generated during production processes in specific industries such as the chemical, metal or glass industry. Emissions in general are produced by economic activity, and an entirely different body of literature in environmental economics treats this topic. While earlier works have mainly focussed on emissions of other pollutants such as sulphur dioxide or nitrogen oxids (NOx), recent contributions to this strand of literature increasingly focus on carbon emissions. This literature provides a highly relevant source for the present study since it offers a framework in which to execute an analysis of ICT effects on GHG emissions.

The most substantial and relevant empirical studies used as sources in this report come from this body of literature on economic activity and emissions. Typically, these studies assess the *environmental Kuznets curve* (EKC) hypothesis, which presumes that pollution levels initially increase with economic development – typically measured by income – and subsequently decreases after development and income have reached a certain threshold. Graphically, this leads to an inverted parabolic or U-shaped relationship between the two variables.[25] This relationship is postulated to derive from a variety of effects that occur as economic activity increases, as follows:[26]

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23 Available at http://www.ebusiness-watch.org/studies/special_topics/2007/ict_energy.htm

24 See section 2.2 for the structure of GHG emissions accounting.

25 Originally, the Kuznets curve describes the relationship between inequality and economic development of a country. It is based on the hypothesis that inequality initially increases with e.g. per-capita income but decreases after per-capita income has reached a certain threshold. The analogy to pollution has been established by Grossman and Krueger (1995) and Panayotou (1993).

26 See Aslanidis (2009) and Stern (2004).

- **Scale effect**: emissions increase with a larger scale of economic activity;
- **Output effect**: the emissions-producing entities switch the structure of output from basic manufacturing to more sophisticated value-added activities, reducing emissions per unit of output;
- **Input effect:** the emissions-producing entities switch the structure of inputs from more to less environmentally-damaging inputs (e.g. substituting natural gas for coal), reducing emissions per output (at a constant level of input per output);
- **Technology effect**: the emissions-producing entities reduce emissions per output due to innovations which increase energy efficiency or allow for changes in production processes.

According to the EKC hypothesis, the scale effect tends to prevail in the initial stages of economic development, while the other effects prevail in later stages. The inverted U-shape is produced as the output, input, and technology effects overwhelm the scale effect.

- Various studies assess the empirical relevance of the EKC hypothesis.[27] The hypothesis has also been expanded to analyse the relationship of other variables. For example, Judson et al. (1999) estimate an EKC curve between income and energy consumption for a variety of energy-intensive sectors. The authors find a U-shaped relationship in the industry and construction sectors for a large panel of data across countries and years.

- Despite the evidence for the relevance of the EKC hypothesis, both the theoretical foundations as well as technical details in the empirical investigations have been challenged. Most importantly, Arrow et al. (1995) observe that the EKC hypothesis postulates a unilateral causality from income on pollution which does not allow for feedback from environmental damage to economic development. In fact, this implies that environmental damage does not reduce economic activity sufficiently to stop the growth process and that any irreversibility is not severe enough to reduce the level of income in the future. Hence, the EKC hypothesis implicitly postulates that the economy is sustainable. Moreover, Arrow et al. argue that the EKC type relationship that several studies observe might be largely due to the relocation of emission-intensive industries from high- to low-income countries.

- Overall, the empirical literature on the EKC hypothesis has a significant impact on the methodological approach used in the present study. It offers insightful guidance on how the relationship between GHG emissions and economic variables such as capital stock can be empirically analysed for different sectors and countries. Furthermore, the discussion on technical issues in the estimation of panel data that accompanies the EKC literature is valuable for this study's econometric estimation process. However, taking into account the fundamental criticism on the EKC hypothesis made by Arrow et al., the econometric approach discussed in section 3.1.1 is flexibly specified in order to allow for different patterns between GHG emissions and capital.

In parallel to the literature on the EKC hypothesis, recent research in production theory offers further guidance for this study. This field of microeconomic studies focuses on the production processes that convert inputs into outputs. Specific points of interest in this theory are productivity and efficiency. Productivity measures the amount of inputs that a production activity converts into outputs. Efficiency is a measure that compares two

[27] See for example Stern (2004) and Aslanidis (2009) for reviews on this literature.

production activities. The activitiy (or entity) that produces the same outputs from less inputs (or, equivalently, more outputs from the same inputs) is generally more efficient.

The main interest of empirical efficiency and productivity analysis is to estimate the level of both indicators (Coelli, 2005). Comparing efficiency and productivity measures across different firms, sectors or countries allows us to identify efficient and inefficient entities and to identify those with highest productivity levels. Likewise, comapring both measures over time allows us to quantify the rate of technological change. In this study, we are concerned not just with conventional output, however, but also with greenhouse gas emissions produced during production. The inclusion of pollution as *undesirable output* in efficiency and productivity analysis is straightforward, as numerous contributions have demonstrated (Fähre et al., 1989). Recent analyses have even explicitly considered GHG emissions. For example, Zhou and Ang (2008) present a detailed method for decomposing changes in CO2 emissions in different industries into contributions from different factors including changes in energy intensity, GDP and technology. For the present study, these empirical advances in production theory serve as the source for the design of a second econometric analysis method (described in section 3.1.2), which we employ in parallel to the econometric analysis based on EKC literature. The use of two complementary econometric methods, based on the two most relevant strands of empirical literature on ICT and emissions, improves the robustness of the results presented in this study.

3 Econometric analysis

As a building block for the analysis in this chapter, chapter 2 illuminated trends in greenhouse gas emissions and ICT capital in five European energy-intensive industries. Now, econometric analysis takes centre stage in order to examine the relationship between ICT and carbon emissions.

The first section of this chapter describes the approach and methodology employed for this study's econometric analysis. Two methods (parametric and semi-parametric) are used, each with the ability to provide unique insights into the effect of ICT on the greenhouse gas emissions and efficiency levels in European energy-intensive industries. In the remainder of this chapter, these two methods are applied to each of the five energy-intensive industries treated in this study, in keeping with the sector-based approach described in section 2.1. The conclusions from each method are synthesised as key findings, which conclude each of the industry-specific analysis sections. These key findings are further integrated in a summary section at the end of this chapter.

3.1 Approach and methodology

As the review of relevant literature reveals, a comprehensive, well-defined modelling framework that is directly applicable to this study must be constructed from relevant bodies of literature from environmental economics. The challenge for this study is to design a methodological approach that is simple enough to utilize limited data and complex enough to address all the avenues through which ICT can affect GHG emissions. To integrate knowledge found in literature as described above, this study employs two different approaches:

- **Parametric regressions** based on EKC theory on the relationship between economic activity and pollution allow us to directly model and estimate the relationship between ICT capital and greenhouse gas emissions.
- **Semi-parametric analyses** based on recent research in production theory and allow us to discover and describe the relationship between ICT capital and the efficiency and sustainability of production while making fewer formal assumptions.

In this section, the basic principles and assumptions of both approaches are discussed, setting the stage for the discussion of empirical results in section 3.2.

As an essential precursor to the following methodology explanation, it is important to understand the limitations imposed by the available data . As mentioned in section 2.2, the production data from EU KLEMS is only available until the year 2005, meaning that the effect of changes in the ICT sphere or in GHG emissions regulation since 2005 will not be captured by the econometric analysis. In particular, the EU ETS implemented in 2005 is expected to have increased firms' incentives to develop and implement energy-management and emissions-monitoring systems. The more these systems are ICT-based, the greater the significance and/or magnitude of the effect of ICT on GHG emissions as measured by econometric methods. This report does not capture these post-2005 changes, suggesting that estimated effect of ICT in the parametric regressions and semi-parametric efficiency analysis is likely weaker or different than the true effect.

In addition to the limitations introduced by the length of our data set, the use of aggregated data can also bias the econometric results. First of all, production and emission data is available only at the industry or sector level, which obscures important differences among firms *within* a given industry. Most importantly, the true relationship between ICT and GHG emissions is difficult to identify at the sector level because it cannot be assumed to be the same for all firms within the sector. When firms' production processes and technologies are highly heterogenous within a sector, for example, the parametric analysis is less likely to find strong evidence in favour of one possible model of the relationship between ICT and GHG emissions. In the worst case scenario of sub-sectoral divergence over time, neither this report's parametric regressions or semi-parametric analysis can be meaningfully performed using aggregated sector data.

In parallel to the complications introduced by using data that is aggregated across producing entities (e.g. firms), the aggregated nature of our available ICT also introduces a bias in the results. Fixed ICT capital stock, our available indicator for the level and value of firm ICT deployment, is a highly aggregated variable that does not exactly reflect the total ICT that is relevant for emissions levels and production efficiency. On one hand, it may include ICT capital infrastructure that is not employed for the purpose of efficiency gains and GHG reductions. On the other hand, the variable does not include "embedded" ICT – the ICT systems used in other capital stock, such as automobiles, which may contribute to the potential of ICT to reduce GHG emissions. With such an aggregated ICT measure, we cannot exactly estimate the climate impact of investment in ICT capital for the express purpose of directly reducing GHG emissions. However, the fixed ICT capital stock metric is a useful proxy for the extent to which a given sector deploys ICT for efficiency gains and reductions in GHG emissions. In this sense, our econometric methods meaningfully evaluate the form and significance of ICT's effect on GHG emissions and efficiency.

In light of the potential problems introduced by aggregated data, quantification of the estimated effects of ICT should be done with great care. For example, this chapter quanitifies the "cost" in ICT capital necessary to achieve a 1 tonne reduction in GHG emissions. The implementation costs related to employing ICT capital for energy-management emissions reductions is not fully captured by the ICT capital stock metric, however, and taking them into account could change our evaluation of the "ICT costs" associated with emissions reductions. In order to avoid the misinterpretation of these values, we caution that the "ICT capital cost of GHG emissions reductions" should be used as a reference point for comparison among sectors, rather than as an exact value on which to make policy or business decisions.

3.1.1 Parametric analysis

The objective of the parametric regressions is to test for and estimate the direct effects of ICT capital on GHG emissions while controlling for the effects of a variety of other variables that may influence the relationship. In particular, this approach separates the effects of non-ICT capital stock, energy price changes, time trends, and structural differences across countries from the true impact of ICT capital.

After explaining the design of the basic regression models, this section clarifies the logic behind the design of the variables included in each model and reviews the data utilised in the estimation of each regression model. We finish with an explanation of the process by which the most appropriate model for the relationship between ICT and GHG emissions is selected for each sector.

Design of regression models

As discussed in section 2.4, the explicit link between ICT capital and GHG emissions in energy-intensive industries has not been comprehensively studied in economic literature. Because a well-defined model is not available, our analysis starts by constructing an original parametric model through an iterative bottom-up approach. Previous econometric studies in the field of emissions, especially from the area of environmental economics that investigates the so-called EKC relationship between economic activity and emissions, provide theoretical grounding and support. We design three basic regression models – a linear, log-linear, and non-linear model – as explained below.

In parametric regressions GHG emissions are commonly treated as *inputs* within a production framework, alongside the other common production inputs of capital and labor.[28] Typically, using parametric regression techniques within a production framework requires one to decide on a functional form for the underlying process that generates emissions ex ante, and then produce an estimable form.[29] However, when it is not known how GHG emissions are produced, or if emission levels are compared over a number of sectors that use different technologies, the design of a general emission production function can be imprecise and/or lose theoretical grounding. In order to allow for different functional and technical relationships between ICT and emissions to be tested, this paper implements three basic models.

The first model implemented is the **linear model.** Stern (2002) provides the theoretical basis for this model through his econometric decomposition of national sulphur emissions into national output mix, input mix, and productivity.[30] In Stern's study, inputs are modelled to have a linear impact on emissions within the framework of the larger decomposition model. Following Stern, our linear model is comprised of a linear relationship between ICT capital as independent and GHG emissions as dependent variable. This model allows the impact of ICT on emissions to be tested at constant rates of change.

Stern (2002) made his choice of linear functional form based only on the inclusion of energy inputs as explanatory inputs, which have different and distinct properties from ICT inputs in relation to emissions. Indeed, ICT is a form of capital, and capital inputs are often modelled in a Cobb-Douglas production function. In fact, Stern's overall economic

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28 For example, Fisher (2004) treats the problem of a competitive firm facing an emissions price and receiving a permit allocation according to its output. The analysis models a firm that maximizes profit with respect to emissions intensity. This model treats emissions as an influence on cost, including emission abatement cost as a specific part of the profit function. These sort of models are meant for evaluating policy regarding emission-regulation frameworks and are thus not appropriate for this study.

29 This estimable form is usually based on the first order conditions as derived from an underlying maximisation problem.

30 Stern (2002)'s discussion of his choice of functional form is illuminating. He argues that the emission production function must be homogenous of degree zero in the outputs, choosing a traditional Cobb-Douglas function with decreasing returns to scale. The relation of input mix to emissions, in contrast, must be homogeneous of degree one. ((A function f of n variables is homogeneous of degree k if $f(t^*x_1,..., t^*x_n)= t^*kf(x_1,...,x_n)$ for all $(x_1,...,x_n)$ and all $t> 0$. For example, the typical production function $f(x_1,x_2)= Ax_1^a x_2^b$ is homogenous of degree one, as is a simple linear function. In contrast, the function $f(x_1, x_2)= x_1+ x_2$ is homogenous of degree zero.)) However, Stern notes that the traditional constant returns-to-scale Cobb-Douglas function imposes the restriction that as a single input increases, while other inputs are held constant, emissions increase at a decreasing rate. Stern argues that this relation is unlikely for energy inputs, and chooses to model inputs to emissions using a linear function.

decomposition of emissions into output and inputs is based upon the assumption that emissions are generated from a typical Cobb-Douglas production function. Thus within the framework of the linear model, this study also considers the ICT as an "input" to emissions through a Cobb-Douglas production function. All variables in the linear model are transformed with natural logs in order to produce a Cobb-Douglas function in estimable form, which is referred to as the **log-linear model** in the rest of this paper. The interpretation of the effect attached to ICT is slightly different in this case: as ICT capital changes by one percent, GHG emissions change at a constant percentage level.

Finally, a third model is introduced, in which the assumption of a simple linear relationship between GHG emissions and ICT capital is relaxed. This **non-linear model** resembles the linear term for of the ICT capital variable but also includes a squared term for the independent variable. In fact, this specification is motivated by the literature on the environmental Kuznets curve (EKC) as reviewed in section 2.4. Judson et al. (1999) use a similar specification and find an inverted U-shaped relationship (corresponding to the EKC hypothesis) for income and energy consumption for a variety of energy-intensive sectors over a number of countries and years. Since the use of ICT is expected to affect energy consumption, and emissions are expected to move closely with energy consumption, the inclusion of the stock of ICT capital as an independent variable and emissions as dependent variable in an EKC-type analysis appears to be a logical choice:

Initially, ICT is introduced in firms as part of the growth process; ICT is contributing to firm expansion and thus greater emissions through the "scale effect". This ICT could be heavy in computers and software, which have been shown to increase emissions (in contrast to communications devices, a type of ICT capital that has been shown to reduce emissions)[31] in which case emissions would increase with ICT. Once this basic ICT capital is in place, marginal ICT could go to optimise production processes, increasing energy efficiency and reducing emission intensity through the technology effect.[32] The input and output effects are also possible, if ICT capital enables the use of cleaner inputs or the production of more ICT-based output. For instance, publication companies classified in the paper sector could shift toward online instead of print media, utilising ICT to produce output that is service-based and cleaner than newspaper printing.

Variable design

With three basic model forms in mind – the linear model, the log-linear, and the non-linear model – the variables included in the models are selected and designed. The variables are the same in the three basic models. The best way to design the GHG emissions variable so the regression results are useful for firms and policy makers is to use a measure of **emission intensity**, defined as million tonnes CO2 equivalent emissions per gross output in million Euro.[33] Policy makers and firms are not only concerned with reducing emissions, but rather reducing emissions without a debilitating cost to output. The object of practical concern is GHG emission *intensity*, not emission levels, and so the dependent variable in this study's parametric regression should also be emission intensity. Modelling emission intensity as the dependent variable is also convenient for

31 See Collard et al. (2005) and Bernstein and Madlener (2008).

32 Literature on the impact of ICT on production has found ICT to improve productivity. See Zwick (2002) or Bresnahan, Brynjolfsson and Hitt (2000), for example.

33 Fisher (2004) provides an analysis of when to use absolute emissions and when to use an emission intensity measure to model emissions in a given analysis. As Fisher points out, the choice depends on where policymakers' concerns lie.

making comparisons across countries (as observed in section 2.3), creating a "level playing field" by scaling absolute emissions by gross output. Furthermore, the use of an intensity measure is strongly supported in the literature on both the effect of ICT on energy use and on emission decomposition and EKC analysis.[34]

ICT capital is also modelled as an intensity measure in this study's parametric regressions. ICT capital stock is scaled by gross output in million Euros, consistent with econometric literature and with the scaling of GHG emissions by gross output as emission intensity.[35] The design of the ICT variable as ICT capital intensity allows for a simple estimation procedures to be used and for the addition of non-ICT capital intensity as its own variable.[36] With further consideration of econometric literature, ICT capital is modelled in this study as an aggregated stock of computers, software, and communications devices,[37] and only contemporaneous effects on emissions are included in the model.[38]

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34 In literature on the ICT impact on energy, see Cho et al. (2007), Collard et al. (2005), Bernstein and Madlener (2008), and Ang and Zhang (2000). Freeman et al. (1997) further specify that a value measure of gross output is better than a volume-based measure when more aggregated data are used (cited in Cho et al., 2007). Stern (2002) and EKC analyses use an intensity measure as well, but the measure is emissions per capita.

35 In literature on ICT's effect on energy intensity, ICT capital is overwhelmingly measured as a stock, as opposed to an investment flow, which has been normalised by either total capital stock (capital share) or by an output measure (capital intensity). See Laitner (2000), Romm (2002), Collard et al. (2005), Cho et al. (2007), and Bernstein and Madlener (2008). A capital stock measure also makes sense in the context of emissions: emission intensity is explained by the entire ICT capital stock in relation to gross output, not just by the change in ICT capital intensity (a.k.a. annual ICT investment per gross output).

36 The most widely-used alternative to ICT capital intensity is ICT capital share, defined as ICT capital per total capital. When the ICT capital share measure is utilised in the econometric literature on ICT and energy use, it is as a result of the derivation of an estimable function from an assumed production function (Collard et al., 2005; Bernstein and Madlener, 2008). When a logistic diffusion model is used to model the relationship between ICT and energy efficiency, a non-scaled stock measure is used (Cho et al. 2007). In literature on emissions production and the EKC, Stern (2002) includes energy capital as an explantory variable and seemingly arbitrarily divides by total capital. Thus the construction of an ICT variable is a function of the goal of the regression and the properties of the underlying theoretical model. In this study, the use of a capital share measure would bound the explanatory capital variables by (0, 1), unnecessarily complicated the regression estimation, with no additional benefit to the interpretation of the results. ICT capital intensity is preferred as a measure of ICT.

37 A further issue that arises in the modelling of ICT is whether to specify the difference between computers/software and communication devices. Collard et al. (2005) and Bernstein and Madlener (2008) show that dis-aggregation is significant, as these devices have opposite effects on energy output and efficiency. However, the ICT effect on emissions is not wholly equivalent to the effect on energy, and so this dis-aggregation of ICT capital will not necessarily be significant in this study. The modelling of computers and communication technology together could be important in order to capture the effects of ICT through new emissions-abatement systems, for example. This study models ICT capital in an aggregated variable in order to capture interaction effects that would not be correctly captured by disaggregated measures.

38 The use of ICT as a concurrent or lagged variable in similar related literature varies considerably, allowing room for judgment. ICT is modelled consistently as a lagged variable in the literature on ICT's effect on productivity (Zwick, 2002), but in the context of modelling ICT's effect on energy intensity, Cho et al. (2007) finds that the number of lags that produce the best models varies according to the industry examined. Furthermore, Bresnahan, Brynjolfsson and Hitt (2000) argue that the short term (contemporary period) effects of ICT represent the direct effects of ICT investment on productivity, while the longer-term productivity returns are a result of ICT combined with organisational change. In order to isolate the direct effects of ICT investment on emission intensity from subsequent productivity interactions, this study finds it most methodologically conservative and theoretically appropriate to model only contemporary period effects.

With the dependent variable and key explanatory variable modelled, particular additional explanatory variables are added to the models in order to isolate the effect of ICT capital intensity on emission intensity. The first is naturally **non-ICT capital**, which controls for the effect of non-ICT capital on emissions and allows a more useful interpretation of the ICT variable: the effect of a change in ICT on emission intensity *at given levels of non-ICT capital*. Non-ICT capital is modelled as capital intensity as well, also scaled by gross output in million Euros.

The second additional variable introduced is **energy price**. The assumption that energy use determines a large part of emissions would suggest that energy prices also explain variations in emission intensity.[39] In order to control for this effect, energy prices are included in the regression. In the particular time period addressed by the present study, controlling for energy price changes is all the more relevant as the European energy market underwent significant changes. In the late 1990s, real energy prices were consistently decreasing as a result of market liberalisation. In the years after 2000, energy prices began to rise as a result of increased global growth and demand for raw materials. These changes could have affected sector energy use, and thus emissions, and so are important to control for.

All three models also include a **time** variable as a matter of course, which controls for exogenous effects of changes in technique and productivity in a given sector on emission intensity. This time effect is assumed to be the same across countries within a given sector. As a final element, controls for **country-specific structural effects** are added to the model during estimation.[40] In this study, the concept of structural effects refers to the static environment in which a given sector operates – environmental regulation, investment policy, geography and natural resources – that influences the base level of emission intensity in the sector. Together, ICT capital, non-ICT capital, and energy prices are assumed to generally determine energy use in production and thus model the largest sources of emissions in the analysed industries, while time and structural effects control for other non-static and static influences on the level of emission intensity in each sector.[41] These reduced-form models are relatively simple, interpretable, and sufficiently isolate the effect of ICT capital on emission intensity.

This approach is in line with Bernstein and Madlener (2008), who study the impact of ICT on electricity intensity of production. Bernstein and Madlener (2008) work off a similar data set of mainly older member states of the EU (exception of Slovenia) and choose to perform sector-specific regressions with European countries as the cross-sectional element, making the assumption of constant elasticities across countries in order to controlling for fixed effects. The regression choices and assumptions made by Bernstein

39 A collection of studies on have found energy prices to be significant on energy use and energy efficiency, notably Skiadas et al. (1998) and Cho et al. (2007). Energy prices have also been included in EKC regressions by Unruh and Moomaw (1996).

40 See Appendix I for a detailed discussion of the modelling of time and structural effects in the context of panel regressions such as this study.

41 While omitting other sources of emissions in the production process, such as labour, may be of a concern, this study finds that the implementation of a reduced-form or partial regressions is not treated in the literature as grounds for dismissal of the estimation results. Indeed, even Stern (2002), who complains about the lack of comprehensiveness of EKC estimations, only includes energy inputs as explanatory inputs in his econometric decomposition of national sulphur emissions. Collard et al. (2005) and Bernstein and Madlener (2008) both include a production-size proxy in their regression of the effect of ICT capital on electrical intensity of production, which non-ICT capital can be assumed to control for.

and Madlener (2008) and echoed in this study are restrictive, but do not prevent the estimation of an appropriate model and the discovery of informative and significant results.

Based on the limitations encountered during the execution of this study's parametric regression analysis, we encourage the collection of more data. Complete data from a wider span of countries over time will allow for these assumptions to be relaxed in further estimations. In addition, further analyses could perform separate regressions by countries, instead of by sectors, in order to illuminate the difference in the impact of ICT on GHG emissions for countries with lower income or in transitional stages of development.

Model selection process

Due to the varying growth trends in ICT capital intensity (and non-ICT capital intensity) and GHG emission intensity across sectors, as observed in section 2.3, one cannot reasonably expect to find a single model of the impact of ICT capital intensity on emission intensity that is appropriate for all of the five analysed industries. Rather, the selection of the most statistically significant and theoretically appropriate sectoral model is made through an iterative process that can produce different outcomes for each sector.

In order to find the appropriate model for each sector, the linear, log-linear, and non-linear models are estimated. In the estimation of all three equations in each of the five sectors, two specific estimators are used that imply different assumptions about the character of the country-specific effects (as described above) included in the model.[42] This process is performed for each sector separately. The statistically appropriate model is then identified through a series of statistical tests[43] performed during the estimation process, as detailed below.

Check for whole model validity:

- The first step in evaluating the estimated models is to determine their overall significance. Any model that is not significant will not be considered an appropriate model.
- If there is more than one significant model, the choice is based on the R squared, i.e. the proportion of variability in the dependent variable that can be explained by a particular model

The choice between the linear and non-linear model:

- The non-linear model represents a more complex version of the linear model, with a quadratic effect of ICT included. Since this study is primarily concerned with modelling the effect of ICT capital intensity on GHG emission intensity, the decision to move from a simple model to one with quadratic elements is made primarily on the significance of the quadratic element. When the quadratic effect is significant, assuming the whole model is significant, the non-linear model is preferred over the linear model.

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42 A total of nine estimations are made, as explained in Appendix I.

43 The method and statistical tests are described in detail Appendix I.

The choice of how to treat country effects:

- When considering the use of country effects, as described in the previous section on model design, two estimation options are possible: so-called fixed effects or so-called random effects. Statistical tests determine if each of these effects is significant.[44]
- When both of the above tests for the fixed effects and random effects estimator determine that the model as a whole *and* the specific effects are significant, a choice must be made between the two estimators. The so-called *Hausman test* is used to make this decision.

General goodness-of-fit measures:

- As a final tool for comparing models, goodness-of-fit measures can be used. A typical goodness-of-fit measure is R squared, which identifies the proportion of variability in the dependent variable that can be explained by a particular model. A higher R squared would imply that the particular model explains more of the variation in the dependent variable. When moving from a simple model to one with quadratic elements, while maintaining the same set of explanatory variables, the change in R squared can be observed as an indicator of the overall explanatory value of the model.[45] However, R squared is used in this analysis merely as an indicative statistic rather than as a decisive one.

While the statistical tests are a necessary component of choosing a valid model, any statistically-proven model must be consistent with theory and logic. As a final check, the selected model must be able to be explained by the context of the sector's particular structure, industrial processes, and ICT use. The results of the statistical validation process and a discussion of the implications for the sectors are displayed in section 3.2.

3.1.2 Semi-parametric analysis

The parametric approach detailed in the previous section provides a necessary base and useful complement for the semi-parametric regressions described in this section. The fully-parametric approach models the direct relationship between ICT capital and GHG emission. In contrast, the semi-parametric approach employs a production-theory take on GHG emissions to construct a measure of sustainable efficiency and test for the significance and direction of the impact of ICT capital share on a country's sustainable efficiency within each sector. In this way, the results of this analysis add depth and specificity to the conclusions derived from the parametric analysis.

Estimating efficiency scores

Essentially, **production theory** studies the relationship between a set of inputs which is used to produce a set of outputs. The relationship between inputs and outputs is determined by production technologies as described by production functions in economic

[44] Under Fixed Effects, the explanatory variables are correlated with structural effects, under Random Effects they are not.

[45] When we compare competing models, e.g. when one of the models is not strictly nested within the other, comparing R squared of the models is not likely to yield conclusive results and lacks a statistical rationale (Baum 2006, p.100). This is the case if the log-linear and non-linear model R squared measures were to be compared, for example.

theory. A major point of interest of production theory is the *efficiency* of the production process. The most efficient firm is the one that either:

- uses a fixed amount of inputs to produce the largest amount of outputs (**output oriented**); or that
- uses the lowest amount of inputs to produce a fixed amount of outputs (**input oriented**).

Empirically, measuring and comparing the *absolute* efficiency of production across different *Decision Making Units* (DMUs) such as companies, business units, sectors and countries requires objective knowledge of the potential of state-of-the-art technologies. This, however, is typically not observable. A pragmatic solution is to focus on relative *technical efficiency*, which is determined by those DMUs that produce the largest amount or value of output by using the same input and are thus relatively efficient. Together, these DMUs form the *efficiency frontier* which approximates the state-of-the-art technology. The technical efficiency of all other DMUs can be measured relative to this efficiency frontier. In this way, an *efficiency score* can be specified for each DMU and, for example, be expressed in percentage points equalling 100% for fully efficient DMUs and lower values for all remaining ones.

A non-parametric estimation approach

Applied production economics offers several approaches to empirically measure relative efficiency of different DMUs (see Coelli et al. (2003) for an intensive discussion). The relationship between inputs and outputs can be derived directly from an a priori specified production technology[46] or be measured by means of non-parametric estimation technologies such as the **Data Envelopment Analysis** (DEA).[47] While the first group of approaches has strong theoretical foundations and is best suitable to deal with stochastic effects in the data, they require sufficient up-front knowledge on available technologies as well as on specific data such as prices of factor inputs. In contrast, the main advantages of the DEA are that it requires:

- no or little preference, price or a priori information;
- no or little technological information; and
- only weak a priori assumptions on production technology.

Obviously, these advantages make DEA especially suitable for use in the present study.

Considering GHG emissions in efficiency analysis

In general, emissions are by nature the result of production processes and thus, an output. In contrast to other physical outputs, this specific type of output is usually considered to be *undesirable*. The inclusion of undesirable outputs such as pollution or emission levels into DEA analysis has been discussed by several economists (e.g. Fähre et al., 1989). As they argue, the role of undesirable outputs can be assed by comparing the following two efficiency measures:

46 The most frequently used models of this type are Corrected Ordinary Least Square (COLS) or Stochastic Frontier Analysis (SFA).

47 In an advanced version, the DEA can also be extended by stochastic components.

- **Conventional technical efficiency** estimates the performance of a DMU based only on inputs (e.g. labour and capital) and desirable outputs (e.g. gross output).
- **Sustainable technical efficiency** estimates the performance of a DMU based on inputs, desirable outputs as well as on undesirable outputs (e.g. GHG emissions).

Under the *conventional* efficiency measure and using the *output oriented* definition of technical efficiency, countries that produce the highest level of output by using a given combination of inputs are considered to be fully efficient. In contrast, the *sustainable* measure also considers the amount of undesirable outputs. In comparison to desirable output, undesirable outputs are minimised rather than maximised[48]. Thus, a country which produces less desirable output could still be considered efficient, as long as it compensates this by lower levels of undesirable outputs per unit of desirable outputs (e.g. GHG emissions per gross output).[49]

Undesirable outputs such as GHG emissions can also be incorporated into the analysis as an additional input since they are often costly for companies. For example, environmental regulations can impose emission taxes or physical emissions need to be backed by tradable permits as it is e.g. practised under the EU ETS. In this case, companies can simply view emissions as an additional input factor which must be minimised at given output levels. Obviously, the efficiency analysis as described in this section can readily consider GHG emissions as an additional input factor. In this case, the estimation is based on the *input oriented* definition of technical efficiency and conventional and sustainable efficiency differ in that the former considers only conventional input factors whereas the latter also includes emissions. In practice, the choice of the relevant specification depends on the specific conditions in a given sector and can even differ from country to country, in particular prior to the introduction of the EU-wide emissions trading scheme in 2005. While the input- and output oriented approach do not lead to fundamentally different assessments, the respective results can still differ. To account for this, the analysis as described in this section has been conducted based on both, *input* and *output oriented* technical efficiency.

Independently of this specific definition, sustainable efficiency is constructed so as to allow a DMU to improve its conventional efficiency score by compensating inefficiencies in the production of desirable outputs with relative low levels of undesirable outputs.This implies that sustainable efficiency scores can not be worse than their corresponding conventional efficiency score. In fact, including an additional input or an additional output can only result in improvements or no change of technical efficiency scores. Figure 8 illustrates this for the case of an output oriented efficiency analysis.

Picture a) depicts the simplified case where three DMUs use a single input to produce a desirable output. The vertical vector is defined as volume of output per input. Obviously, DMU "*A*" operates with the highest conventional efficiency as it produces the highest amount of output per input. DMUs "B" and "C" are not efficient because they produce lower output volumes from the same input. Their respective scores in (relative)

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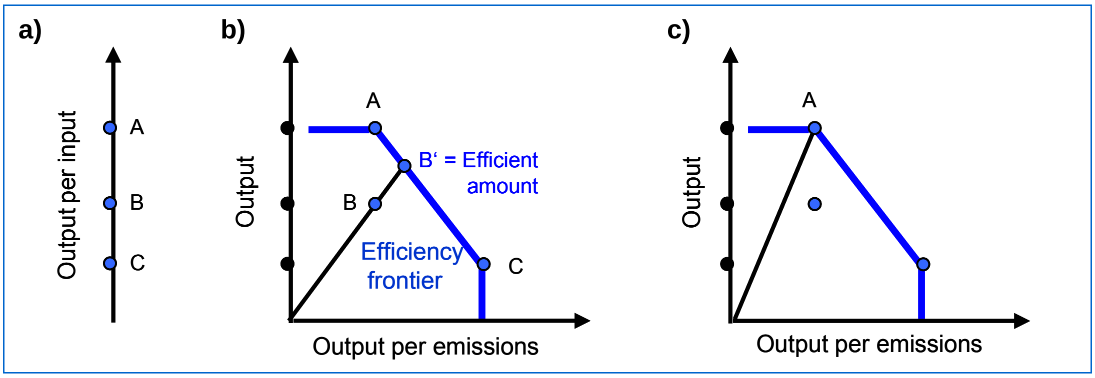
48 Technically, we consider this by maximising the ratio of output per emissions, i.e. the value of physical output which is produced per ton of CO2 emissions.

49 The specific underlying technology will be estimated by the DEA based on the actual data. A generally important assumption is the extent to which the undesired output is freely disposable by the DMU. If e.g. emissions are limited due to specific regulatory measures, the free disposability assumption does not hold (see Fähre et al. (1989) for technical implications). For the present case, GHG emissions are considered to be freely disposable since no binding regulations are in place in any of the eleven countries.

conventional efficiency are defined as the ratio of actual output over the efficient output as determined by DMU "A".[50]

This assessment is extended in the next pictures by considering emission levels as undesirable output. In picture b), the vertical axis still depicts the level of output per input, while the horizontal axis measures the ratio of output over emissions (which is the inverse of the emissions intensity discussed in section 2.2). Hence, the three DMUs are now assessed in a two-dimensional space. *"A"* remains fully efficient as it still produces the highest amount of output per input. However, DMU "*C*" produces the most output per emission and can therefore compensate for relative inefficiencies in conventional production. Together, both DMUs determine the frontier of sustainable efficiency (blue line). This frontier is defined such that production of all non-efficient DMUs is located in the area between the horizontal and vertical axes and the efficiency frontier.[51] For example, production of DMU *"B"* is not efficient under either type of efficiency. In fact, the comparison with the other DMUs demonstrates that "B" could increase its output at constant levels of inputs up to the frontier, as indicated by "B' "(see picture b). Hence, it sustainable efficiency score is calculated as the ratio of actual production volume over the efficient amount.

Figure 8: Relationship between conventional and sustainable efficiency



Source: DIW econ, 2009.

In picture c), the relationship between conventional efficiency and sustainable efficiency is demonstrated. The line between the origin and point "A" is characterised by constant levels of emissions, given by the slope of the line.[52] Hence, the line represents all possible efficient and inefficient production possibilities that generate the same level of emissions than DMU "A" does. Any production possibility located to the left of this line generates higher emission levels. Hence, the corresponding conventional efficiency score can not be improved by considering emissions. On the other hand, DMUs located to the right of the line produce at lower levels of emission so that their sustainable efficiency score is higher than the conventional one.

Specification of DEA models

As described in section 2.2, the available database comprises information on inputs, outputs and GHG emissions of five sectors in eleven countries from 1995 to 2005. It is

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50 Hence, efficiency scores are defined over a range of 0% to 100% and can be understood as the share of actual production in the efficient production volume.

51 The DEA estimates this frontier as piecewise linear hull which includes all efficient DMUs as illustrated in Figure 8.

52 The slope equals the ratio of output over output per emissions and thus, emissions.

hence appropriate to take – for each sector and in each year – the eleven countries as separate DMUs and estimate the efficiency of each such DMU (country) by using DEA. This will yield eleven efficiency estimates for each sector and year, for example $e_{TR,1998,CZ}$, $e_{TR,1998,DK}$, $e_{TR,1998,DE}$, as estimated technical efficiency of the transport sector in the Czech Republic, Denmark and Germany in the year 1998.

For each sector, the DEA includes two different inputs plus a desirable and an undesirable output. These variables are defined as follows:

- The first input is *Labour*, defined as number of hours worked by persons engaged in the respective sector.
- The second input is *Capital*, defined as total fixed capital stock including ICT and non-ICT capital.
- The desirable output is *Gross output*, reported in millions of Euros.
- The undesirable output is greenhouse gas (GHG) emissions in million tonnes of CO2 equivalent as in section 2.2.

Given the intention to analyse the impact of ICT capital on technical efficiency, it appears desirable to divide capital into ICT and non-ICT capital. However, allowing for a third input factor reduces the variance of efficiency scores in this analysis since the different DMUs can be differentiated by their use of an additional input factor. Because the data set includes only eleven DMUs per year, a reduction in variance should be avoided when possible. For this reason, the analysis proceeds in two steps:

- First, technical efficiency frontiers are estimated using (non-parametric) DEA and based on aggregate capital.
- Second, the relationship between ICT capital and efficiency scores is analysed by estimating parametric regressions as described below.[53]

Generally, technical efficiency scores can be estimated by assuming that the underlying technology exhibits either constant or variable (increasing or decreasing) returns to scale. Under constant returns, all DMUs are compared to the same benchmark, independently of their respective size of production. In contrast, under variable returns only DMUs of a similar size can be compared with one another. In this study, each year allows for comparison of only 11 countries of rather heterogeneous size. Hence, to allow for a reasonable comparison between all countries the analysis is assumes constant returns to scale.

Since the efficiency scores are defined as relative measure between DMUs (countries) in a given year, they are fully comparable across countries within a year. However, the frontier formed by the most efficient DMUs is likely to change over time due to structural change, technological progress etc. Given that the benchmark for comparison changes over time, efficiency scores for the same DMUs cannot be compared over time. Nevertheless, the overall shift of the frontier – that is, the change in total factor productivity – can be measured by using an index to compare inputs and outputs over different periods (see Coelli et al. 2005).

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[53] Because of the combination of non-parametric DEA and parametric regressions, the overall approach is labelled as semi-parametric.

The relationship between efficiency and ICT capital

Once conventional and sustainable efficiency scores have been estimated, the impact of ICT capital on both efficiency measures is analysed in a subsequent step. Therefore, a parametric regression model is estimated to assess the impact of the share of ICT in total capital stock as independent variable on (conventional and sustainable) efficiency scores as dependent variables. As for the parametric analysis described in section 3.1.1, model is estimated separately for each sector based on panel data for 11 countries over the period from from 1995 to 2005. In this way, the analysis reveals for each sector whether the share of ICT capital has a significant impact on one or even on both efficiency scores as well as the direction of this impact. By comparing the impact of ICT capital on sustainable efficiency with that on the conventional efficiency scores the particular impact on GHG emissions can be identified.

In practice, the following two issues need to be considered when estimating the regression models:

First, the observed efficiency scores are defined as relative measure over a range between zero and 100%, where the later indicates full relative efficiency. However, absolute efficiency levels might also be higher than this threshold but are unobservable. In this case, a simple Ordinary Least Squares (OLS) regression cannot consistently estimate the impact of independent variables on the latent, unobservable variable. A way to consider this is estimating a so-called *Tobit model*. While using this model does not greatly complicate the analysis, the estimated coefficients cannot be simply compared to those obtained from OLS regression. Instead, the impact of a change in the independent variable has on the dependent one (marginal effect) can only be assessed at a specific level of the independent variable. In section 3.2 below, all marginal effects are calculated at the mean of the independent variable (ICT capital share).

Second, efficiency scores are defined to be fully comparable over different DMUs (countries) in a given year, but not over time. Hence, the panel regression must be structured so as to estimate the impact of the independent variable (ICT capital share) on the dependent one (efficiency scores) across countries within the same year while assuming that efficiency scores for different years are structurally different.[54]

3.2 Results for individual sectors

The semi-parametric and parametric analyses, explained in the previous two sections of this chapter, were individually conducted for each of five European energy-intensive industries on data from eleven sample European countries. These industries were pre-defined as appropriate aggregations of various subsectors, as listed in section 2.1 of this report. The spectrum of countries was determined by data availability, as clarified in section 2.2. As expected, the results for each defined sector vary considerably, reflecting different industry structures and different available technologies.

The following discussion treats the results from each sector separately, allowing for the necessary in-depth discussion of each industry's unique characteristics and the implications for the relationship between ICT and greenhouse gas emissions. The

[54] Technically, the regression is estimated as a Tobit model with random effects.

discussion of results for each industry contains four major parts: a discussion of data trends, a summary of the parametric results, a summary of the semi-parametric results, and a concluding analysis with key findings.

First, we summarize the evolution of energy expenditures, emissions, capital, and output in the sector over the sample time period, from 1995 to 2005. Knowledge of such changes is necessary for understanding the production of emissions in the sector, the use of ICT capital, and the relationship between the two. With this context in mind, we examine the results of the two analyses. We start with the parametric analysis, which goes straight to the heart of the matter, testing for a direct impact of ICT capital intensity on emissions per output. When a significant impact of ICT is discovered, we analyse these results in-depth and provide additional calculations that help one quantify and concretize the estimated impact. When no significant impact of ICT is discovered, we offer explanations and suggestions to allow for more meaningful analysis in the future. From the parametric analysis results, we move to a discussion of the semi-parametric results. This analysis searches for an impact of ICT on the sustainability and efficiency of the sector, without assuming a specific relationship between ICT and emissions. We also treat ICT differently, looking at its share in total capital rather than in gross output, which enriches the analytical findings. Finally, each sector's discussion finishes with a summary of key findings. We integrate the lessons from the parametric and semi-parametric analyses to provide a multifaceted image of the relationship between ICT and climate impact in each sector.

After each of the five industries has been discussed separately, this chapter provides a comprehensive summary of the econometric analyses. This summary, which follows in section 3.3, illuminates the most important conclusions and relevant interpretations of the econometric analysis results.

3.2.1 Basic metal and fabricated metal sector

The **basic metal and fabricated metal** sector (hereafter refered to as the metal sector) produces primarily iron and steel but also aluminium and other non-ferrous metals. The industry is a large consumer of energy and producer of greenhouse gas emissions in absolute terms. However, changes in measures of energy use, emissions, and capital stock (Table 5) are suggestive of structural changes in the sector that are generating momentum for substantial improvement in the efficiency and sustainability of the sector.

The competitiveness of the European basic metal industry is closely linked to energy policy and pricing, so energy use and energy prices are likely to play a strong role in the emission output of the metal sector. For the aggregate sector in the eleven sample countries expenditures for intermediate energy inputs (in constant 1995 prices) have fallen by 6% between 1995 and 2005, the strongest decrease of the five sectors in this study.

Despite falling absolute energy inputs, the industry is a major producer of greenhouse gas emissions worldwide, especially at the start of the production chain. According to the International Iron and Steel Institute, the iron and steel industry accounts for 3 to 4% of world-wide man-made greenhouse gas emissions. With regard to the eleven countries examined in this study, emissions from the metal industry similarly comprise (on average) 4.6% of the total country emissions each year from 1995 to 2005. When compared to the emissions shares of the other four sectors in this study, this share is second only to transport, although the shares of the chemicals, rubber, plastic and coke sector and the glass, cement, and ceramic sector are not much lower. Relative to peers, the metal industry has made only weak progress in reducing absolute emissions levels. The reduction in total greenhouse gas emissions of the industry in the eleven countries in this study ranks fourth out of five industries. Absolute greenhouse gas emissions, measured in million tonnes of CO2 equivalent, were reduced by 4.7% from 1995 to 2005.

Table 4: Overview of structural changes in the basic metal and fabricated metal sector in the eleven sample countries

	1995	2005	Change
Gross output (million Euros, 1995 prices)	345,284	400,416	16%
Energy expenditure (mil. Euros, 1995 prices)	7,420	6,958	-6%
GHG emissions			
- Aggregate (mil. tons CO2 equivalent)	147	140	-4.6%
- Share in total economy emissions in the eleven countries	4.7%	4.7%	
- Per gross output (tons CO2 equivalent per mil. Euro, 1995 prices)	426	350	-18%
Real fixed capital stock			
- ICT capital stock (mil. Euro, 1995 prices)	4,742	14,687	210%
- ICT capital intensity, defined as ICT capital stock per gross output (%)	1.4%	3.7%	167%
- Non- ICT capital (mil. Euro, 1995 prices)	188,364	216,956	15%

Source: EU KLEMS, EUROSTAT, DIW econ, 2009.

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A comparison of emission intensity across sectors tells a different story. The industry is making strong progress in reducing emission intensity, in keeping with its aforementioned progress in reducing energy inputs. The sector reduced its aggregate emission intensity by 18% from 1995 to 2005, which was second only to the reduction achieved by the chemicals, rubber, plastic and coke sector during the same period. Of the five European energy-intensive industries in this study, the metal industry ranked third in average emission intensity in 2005 at 383 million tonnes CO2 equivalent per Euro in 1995 prices.

Changes in output and capital composition can help explain some of this notable reduction in emission intensity. First of all, output for the sector grew at a relatively normal 16% (in comparison to the sectors analysed) during the same period in which expenditures for energy inputs were reduced by 6%. Of the remaining four industries, only one (pulp and paper) has also managed to reduce its total energy expenditure, although at a much lower rate of output growth. In fact, these improvements in energy intensity likely improve emission intensity of production. Secondly, the industry has increased its aggregate ICT and non-ICT fixed capital stock by 210% and 15% from 1995 to 2005, respectively. ICT capital intensity grew a strong 167% during the period, the highest level of the five countries analysed. Even more noteworthy, the difference between the respective growth rates of ICT and non-ICT capital stock is the largest among the five sectors, indicating that investments in capital stock had a relatively strong focus on ICT. In turn, this ICT has affected industry performance through different channels. According to e-Business W@tch (2008 b), ICT enabled innovations in the metal industry are positively linked to turnover growth, and the stock of ICT capital[55] in this sector has a significantly positive impact on labour productivity. Thus the observed bias toward ICT investment could be a sign of a commitment to renovation and optimisation of production processes within the sector. More efficient production would help explain the decrease in both demand for energy inputs and in emission intensity of production.

Sustainability can be viewed in terms of reductions in absolute emissions or in emission intensity. With the latter measure, the metal sector is a stand-out among European energy-intensive industries. Just based on a glance at available data, ICT is likely an important factor in the reduction of emission intensity in the European metal industry.

Parametric analysis

As explained in section 3.1.1, the parametric regressions model the relationship between ICT capital and GHG emissions using three different regression models. In order to sufficiently isolate the true impact of ICT capital, further variables are included in all models that control for the impact of non-ICT capital, energy prices, time and structural effects on GHG emissions. As described in section 3.1.1, all size-related variables (i.e. capital stock and emissions) are normalised by gross output in million Euros (1995 prices). In sum, the three models describe the development of GHG emissions per output as a function of ICT and non-ICT capital intensity (capital stock per output) and other important variables.

The results of this analysis are highly encouraging with respect to the potential for ICT to reduce GHG emissions in the metals sector. The relationship between ICT capital and emissions is found to be highly significant and robust with respect to model specification. Overall, greater use of ICT is predicted to reduce the level of emissions per output, but most likely with diminishing impact. The effect of structural (country-specific) effects is

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55 ICT capital in e-Business W@tch (2008 b) was defined consistently to the definition in this study (chapter 2.2).

also highly significant in every model, signaling that the base level of emissions per output in the metals sector is significantly different in each of the European countries tested. Levels of non-ICT capital, energy prices, and a time trend, in contrast, do not conclusively contribute to explaining the emission levels of metal sector in Europe.The results of the estimations are shown in Table 5 and are discussed below. [56]

Table 5: Results of the parametric analysis for the basic metal and fabricated metal sector

	Linear Model	Log-Linear Model	Non-Linear Model
Dependent variable: GHG emissions per output			
Independent variables:			
- Energy prices	-0.00017	+0.1805*	-0.00079
- ICT capital intensity	+0.00116*	-0.2878***	-0.00679***
- ICT capital intensity, squared			+0.06599***
- Non-ICT capital intensity	+0.00022	+0.0433	+0.00019
- Time	-0.00001***	-0.0105	-3.04e-06
Model statistics:			
Significance of Whole Model	***	***	***
Hausman Test: Are there significant structural effects?	Yes *** (Random Effects)	Yes *** (Random Effects)	Yes *** (Random Effects)
R squared (within)	0.3308	0.4519	0.4637
Significance levels: * = 90%, ** = 95%, *** = 99%			

Glossary:

- A **dependent variable** is the one observed to change in response to the **independent variables**, which are deliberately manipulated to invoke a change in the dependent variables;
- The **coefficient** is a constant multiplicative factor that is estimated for each independent variable;
- **Significance levels** indicate the statistic probability with which the estimated coefficient describes the impact of an independent variable on the dependent one;
- The **Significance of Whole Model** indicates the probability that the model's variables explain the changes in the dependent variable better than a simple constant does. As explained in Appendix II, the significance is determined by an ANOVA whole Model F-test. A higher level of significance indicates a better model;
- The **Hausman Test** assesses how structural effects (differences) between countries should be considered, once these effects are determined to be significant: under *Fixed Effects*, the explanatory variables are correlated with structural effects, under *Random Effects* they are not (Appendix II);
- The **R squared** reports the proportion of variation in the dependent variable that can be explained by the specific model (if structural effects are significant, the R squared refers to the proportion of variation in the dependent variable within each country).

Source: DIW econ, 2009.

[56] Note that only relevant estimation outputs are shown here. Both models were estimated with the random and fixed effects estimator in order to compute the Hausman test. Reported significance levels of the coefficients were computed using cluster-robust standard errors, as is common with panel data. Further information can be found in Appendix I.

The linear model (column 2 in Table 5) is significant as a whole, but it offers inconclusive results with respect to both ICT and non-ICT capital intensity. Although the effect attached to ICT capital intensity is positive, suggesting that greater ICT capital intensity contributes to increased emissions per output, the result is only weakly significant. Instead, the time trend and country effects seem to be at the heart of the linear model's ability to explain over 30% of the variation in GHG emission intensity (as noted by the R squared value for the model). Structural effects are found to create significantly different base levels of emission intensity in the metal sector in different countries, and the effect of time-induced industry change is small in magnitude but highly significant.

Like the linear model, the log-linear and non-linear models are also significant. Both explain a larger part of the variation in the dependent variable (higher R squared values), however, and thus are considered to provide more appropriate results. Under the log-linear model (column 3 in Table 5), the negative and highly significant coefficient for ICT capital rejects the results suggested by the linear model. Rather, the estimated coefficient suggests that a 1% increase in the intensity of ICT capital generates a 0.29% decrease in emissions per output. Although not one-for-one, this result clearly supports the hypothesis that ICT capital contributes to a reduction in GHG emissions in the metals sector.

The estimation of the non-linear model (column 4), which assumes a quadratic pattern of impact, confirms the basic negative relationship between ICT and emissions. In this model, a marginal increase in ICT capital intensity is expected to decrease GHG emissions per output as long as the ICT capital intensity is below a specific turning point. Beyond this point, the marginal impact of ICT capital intensity on emissions is estimated to be positive (i.e., emissions per output increase with ICT capital intensity). However, this turning point is at 5.14% ICT capital per gross output, which is at the higher end for most of the eleven countries analysed. In fact, only four of the eleven countries display intensities that eventually exceed this level.

The other variables in the regression, non-ICT capital intensity and energy prices, offer few additional insights aside from acting as controls that help isolate the effect of ICT capital intensity on emission intensity. Non-ICT capital intensity is estimated to have a positive effect on emission levels, but the result is not significant.[57] Energy prices exhibit the same positive influence and show a weak signal of significance only in the log-linear model, so results are inconclusive.

The generally *emissions-reducing* effect of ICT in both complex models suggests an important role for ICT in the sustainability of the metals sector. However, the incongruous positive effect of ICT found in the estimation of the linear model suggests that the underlying model assumptions might be not consistent with the information contained in the data. In particular, all models assume that the effects of each variable on emission intensity in the sector are the same across countries.[58] However, this assumption may not mesh with the history of the sector. During the transition process from planed to market economies, firms in Eastern European EU member states have experienced substantial change. Although our econometric models control for the possibility of different structural effects in each country and for a common process of change over

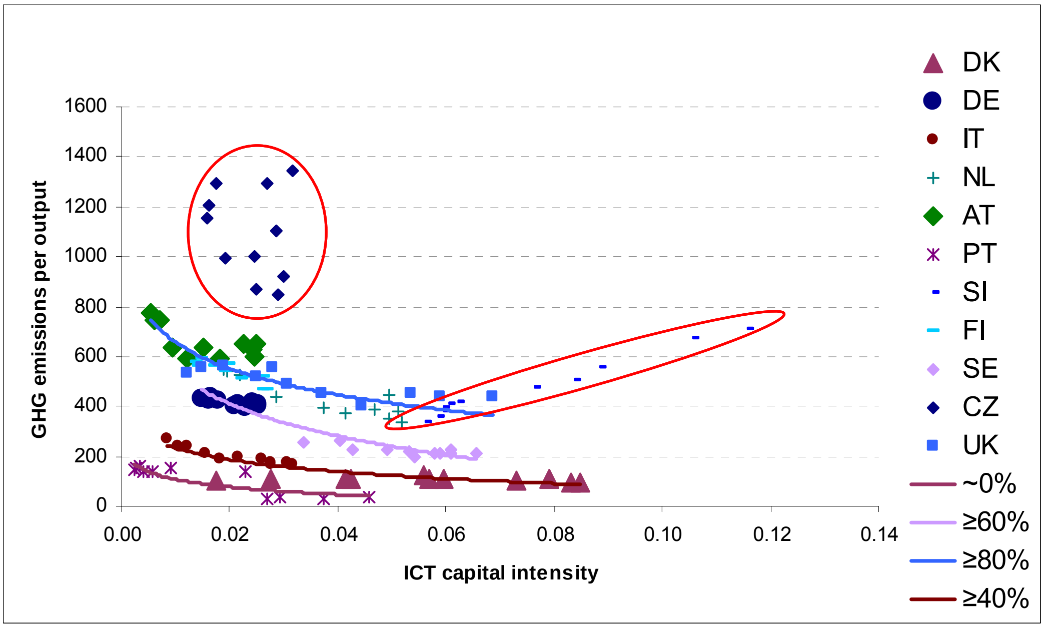
57 This result is robust with respect to the functional relationship between non-ICT capital an emissions. For example, when the non-linear model is estimated with the inclusion of a quadratic term for non-ICT capital intensity, the term is not significant and the direction and significance of the effect of ICT capital do not change.

58 See Appendix I for a further discussion of estimation procedures and assumptions.

time, the experience of Eastern European member states is likely an aberration from the pattern of structural change in an established market economy. As a result, the impact of non-ICT and ICT capital on production and GHG emissions is likely significantly different for these Eastern European countries. A simple plot of ICT capital intensity and GHG emissions per output suggests that the Eastern European member states included in our sample (Slovenia and the Czech Republic) indeed may exhibit unconventional trends (Figure 9).

Each dot in Figure 9 plots GHG emissions per output against the ICT capital intensity for a given country and year. For each of the eleven countries there are 11 individual observations for each year from 1995 to 2005. Overall, the figure does not exactly display the estimated relationship because it does not adjust for the estimated structural differences between countries. However, the figure is still useful for indicative purposes because it shows the trend for each industry. Obviously, the two countries that do not display a negative or parabolic U-shaped trend are the Czech Republic (CZ) and – most clearly – Slovenia (SI). In order to evaluate the possibility that the impact of ICT capital intensity on emissions is skewed by the Eastern European member states for the reason as explained above, the regression models are re-estimated on a data set that excludes Slovenia and the Czech Republic. The results are shown in Table 6.

Figure 9: Trends in ICT capital intensity and GHG emissions per output in the basic metal and fabricated metal sector



Source: EUROSTAT and EU KLEMS.

The metal sector as defined in this study includes the production of basic metals as well as the manufacturing of fabricated metal products. By nature the latter production process does create considerably less GHG emissions than the fabrication of basic metals which requieres the use of a blast furnace. Countries can focus on different segments of the metal sector and therefore use different production technologies. Table 7 illustrates these differences as a shift between different groups of countries as countries as categorisied according to their average share of blast furnace use in total production. Obviously, there is not only a specific trend within each group, but also this trend seems to be the same in all groups only shifted proportionally corresponding to the individual levels of blast furnace usage. The parametric models applied in this study are able to capture these shifts and focus on the trends within countries.

In order to evaluate the possibility that the impact of ICT capital intensity on emissions is skewed by the Eastern European member states for the reason as explained above, the regression models are re-estimated on a data set that excludes Slovenia and the Czech Republic. The results are shown in Table 6.

Table 6: Results of the parametric analysis for the basic metal and fabricated metal sector (excluding the Czech Republic and Slovenia)

	Linear Model	**Log-Linear Model**	**Non-Linear Model**
Dependent variable: GHG emissions per output			
Independent variables:			
- Energy prices	-0.00042	-0.0116	-0.00110***
- ICT capital intensity	-0.00147***	-0.5187***	-0.00575***
- ICT capital intensity, squared			+0.04480***
- Non-ICT capital intensity	+0.00046***	-0.2397	+0.00044***
- Time	-5.70e-06***	+0.0274**	-2.35e-06***
Model statistics:			
Significance of Whole Model	***	***	***
Hausman Test: Are there significant structural effects?	Yes *** (Random Effects)	Yes *** (Random Effects)	Yes *** (Random Effects)
R squared (within)	0.6195	0.6077	0.7272
Significance levels: * = 90%, ** = 95%, *** = 99%			

Source: DIW econ, 2009.

The results of the estimation on the reduced data set of nine countries strongly support the basic conclusions from the full-sample estimation: greater ICT capital intensity is associated with reduced emission intensity in the metal sector. With Slovenia and the Czech Republic excluded from the data set, all three models – including the linear model – estimate a significantly negative impact of ICT capital intensity on emission levels per output. Moreover, the reduced-sample estimations for the log-linear and non-linear model are fully consistent with the full data set estimation in both the direction and significance of effects.

The comparison of estimated coefficients for the full and reduced-sample demonstrates how excluding the Eastern European member states improves the estimated impact of ICT capital on emissions. For the log-linear model, the effect of ICT capital intensity doubles in the reduced-sample estimation, with a 1% increase in ICT capital intensity now estimated to generate a 0.52% reduction in emission intensity. The magnitudes of the results for the non-linear model in the two rounds of estimations are very similar. The turning point beyond which further growth in ICT capital stock relative to gross output loses its emissions-reducing power is estimated to be an ICT capital intensity level of 6.42%. However, ICT capital intensity levels greater than 7% are beyond the range of the data used in the reduced sample (see Figure 9), so interpreting the effect of ICT capital intensity on emission intensity beyond that point is rather speculative. The meaningful results from the reduced sample estimation suggest that ICT capital has a negative impact on GHG emissions per output, although the impact diminishes with higher ICT capital intensity.

Regarding non-ICT capital intensity and the estimated time trend, results are inconclusive. Non-ICT capital intensity carries an emission-increasing effect in almost all models with both the full and reduced data set. The effect reverses to emission-reducing in the log-linear model, but is not significant, whereas the positive effects in the two other models in Table 6 are highly significant.[59] Although some strong evidence supports the assertion that greater non-ICT capital intensity increases emission intensity in the metals sector, results are thus inconclusive. The effect of energy prices and time also switches signs and significance levels across the various models and estimations, with similarly inconclusive results.

In terms of selecting the most appropriate model for the reduced-sample estimation, the quadratic model is clearly better than the linear one due to the significance of the quadratic term. However, the choice between the non-linear and the log-linear model is not clear.[60] The R squared values offer an indicative metric regarding the choice, but the comparison is not conclusive. Of particular interest is the R squared value of the non-linear model, which increases more than that of the log-linear model when Slovenia and the Czech Republic are omitted from the data set. This relatively greater change suggests that the non-linear model better explains the relationship between ICT and emissions across most European countries.

Overall, evidence from the metal industry in eleven EU member states analysed suggests that greater ICT capital intensity reduces the level of GHG emissions per output. However, the impact of this effect tends to diminish as the level of ICT capital increases relative to gross output. The emission-reducing potential of ICT capital is evident when the entire data set is analysed, and it is found to be even stronger when the data set is reduced to older EU member states.

Table 7 summarises the respective changes in GHG emissions as implied by the estimated coefficients for both the full data set and the reduced data set of only older EU member states. When the results are viewed as a whole, the impact of ICT capital intensity on reducing emissions per output in the metal sector is quite robust across models and sample sets. It is important to note that the calculations made based on model estimations for the reduced data set (right column) demonstrate a greater emissions-reducing potential for ICT. This difference could signal either structural differences within the sector in these newer states that are less conducive to ICT-based efficiency improvements, or simply a different composition of ICT capital stock in older EU member states that is directed more toward emissions-reducing innovation. Finally, the achieved reductions in GHG emissions are compared with the investment volume necessary to increase the intensity of ICT capital as indicated in Table 7. This yields an estimated on the costs of reducing GHG emissions by increasing the stock of ICT capital in the metal sector. As mentioned at the beginning of this chapter, the quantification of the ICT costs of emissions reductions is presented as a reference point for comparison

[59] The quadratic term for non-ICT that was additionally estimated in the non-linear model is insignificant and does not affect estimation results.

[60] Appendix I provides a discussion of the model selection process.

purposes. The nature of the ICT variable and aggregated data used means that the true ICT cost is likely different; implementation costs are not captured, and the capital stock value may include value from ICT infrastructure that does not directly affect emissions.

Table 7: Summary table of effects of ICT for the basic metal and fabricated metal sector

Summary Table of Estimated Effects of ICT		
	Full data set	**SI and CZ excluded**
(a) % Change in emissions per output due to 1% increase in ICT capital intensity		
Log-linear model	-0.29%	-0.52%
Non-linear model	-0.18%	-0.26%
(b) Equivalent absolute *reduction* in GHG emissions from (a)		
Log-linear model	42,100 tonnes	74,000 tonnes
Non-linear model	26,400 tonnes	37,300 tonnes
(c) Cost in ICT fixed capital stock of a 1 tonne reduction in GHG emissions		
Log-linear model	276.14 €	168.68 €
Non-linear model	439.77 €	334.63 €

Calculation Details:

(a) For the log-linear model, this value is simply the marginal effect attached to ICT capital intensity in the model. For the non-linear model, this value is the percentage change off the mean emission intensity level that corresponds to a 1% increase off the mean ICT capital intensity. The mean emission intensity was calculated to be 430.69 tonnes CO2 equivalent per mil. Euro (1995 prices) for the full data set and 352.14 tonnes CO2 equivalent per mil. Euro (1995 prices) for the reduced data set.

(b) The absolute change was evaluated using the percentage change from (a) off the mean emission intensity which was calculated as the mean value across all years and countries. The absolute change in emissions was evaluated assuming ceteris paribus, in which gross output was held at the mean of 33,966 million Euro (1995 prices) for the full data set and 40,507 million Euro (1995 prices) for the reduced data set.

(c) These measures were calculated as the absolute change in GHG emissions from (b) divided by the absolute change in ICT capital stock that corresponds to a 1% increase in ICT capital intensity off the mean ICT capital intensity level. The mean ICT capital intensity level was calculated to be 0.0342 million Euro ICT fixed capital stock (1995 prices) per million Euro gross output (1995 prices) for the full data set and 0.0308 million Euro ICT fixed capital stock (1995 prices) per million Euro gross output (1995 prices) for the reduced data set.

Source: DIW econ, 2009.

Although not a one-to-one ratio, ICT certainly has a significant ability to reduce GHG emissions. A reduction in emissions is always worthwhile, but the decision to pursue such a reduction will likely be made by a firm through a cost-benefit analysis – and the actual price in Euros per tonne reduction in CO2 equivalent in the metals sector is estimated at between 168 and 440 Euro per tonne (in prices of 1995). Judging from current prices for emission permits under the EU ETS of around 15 Euro per tonne,[61] the reduction of GHG emissions based on ICT capital seems to be very expensive.[62] However, the cost estimated in Table 7 is based on the assumption that the increase in the ICT capital stock is paid for only by a marginal reduction in GHG emissions. Hence, it is obvious that the producers of metal and fabricated metal products in the eleven countries must have undertaken their investments in ICT not solely in order to reduce GHG emissions but also to generate other value such as reduced energy expenditure or production efficiency

[61] For example, European Carbon Futures 2009 are traded at the European Energy Exchange (EEX) in the first days of August 2009 at between 14.35 and 14.56 Euro per tonne.

[62] Even more so if one recalls that the estimated range of 168 to 440 Euro per tonne is in 1995-Euros and will be even higher in current prices.

improvements. For example, the case study on Corus Rail in section 4.3 demonstrates the great impact of ICT on energy efficiency, even when production is already focussed on high-quality products such as special rails for high-speed trains.

Semi-parametric analysis

The second estimation approach, a semi-parametric data envelopment and regression analysis puts the results from the parametric regressions in the previous section in context. Stepping back from the specific dynamics and magnitude of the relationship between ICT capital and GHG emissions, the non-parametric Data Envelopment Analysis (DEA) technique is used in combination with parametric methods in order to analyse the effect of ICT capital on broader measures of efficiency. As explained in section 3.1.2 two measures of technical efficiency are analysed. The DEA procedure is used to identify those countries in which the metal industry produces most efficiently for each year – both when only gross output (*conventional efficiency*) and when GHG emission intensity in addition to gross output (*sustainable efficiency*) is considered. The conventional and sustainable efficiency measures are calculated for the output- and input-oriented definitions of technical efficiency.[63]

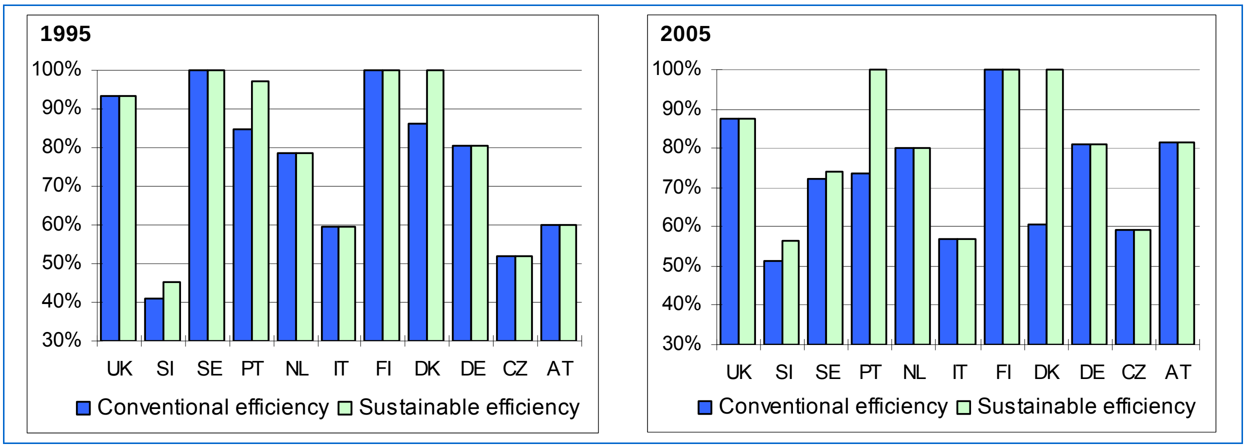
Results from the non-parametric DEA for two selected years are shown in Figure 10 (output-oriented efficiency).[64] In 1995, the metal industry in Finland (FI) and Sweden (SE) operated at the conventional efficiency frontier. The UK sector also reached an efficiency score of more than 90%. When GHG emissions are considered under the sustainable efficiency measure, the Danish metal industry (DK) joins Finland and Sweden to determine the sustainable efficiency frontier. The sustainable efficiency for Portugal is also above the 90% level.

This structure changes remarkably during the next ten years. In 2005, only Finland remains 100% efficient under the conventional measure and only three countries (Finland, Portugal and Denmark) operate at 100% sustainable efficiency. During this period, the change of the conventional efficiency frontier due to changes in total factor productivity is an average of 0.2% annually while total factor productivity changes shift the sustainable efficiency frontier much more stongly at an annual average of 1.2%.

63 As explained in section 3.1.2, the difference between the two definitions is that under the output oriented efficiency, the DMUs which produce the largest amount of output at given amounts of inputs are most efficient, while under input oriented efficiency it is the ones that use the smallest amount of inputs to produce a given amount of outputs.

64 Results for the input-oriented specification are similar for conventional efficiency (due to the assumption of constant returns to scale) and only slightly different for sustainable efficiency (because GHG emissions are considered as output or input, respectively).

Figure 10: Conventional and sustainable efficiency (output-oriented) in the metal sector in 1995 and 2005



Source: DIW econ, 2009

The improvements in ranking from conventional to sustainable efficiency indicate that production inefficiencies are partly compensated for by producing at a relatively low level of emissions per unit of output. As described in section 3.1.2, the specific attention in this study will be on analysing the extent to which ICT capital contributes to these improvements in efficiency. To address this question, we estimate the extent to which efficiency scores change when the share of ICT in total capital stock changes by using a parametric regression method (Tobit estimator with random effects).[65] Table 8 summarises the results.

For the conventional efficiency measure, the analysis fails to identify a significant relationship between the share of ICT in total capital and the determined efficiency scores. The lack of significant results suggests that the share of ICT capital is not significantly relevant with regards to the ability of the metal industry for the eleven countries analysed to either (a) increase gross output at given total labor and capital input levels or (b) reduce inputs at given output levels.

With regards to sustainable efficiency, in contrast, the estimated regression reveals a positive and weakly significant impact for both the output- and input-oriented measures. The estimated marginal effects suggest that a one percentage increase in the share of ICT capital in total capital increases efficiency scores by between 0.8 and 0.9 percent point (e.g., from an efficiency level of 80% to one of 80.9%). For the output-oriented sustainable efficiency measure, the one percentage point increase in ICT capital intensity corresponds to an increase in gross output of 330.9 million Euros[66] at given levels of emissions, holding total labor and capital stock constant. For the input-oriented measure, the increase in ICT capital intensity corresponds to a reduction in emissions at given levels of output.

Taking both output- and input-oriented results as a whole, the estimations find that ICT capital does not seem to have a significant impact on conventional efficieny when only labour and aggregate capital stocks are considered as inputs. However, when GHG

65 According to the efficiency score definition, technical efficiency scores can only be compared across countries for the same year. Hence, the standard structure of a panel regression is transposed to estimates the impact of the independent variable (ICT capital share) on the dependent variable (efficiency scores) across countries within the same year while assuming that structural differences between different years are randomly distributed.

66 This number was calculated off a data mean of 33966.07 million Euros (1995) gross output.

emissions are considered as well, the use of more ICT relative to the total capital stock improves the sustainable efficiency of the metals sector, with a slightly less than one-to-one impact.

Table 8: Results of the semi-parametric analysis for the basic metal and fabricated metal sector

Dependent variable: Efficiency score		
Independent variable: ICT capital share		
	Conventional efficiency	**Sustainable efficiency**
Output-oriented efficiency:		
Marginal effect of ICT capital share	-	0.794 *
Significance of the whole model	Insignificant	*
Input-oriented efficiency		
Marginal effect of ICT capital share	-	0.890 **
Significance of the whole model	Insignificant	**
Significance levels: * = 90%, ** = 95%, *** = 99%		

Glossary:

- A **dependent variable** is the one observed to change in response to the **independent variables**, which are deliberately manipulated to invoke a change in the dependent variables;
- The **marginal effect** specifies the impact of an incremental change in the independent variable on the dependent one (technically, this is the unconditional marginal effect evaluated at the mean of the independent variable);
- **Significance levels** indicate the statistic probability with which the estimated coefficient describes the impact of an independent variable on the dependent one;
- The **Significance of the whole model** indicates the probability that the model's variables explain the changes in the dependent variable better than a simple constant does. The significance is determined by a likelihood-ratio chi-squared test.

Source: DIW econ, 2009.

Key findings

The parametric and semi-parametric analyses demonstrate that increased ICT capital stock (relative to gross output and relative to total capital, respectively) benefits the environmental impact and efficiency of the metal sector.

The parametric regressions find the effect of ICT capital intensity to be highly significant and emissions-reducing with regard to both old and new EU member states. Two parametric models find versions of diminishing returns to ICT capital to be significant. In these models, marginal increases in ICT capital intensity have a lesser impact on emission intensity as the level of ICT capital intensity climbs. When various results regarding the effects of ICT are calculated using the estimated effects from both models, the resulting impact measures are relatively comparable, which bodes well for the ability of ICT capital to reduce emissions in the metal sector. Specific impacts should still be reported within a range, however, as displayed in Table 6. As indicated, a 1% increase in ICT capital intensity reduces emissions per output by between 0.18% and 0.52%. When this percentage change is translated into an absolute change, at constant levels of gross output, the reduction in GHG emissions is on the order of ten thousand tonnes: between 26,400 and 74,000 tonnes of CO2 equivalent emissions. The estimated "cost" in ICT capital of achieving such emissions reductions is estimated to be relatively high, but can be explained by the ability of ICT to create additional value for the firm, e.g. in terms of improved energy efficiency and thus, reduced energy expenditure.

The semi-parametric analysis confirms this postulated ability of ICT to enable efficiency improvements. The higher the level of ICT capital relative to total capital, the greater the ability of the metal sector to produce more output at constant emissions with a given value of total labor and capital inputs. Specifically, a one percentage point increase in ICT capital intensity is estimated to allow for additional production of 330.9 million Euros of gross output at constant emission levels in a given year. This trend is robust across the ten years analysed, with significantly different structural effects also affecting the efficiency levels in all countries each year. When judged together, the parametric and semi-parametric analysis suggest that not only does greater ICT capital contribute to significant reductions in emissions in the metal sector, but that greater ICT capital share increases the ability of the sector to increase production in a sustainable way.

3.2.2 Chemicals, rubber, plastic and coke sector

The **chemicals, rubber, plastic and coke** sector (hereafter refered to as the chemical sector) is a major energy user, accounting for an aggregate of 68,539 million Euros (1995 prices) of intermediate energy inputs in 2005. This level is the highest out of the five enery-intensive industries analysed, and is more than double the absolute level of the second-place energy consumer (the transport and storage sector). Despite a relatively large level of energy inputs, however, the chemical sector has managed to rank second-to-lowest among the five sectors in terms of absolute GHG emissions. In 2005, the sector emitted 101 million tonnes of CO2 equivalent or 3.4% of total emissions in the eleven countries, which is 16% below its emission levels in 1995.

Table 9: Overview of structural changes in the chemicals, rubber, plastic and coke sector in the eleven sample countries

	1995	2005	Change
Gross output (million Euros, 1995 prices)	448,502	536,568	19.6%
Energy expenditure (mil. Euros, 1995 prices)	67,436	68,539	1.6%
GHG emissions			
- Aggregate (mil. tons CO2 equivalent)	121	101	-16.3%
- Share in total economy emissions in the eleven countries	3.9%	3.4%	
- Per gross output (tons CO2 equivalent per mil. Euro, 1995 prices)	269	188	-30%
Real fixed capital stock			
- ICT capital stock (mil. Euro, 1995 prices)	12,807	22,822	78%
- ICT capital intensity, defined as ICT capital stock per gross output (%)	2.9%	4.3%	49%
- Non- ICT capital (mil. Euro, 1995 prices)	274,879	306,386	11%

Source: EU KLEMS, EUROSTAT, DIW econ, 2009.

Expenditure for intermediate energy consumption in the chemical industry in the eleven countries has remained remarkably flat during the analysed period. Nevertheless, gross output has increase during the same time by almost 20%, the highest increase among the five sectors. Consequently, with absolute levels of GHG emissions declining and output decreasing, emissions per output have gone down by 30%, the largest reduction out of the five industries.

The relatively small stock of ICT capital in comparison to both non-ICT capital and gross output highlights an opportunity to improve efficiency and – possibly – environmental sustainability in the chemicals sector. According to e-Business W@tch (2008 b), for example, ICT-enabled innovations in the chemicals industry are positively linked to turnover growth and ICT capital has a significantly positive impact on labour productivity. Despite a notable achievement in decreasing aggregate emission intensity, however, the sector within the eleven EU member states has only increased its ICT capital intensity by 49% from 1995 to 2005. Aggregate ICT fixed capital stock increased by 78% over the period. In comparison to the four other sectors in this study, both increases are the smallest. In contrast, the non-ICT capital stock of the chemicals sector's has increase by 11%, around the average for the five industries. This suggests that the sector has not increased ICT capital stock relative to non-ICT capital stock to the same extent that its energy-intensive peers have.

Parametric analysis

As explained in section 3.1.1, three different models of the relationship between ICT capital intensity and emission intensity in the chemical industry are estimated. In all three models, non-ICT capital and energy prices are also included as explanatory variables, along with a time trend and structural effects. These additions allow for the investigation of other factors that possibly contribute to GHG emission levels in the chemical sector, which is necessary in order to sufficiently isolate the true impact of ICT capital intensity on emission intensity. Size-related variables (i.e. capital stock and emissions) are standardised by gross output, meaning that the models describe the development of GHG emissions per output as function of ICT and non-ICT capital intensity (capital stock per output) as well as of other variables. The results of the estimations on the full data set from eleven European countries are shown in Table 11.[67]

For the chemical sector in the eleven countries analysed, only the linear model (highlighted in blue in column 2 of Table 11 produces significant results regarding the intensity of ICT capital. These results suggest that greater ICT capital reduces emission levels per output. When other models are considered, the effect of ICT remains emission-reducing but lacks statistical significance. Structural effects are highly significant in all models, however, and the significant effect of time suggests that exogenous change over time contributes (weakly or at a very small magnitude) to a reduction in emission intensity for the sector. Like the time trend, the sign attached to non-ICT capital in each regression model estimation is negative, preliminarily suggesting that greater non-ICT capital intensity in the chemical sector contributes to a reduction in emission intensity. However, just as in the metals sector, the results are not significant.

With a lack of significant effects for ICT capital, it is clear that neither a linear (column 3 in Table 10) nor a non-linear relationship (column 4 in Table 10) accurately describes the relationship between ICT and emissions for the entire set of eleven countries. Even the linear model, in which the effect of ICT is significant, is a poor fit for the data. The R squared indicates that this model explains only 6.5% of the variation in emission intensity

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[67] Note that only relevant estimation outputs are shown here. Both models were estimated with the random and fixed effects estimator in order to compute the Hausman test. Reported significance levels of the coefficients were computed using cluster-robust standard errors, as is common with panel data. Further information can be found in Appendix I.

within each country, which is much lower than found for the linear model in other analysed sectors.

A low R squared and insignificant effects in more complex models gives rise to the possibility that the underlying model assumptions – in particular, that the effect of ICT in the chemicals industry is the same across all countries – are not consistent with the information contained in the data. In order to illuminate whether an emission-reducing impact of ICT capital in the chemical sector is plausibly significant across all eleven countries, Figure 11 maps country trends in ICT capital intensity and GHG emissions per output.

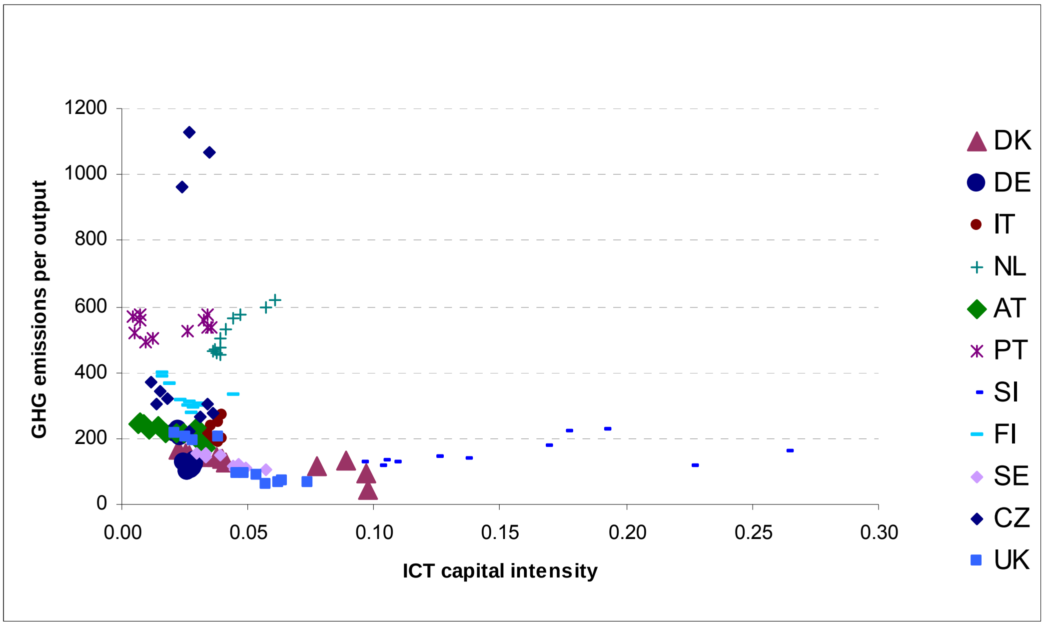
Table 10: Results of the parametric analysis for the chemicals, rubber, plastic and coke sector

	Linear Model	**Log-Linear Model**	**Non-Linear Model**
Dependent variable: GHG emissions per output			
Independent variables:			
- Energy prices	+0.00131	+0.1617	+0.00133
- ICT capital intensity	-0.00074**	-0.1189	-0.00105
- ICT capital intensity, squared			+0.00123
- Non-ICT capital intensity	-0.00037	-0.2630	-0.00035
- Time	-4.57e-06**	-0.0349***	-3.86e-06
Model statistics:			
Significance of Whole Model	***	***	***
Hausman Test: Are there significant structural effects?	Yes *** (Random Effects)	Yes *** (Random Effects)	Yes *** (Random Effects)
R squared (within)	0.0646	0.2400	0.0639
Significance levels: * = 90%, ** = 95%, *** = 99%			

Source: DIW econ, 2009.

Three countries stand out in Figure 11. Just as in the metals sector, the new Eastern European member states in the sample, Slovenia (SI) and the Czech Republic (CZ) are notable. The former country exhibits a relatively large variation of ICT capital intensity over a small range of GHG emission intensity, and the latter displays three observations for which GHG emissions per output are about four times larger than in all other years and also substantially larger than for all other countries. Additionally, the Netherlands (NL) jumps out at the viewer for combination of a strongly monotonic increase in both GHG and ICT intensity. Against a weakly emissions-reducing effect of ICT in all other countries, the inclusion of the Netherlands data could cause estimations of the effect of ICT to lose significance.

Figure 11: Trends in ICT capital intensity and GHG emissions per output in the chemicals, rubber, plastic, and coke sector



Source: EUROSTAT and EU KLEMS.

In order to check whether the relationship between ICT and emissions in the chemical sector depends on the particular group of countries selected, the three models were estimated on a variety of reduced data sets. Just as in the metal sector, Slovenia and the Czech Republic are omitted from the sample in order to estimate the relation between ICT capital and emissions only for older EU member states. The Netherlands was also excluded, testing for the influence of a country with a seemingly different structural pattern on the estimation results. Two central observations from the additional regression estimations can be made. First, the high variance in the data for the Czech Republic and Slovenia is largely responsible for the low R squared in the linear model.[68] Second, whether the Netherlands is included in the data set considerably changes the significance of the effect attached to ICT.

When the additional results are considered together as a body of evidence, a linear model of ICT capital intensity on emissions per output is the most informative model.[69] In

68 In particular, one of the new Eastern European member states, Slovenia, exhibits an extremely large difference between sustainable and conventional efficiency scores in both years, while most other countries have somewhat comparable sustainable and conventional measures. This discrepancy could suggest that while Slovenia's chemicals, rubber, plastic and coke sector is overall inefficient, the composition of its output within the sector is such that its products are biased toward low emissions. With certain sub-sectoral outputs that can be produced with relatively low emissions to output value, Slovenia's efficiency score would rise dramatically under the sustainable measure.

69 When the Netherlands is excluded on its own from the data set, all three models have significant effects attached to ICT and support an emissions-reducing role of ICT in the sector. When only the Czech Republic and Slovenia are excluded, the non-linear model becomes the only significant model, supporting an inverted U-shape. However, when the Netherlands is further excluded (for a total omission of three countries), the linear model again becomes the only significant model, with an emissions-reducing effect of ICT – just as in the estimations on the full data set as shown in

this model, ICT is emissions-reducing. In particular, a one percentage point increase in ICT capital intensity is estimated to reduce emissions per output by between 0.08 and 0.06 percentage points. Using the results from the full model estimation, which falls within this range, a 1% increase in ICT capital intensity is estimated to reduce emissions per output by 0.12%.[70] Regardless of the model and data set, structural effects are of high importance for explaining the observed differences in emissions per output among all countries. In constrast, results regarding non-ICT capital, energy prices and time are inconclusive.

While the linear model provides informative results about the effect of ICT capital intensity on emissions per output in the chemical sector, the variations in effect significance and model R squares when different data sets are used indicates that the true relationship between ICT and emissions is not the same among all EU member states. The new Eastern European member states, in particular, complicate an attempt to describe the effect of ICT capital in the chemicals sector using simple models due to high emissions and ICT data variance. Among older EU member states, some countries (namely the Netherlands)[71] seem to simply experience completely different effects of ICT. Based on the available data a simple model of the effect of ICT on capital intensity in the chemical sector, therefore, appears to be unobtainable. Nevertheless, a linear emissions-reducing effect of ICT is significant for the majority of sample countries.

Semi-parametric analysis

The starting point of the semi-parametric approach is the estimation of two different measures of technical efficiency. The first, *conventional efficiency*, takes only gross output into consideration, while the second, *sustainable efficiency*, considers greenhouse gas emissions as well.

Figure 12 illustrates the efficiency performance of the chemical sector in different countries for two selected years. In 1995, the sector in Sweden (SE) and the Netherlands (NL) determines the frontier for conventional efficiency. Under the sustainable efficiency measure, Slovenia (SI) and Denmark (DK) are also considered to be fully efficient. In 2005, the Netherlands still determines the conventional efficiency frontier, while the Swedish industry has slightly regressed and the German (DE) industry has risen in conventional performance. Both countries operate at a conventional efficiency level of almost 100%. When GHG emissions are included into the assessment of efficiency, Slovenia and Denmark maintain the full efficiency observed in 1995, Sweden also retains its full sustainable efficiency, and the German industry has again risen to a high efficiency level relative to its 1995 level.

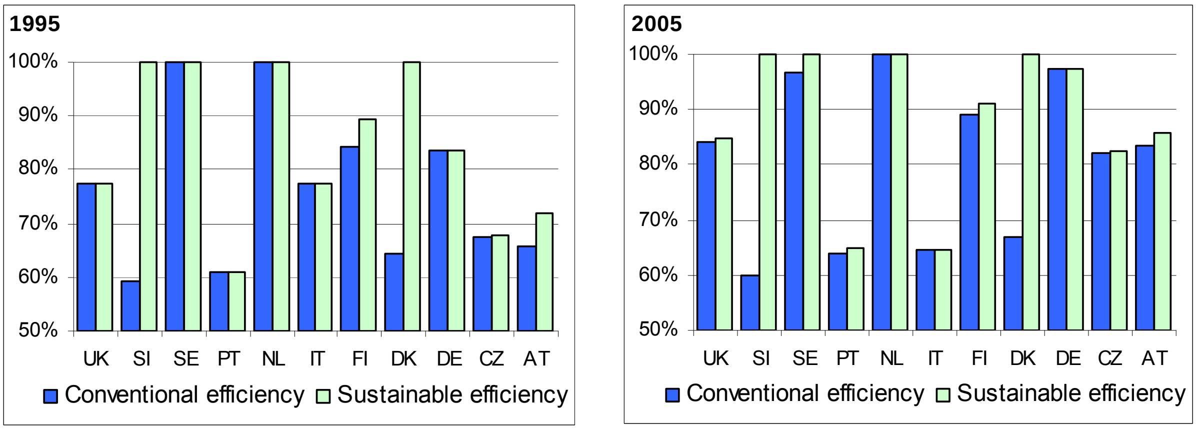
Table 10. The significance of the non-linear model when just the new EU member states are omitted is likely a result of the estimator attempting to reconcile the assumption that the effect of ICT is the same within all countries with the drastically different relationship between ICT and GHG in the Netherlands in comparison to the other older EU members. This confusion is corrected when the Netherlands is further omitted from the data set, producing again a significant linear effect of ICT that is informative if not robust to sample selection.

[70] The estimated coefficient on ICT capital intensity when the Netherlands is excluded from the data set is -0.000813 and -0.0006226 when Slovenia and the Czech Republic are further excluded. These results form a small range around the original estimation on the full data set, creating a body of strong evidence for a significant emissions-reducing effect of ICT of such magnitude. The corresponding percentage change in emission intensity is calculated off the mean of CO2 equivalent per output for the whole data set.

[71] Data from Italy may also appear to mimic the characteristics of data from the Netherlands, but estimations are robust to the exclusion of Italy.

During the analysed period, total factor productivity gains have shifted the conventional efficiency frontier by an annual average of 0.6% and the sustainable efficiency frontier by 1.5% per year.[72] These are the largest rates of TFP induced changes out of the five analysed energy-intensive industries, implying that there has been considerable technological development and productivity advancement in the chemicals sector.

Figure 12: Conventional and sustainable efficiency (output-oriented) in the chemicals, rubber, plastic and coke sector in 1995 and 2005



Source: DIW econ, 2009.

Using these efficiency scores, a regression[73] estimates the extent to which efficiency scores change when the share of ICT in total capital stock changes. The results of the parametric regression suggest that the impact of ICT in the sector is significantly different in different countries in the EU. The data on efficiency scores in Figure 12 also suggests possible incomparability among countries. In order to check for possible changes in the relationship between ICT and efficiency in old and new EU member states, the efficiency regression is done on both a full data set and on a reduced data set with the Czech Republic and Slovenia excluded. Table 11 summarises the results for the estimation on the full data set of eleven sample countries.

Table 11: Results of the semi-parametric analysis for the chemicals, rubber, plastic and coke sector

Dependent variable: Efficiency score		
Independent variable: ICT capital share		
	Conventional efficiency	**Sustainable efficiency**
Output-oriented efficiency:		
Marginal effect of ICT capital share	-	+2.64 ***
Significance of the whole model	Insignificant	***
Input-oriented efficiency		
Marginal effect of ICT capital share	-	+0.334
Significance of the whole model	Insignificant	Insignificant
Significance levels: * = 90%, ** = 95%, *** = 99%		

Source: DIW econ, 2009.

72 TPF change when all countries are included.

73 As described in the previous section, we use a Tobit estimator with random effects.

For conventional efficiency, no significant relationship can be identified between technical efficiency and the share of ICT capital. For sustainable efficiency, the marginal effect of ICT capital share is positive and strongly significant using the output-oriented efficiency score but almost zero and only at the verge of significance (88% level) using the input-oriented score. Specifically, a one percentage point increase in ICT capital out of total capital is estimated to increase sustainable efficiency by 2.64 percentage points. A highly significant effect of ICT capital share on output-oriented sustainable efficiency means that countries with higher shares of ICT capital in total capital are able to produce greater output with given input, holding emissions constant. In absolute terms, a one percentage point greater share of ICT capital in total capital is estimated to allow the chemical sector to produce approximately 1,370 million Euro gross output more in a given year, given input levels, without additional emissions impact.[74]

When the effect of ICT capital share is estimated in just the old EU member states, this effect of ICT capital share is confirmed. In addition, ICT capital share is found to have a significant effect on *all* efficiency measures, not just the sustainable ones. In these results, a one percentage point increase in ICT consistently increases efficiency scores by between 2 and 3.5 percentage points. The four efficiency scores have different interpretations. With regards to the intput-oriented sustainable measure, a greater ICT capital share is found to enable the chemicals sector to decrease emissions at given levels of output. With regards to the conventional efficiency measures, ICT allows the chemicals sector to both increase output at given labor and capital inputs and reduce inputs at given output levels.

Thus when all sample countries are considered, ICT simply and clearly allows output in the chemical sector to grow *without* emissions increasing accordingly. When estimation inference is confined to the old EU member states in the country sample, a variety of additional avenues are discovered in which ICT benefits sector operational efficiency and reduces sector environmental impact.

Key findings

In the chemical sector, the parametric regressions suggest that the dynamics of the relationship between ICT capital intensity and emissions per output in the chemical sector is not consistent across older and newer EU member states. When results of a variety of estimations are considered together, however, a linear model is most informative regarding the effect of ICT on emissions. A 1% increase in ICT capital intensity is estimated to reduce emissions per output by 0.12%, but this emissions-reducing effect of ICT is not robust across all sample countries.

The semi-parametric analysis, in contrast, does produce robust results across all countries regarding the impact of ICT capital share on a measure of sustainable efficiency. The output-oriented assessment of the relationship between the share of ICT in total capital stock and sustainable efficiency demonstrates that ICT plays a significant role in enabling the industry to grow while maintaining GHG emissions constant. A one percentage point increase in ICT capital out of total capital is estimated to increase sustainable efficiency by 2.64 percentage points. This change is equivalent to enabling an increase ingross output in the sector by approximately 1370 million Euro in a given year, given input levels, without additional emissions impact.

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[74] This number is calculated off the data mean gross output of 45498.13 million Euros (1995 prices).

The opportunity to use ICT to expand output at constant emissions levels is clearly available in the European chemical industry. However, the ability of ICT to reduce emissions is found to be less straightforward and vary considerably across particular EU member states. Further evidence for that simple econometric model structures are unlikely to fully capture dynamics of the sector can be found in the Solvay and Eka Chemicals case studies. These studies containt inconsistent perceptions about the potential of ICT to reduce emissions, supporting the conclusion that experiences with ICT in the chemicals sector are extremely varied. Indeed, the results for this sector highlight the advantage for using different methodological approaches in this analysis. While the three parametric specifications all fail to reasonably fit the data, the more flexible non-parametric estimation based on the DEA is still able to identify a reasonable pattern. Further research in this sector should investigate how ICT interplays with different output structures and whether more complex non-linear effects of ICT on emissions can be robustly estimated across all EU members.

3.2.3 Pulp, paper, printing and paper products sector

The **pulp, paper, printing, and paper products** sector (hereafter refered to as the paper sector) in the nine[75] countries has seen gross output growing by 9% between 1995 and 2005, the second-lowest increase among the five energy-intensive industries. At the same time, real energy expenditures have remained almost constant. In Europe, pulp and paper making is estimated to be responsible for almost 2% of the total primary energy consumption. In the Nordic countries, this share is even higher due to the much larger importance of the paper industry there. For the eleven countries in this study, the industry's share in total emissions is very small, however, holding steady around 0.6%.

While energy expenditures have remained almost constant, absolute industry emissions across the sample countries have decreased by 4.5% from 1995 to 2005, signalling that some sustainability improvements are being made. In fact, GHG emissions per output have decreased by 12% during the same period. Indeed, players in the industry confirm their commitment towards environmental goals. In 2006 the International Council of Forest and Paper Associations approved a leadership statement on sustainability. The industry committed itself to continuously improve its sustainability performance through action in core areas such as sustainable forest management, action to combat illegal logging, promoting the recovery of pre-and post-consumer paper, and a commitment to promote innovative energy solutions.

Like the majority of the other energy-intensive industries analysed, the fixed ICT capital stock has increased considerable over the sample period, especially in comparison to a meagre increase in non-ICT capital. Specifically, aggregate ICT capital stock increased by 190%, in contrast to a 18% increase in non-ICT capital. The resulting increase in aggregate industry ICT capital intensity across the eleven sample countries was 166%, ranking second out of five in magnitude by less than a percentage point behind the metal sector.

[75] The UK and Czech Republic had to be excluded for the analysis in the paper sector due to missing data.

Table 12: Overview of structural changes in the pulp, paper, printing and paper products sector in the eleven sample countries

	1995	2005	Change
Gross output (million Euros, 1995 prices)	223,660	244,104	9.1%
Energy expenditure (mil. Euros, 1995 prices)	6,839	6,775	-0.9%
GHG emissions			
- Aggregate (mil. tons CO2 equivalent)	18	17	-4.5%
- Share in total economy emissions in the eleven countries	0.6%	0.6%	
- Per gross output (tons CO2 equivalent per mil. Euro, 1995 prices)	81	71	-12%
Real fixed capital stock			
- ICT capital stock (mil. Euro, 1995 prices)	8,376	24,314	190%
- ICT capital intensity, defined as ICT capital stock per gross output (%)	3.7%	10.0%	166%
- Non- ICT capital (mil. Euro, 1995 prices)	116,754	13,7850	18%

Source: EU KLEMS, EUROSTAT, DIW econ, 2009.

The paper industry seems to be strongly committed to increasing ICT capital stock, especially relative to gross output. With increasingly intensive use of ICT in all areas along the value chain (e-Business W@tch, 2008 a), the impact that ICT could have on emission intensity and production sustainability in the paper sector is highly relevant. The following parametric and semi-parametric analyses investigate this relationship.

Parametric analysis

As in the previous sections, the first analytical approach estimates the relationship between ICT capital and GHG emissions based on three different models – a linear, log-linear, and a non-linear model. In all three models, non-ICT capital is also included as an explanatory variable, as are a variable representing energy prices, a time trend, and structural effects. Again, size-related variables (i.e. capital stock and emissions) are standardised by gross output so that the models describe the development of GHG emissions per output as function of ICT and non-ICT capital intensity (capital stock per output) as well as of other potentially important variables.

Unfortunately, insufficient data from the United Kingdom and the Czech Republic means that the basic dataset for this sector is only comprised of nine countries. The results of the estimation of the three models on this group of nine countries suggest that the relationship between ICT capital and emission intensity in the paper sector is positive and weakly non-linear, with greater ICT capital increasing emission intensity up to a critical turning point and reducing emission intensity thereafter. The effect of non-ICT capital, a time trend, and structural effects are also highly significant and contribute to an economic explanation of the emission intensity of the paper sector in the nine sample countries. In all estimated models, the significance of non-ICT capital is noteworthy, providing strong evidence that the emission intensity of the sector increases with non-ICT capital per output. The results of the parametric estimations on the available data set of nine countries (Table 13) are discussed below.

Table 13: Results of the parametric analysis for the pulp, paper, printing, and paper products sector

	Linear Model	Log-Linear Model	Non-Linear Model
Dependent variable: GHG emissions per output			
Independent variables:			
- Energy prices	+0.00091	+0.1474	+0.00030
- ICT capital intensity	+0.00100**	+0.0786	+0.00306**
- ICT capital intensity, squared			-0.00674*
- Non-ICT capital intensity	+0.00033***	+0.5218***	+0.00028***
- Time	-0.00002***	-0.0208*	-0.00002***
Model statistics:			
Significance of Whole Model	***	***	***
Hausman Test: Are there significant structural effects?	Yes *** (Random Effects)	Yes *** (Random Effects)	Yes *** (Random Effects)
R squared (within)	0.2925	0.1390	0.3427
Significance levels: * = 90%, ** = 95%, *** = 99%			

Source: DIW econ, 2009.

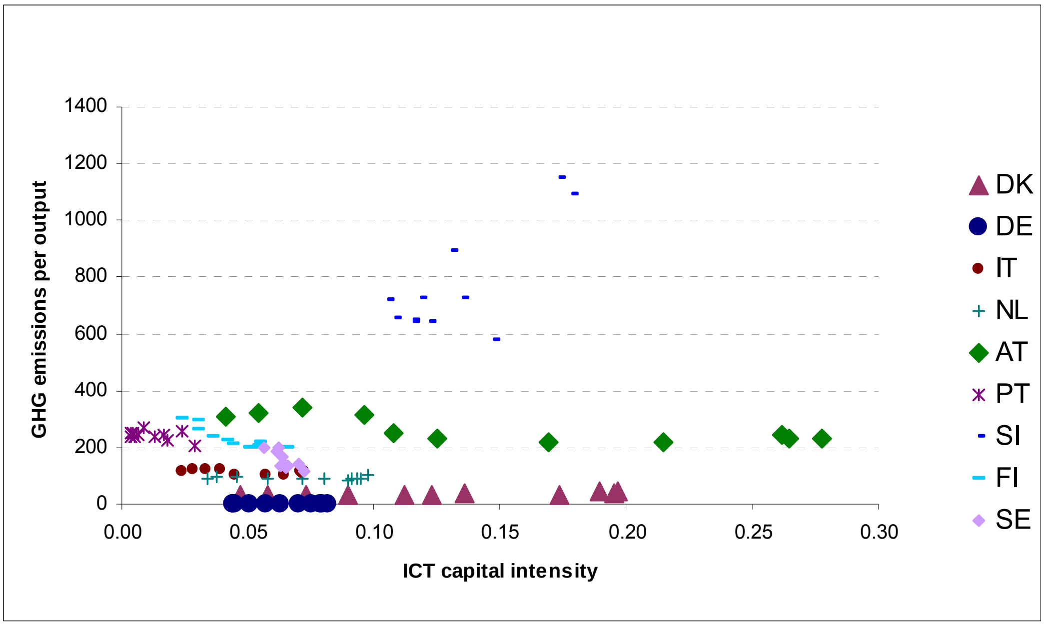
All three models are highly significant. In particular, the estimated coefficients for non-ICT capital intensity are positive and highly significant, suggesting that emissions per output increase with non-ICT capital intensity in the paper sector. The time trend is also significant in all models, estimated to reduce emission intensity. However, this reduction is fairly small in magnitude, suggesting that exogenous industry change over time is unlikely to reduce the sector's emission intensity to an important extent. Structural effects are also very relevant in all three models, suggesting that the base level of emission intensity is significantly different in each country. The effect of energy prices appears not to be significant.

Regarding ICT capital, the linear model (column 2) produces a positive and significant coefficient, suggesting that ICT capital intensity and emissions per output have developed in the same direction. The R squared is almost 30%, indicating that a linear impact model is a reasonable fit to the data from the nine sample countries.

When the log-linear model is estimated (column 3), the results are similar in direction of impact but not in level of significance. Both ICT capital intensity and non-ICT capital intensity are expected to have a positive influence on emission intensity. However, the effect of ICT capital loses significance and the R squared value is considerably smaller, suggesting that the log-linear model does not fit the data better than the linear one.

The non-linear model (column 4) improves upon both the linear and log-linear model, finding a significant impact of ICT and non-ICT capital intensity. Similar to the chemicals industry, the combination of a significant and positive coefficient on the linear ICT term and a (slightly significant) negative coefficient on the quadratic term suggests that the relationship between ICT capital intensity and emissions per output resembles an inverted U-shape. At low levels of ICT, greater ICT capital intensity is associated with increasing emission levels per output. However, once ICT capital intensity passes a certain critical threshold – estimated in this regression to be at a 22.7% share of ICT capital in gross output – emissions per output will decline with greater ICT capital intensity. The R squared of the non-linear model shows that the quadratic fit captures about 34% of the variation in GHG emission intensity within each country, indicating a better fit than the two other models and improving upon the linear model in particular. The non-linear model seems to be the most suitable description of the relationship between ICT capital intensity and emissions per output in the paper sector.

Figure 13: Trends in ICT capital intensity and GHG emissions per output in the pulp, paper, printing, and paper products sector



Source: EUROSTAT and EU KLEMS.

Despite the good fit of the non-linear model and the significance of the estimated coefficients, a graphical visualisation of the relationship between ICT capital intensity and GHG emissions per output (Figure 13) offers little support for the existence of a U-shaped relationship.

While such an inverted-U pattern can be spotted for Austria and – to some extent – for Slovenia, other countries do not seem to exhibit this trend.[76] With Austria excluded from the sample, the coefficients of the non-linear model are no longer significant, and the estimation results display only a significant positive linear relationship. Thus while the results for the full sample suggests that the relationship between ICT capital intensity and GHG emissions per output resembles an inverted U-shape, this pattern strongly depends on the inclusion of a single country in the data set. The robust relationship between ICT capital and emission intensity is actually linear, with only the linear model producing

[76] For Austria, the relationship between ICT capital intensity and GHG emissions per output also notably levels off at higher levels of ICT capital intensity, suggesting that a simple U-shaped pattern may not fully capture the true relationship between the two variables even in that country. Slovenia was also excluded from the data and the estimations were re-run as another robustness check, but direction or significance of effects did not fundamentally change. However, excluding Slovenia from the sample yields an increase in the R squared for all models by almost 20 percentage points, suggesting that the variables included in the model explain the variation in emissions per output much better in the rest of the sample countries than in Slovenia.

consistent results for the nine-country data set (column 2 in Table 13) and with Austria excluded.

In sum, the estimation of the effect of ICT capital intensity on emission intensity in the paper sector performed in this study indicates a significant relationship between ICT capital intensity and GHG emission per output. Higher ICT capital intensity is found to be associated with higher levels of GHG emissions per output. Based on the available data the specific pattern of that relationship cannot be fully assessed, but analysis on full and reduced data sets suggests that a linear relationship between ICT and emission intensity is most appropriate for all the sample countries.

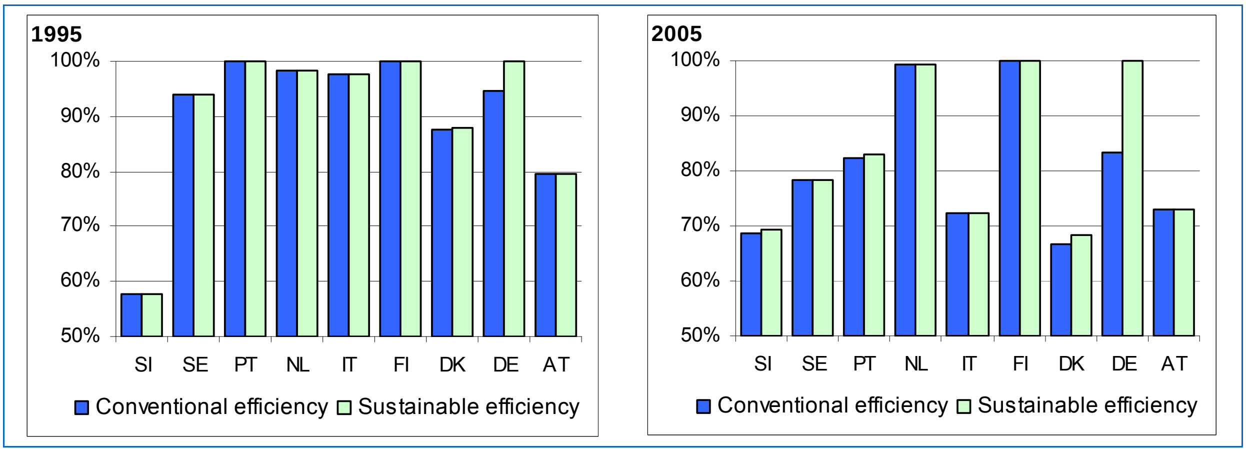
Semi-parametric analysis

The estimated efficiency scores for the nine countries covered in the semi-parametric analysis of the paper sector are shown in Figure 14. As in the previous sectors, both conventional and sustainable efficiency scores were calculated using Data Envelopment Analysis.

In 1995, the sectors in Portugal (PT) and Finland (FI) operated fully efficient in the *conventional* sense. Four additional countries, Sweden (SE), the Netherlands (NL), Italy (IT) and Germany (DE), have conventional efficiency levels above 90%. For *sustainable* efficiency, which also considers GHG emissions, the list of fully or almost fully efficient countries remains unchanged. In fact, with the exception of Germany, which becomes fully efficient under the sustainable measure – 1995 conventional and sustainable efficiency estimates hardly differ within each country.

By 2005, the picture has changed quite substantially. For conventional efficiency, only Finland remains on the efficiency frontier. The Netherlands has increased its score to be almost fully efficient, but efficiency scores for all other countries drop substantially. This pattern is also observed for sustainable efficiency. Only Finland and Germany remain fully efficient in comparison to 1995, and the Netherlands maintains its 1995 status as almost fully efficient.

Figure 14: Conventional and sustainable efficiency (output-oriented) in the pulp, paper, printing and paper products sector in 1995 and 2005



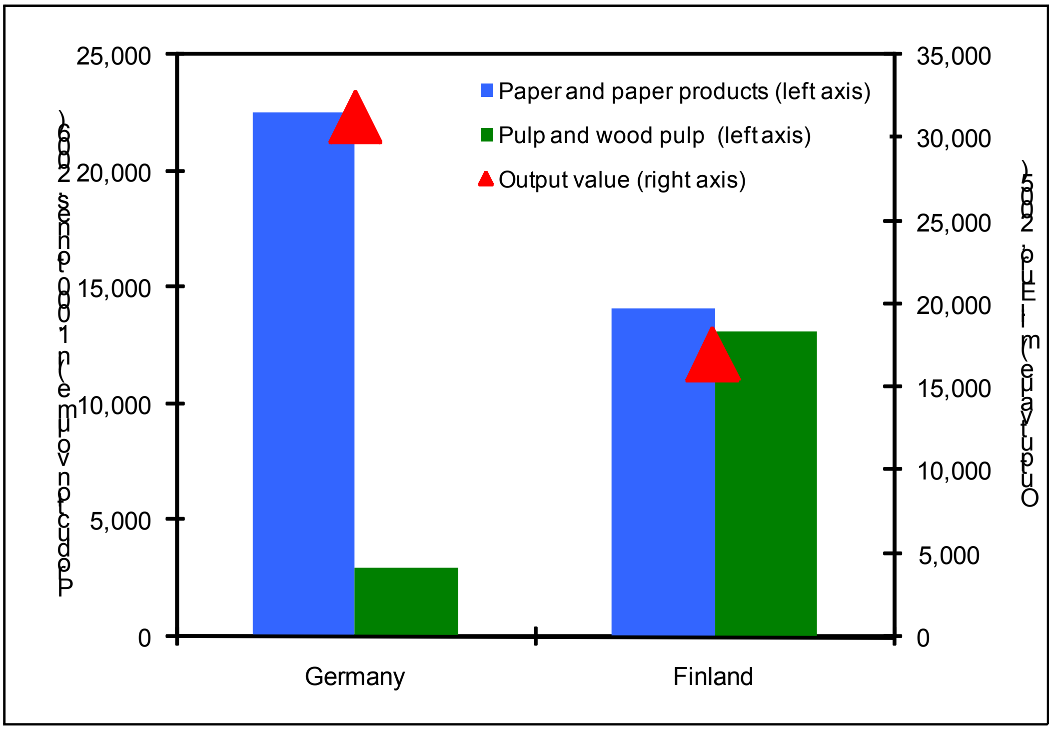
Source: DIW econ, 2009.

The strong differences in the distribution of efficiency levels between 1995 and 2005 are also reflected in negative shifts of the efficiency frontiers. The conventional and sustainable efficiency frontiers decrease at an annual average of -1.1% and -1.7%, respectively, during the period. These decreases suggest that the paper sector has lost productivity over the analysed period. The ratio of input to output values increases in most of the analysed countries, also indicating a loss in productivity.

Given that the sector operates under intense international competition, a loss in productivity is – at first glance – surprising. Generally, structural differences among countries can help explain a decrease in productivity despite increased competition. In addition to factor prices, the availability of natural resources (in particular, of wood as crucial raw product) as well as environmental and regulatory standards are highly important in determining the structure of the sector. Differences in these elements can give rise to substantial structural differences across countries, especially with regards to output and input composition within the defined paper sector.

This phenomenon of structural differences is likely present in the case of the nine[77] sample countries. In fact, the structural composition of output and input aggregates among the analysed countries is substantially different and (possibly) also changing over time, which strongly limits the comparability between countries. A comparison between the paper sector in Finland and in Germany (Figure 15) illustrates this point.

Figure 15: Comparison of the pulp, paper, printing and paper products sector in Germany and Finland



Source: EU-KLEMS, German Pulp and Paper Association (VDP)

As a simple sum of the blue and green columns would indicate, both countries produce roughly the same volumes of physical output. The composition of output is strikingly different between the countries, however. Germany produces twice as much paper and paper products (blue column) as it does pulp and wood pulp products (green column). In contrast, the Finnish production of these two sub-sector output categories is roughly

77 The UK and the Czech Republic did not provide enough data to be included in the analysis of the paper sector.

equal. In fact, German production of pulp and wood pulp is only a fifth of the Finish pulp and wood pulp production.

When a comparison is made in terms of output *value* (the metric used in efficiency calculations) the comparability between the German and Finnish paper sector becomes even more convoluted. Germany's output is two times larger than Finnish output in terms of value, so the comparable *volume* measures mean that the value per ton of Finnish production is almost half that of Germany's. In sum: the Finish industry has a much stronger focus on the production of raw products (pulp) with a rather low value per ton, while the German industry concentrates on final paper products with a considerably higher value per ton.

Input requirements for these production structures are also different, further complicating a comparison. In particular, the production of pulp is very energy intensive, while the production of other outputs included in the umbrella category of "paper, pulp, printing and paper products" is not. The relatively large difference between the conventional and sustainable efficiency score for Germany is clearly due to the difference in production structure. With obvious differences in output and input structure *within the sector,* neither a comparison of emission intensity or ICT capital share for the paper, pulp, printing and paper products sector is appropriate.[78]

While this problem of incomparability generally affects all sectors to some extent, it appears to be of particular importance in the paper sector for the eleven sample countries. Without suitable comparability among sample countries, the estimation of efficiency levels based on the relationship between input and output values cannot produce meaningful results. Consequently, the estimated efficiency scores for the paper sector are not further analysed.

Key findings

As the results of the non-parametric efficiency estimates suggest that important structural differences among countries do not allow for reasonable analyses of the paper sector. In particular, both the output composition and input structure of production in certain countries is significantly different. When output and input structures across countries are not comparable, the efficiency measures and the semi-parametric analysis lose meaning. With regards to the parametric regression, differences in output composition within the sector are also particularly worrisome.

The parametric regression does – to some extent – control for structural differences. During the estimation procedure, so-called fixed and random effects control for static structural differences that produce different base (e.g. 1995) levels of emission intensity for the sector in each country. In the paper sector, these static structural differences are highly significant. A time trend included in the regression allows us to control for structural changes *over time that are the same for each country.* In the paper sector, this trend is also significant, suggesting that exogenous changes over time are important determinants of the industry emissions intensity as a whole. The one case in which structural changes are not controlled for in the parametric regression is when changes in sector structure occur over time and *differ among countries*. This is exactly what happens in the paper sector.

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[78] A further differentiation of output values into these two categories is not possible for the full sample due to lack of sufficient data.

As the efficiency scores in Figure 14 and the structural analysis in Figure 15 demonstrate, output composition has changed drastically within certain countries over the sample period. As a result, measures of ICT capital intensity and emission per output for the entire sample period are rendered largely incomparable among countries. A country that concentrates on printing, for example, might have a low emission intensity and high ICT capital intensity, while a country that concentrates on pulp production would exhibit the high emission intensity and low ICT capital intensity. Furthermore, these different output structure changes over time call the fundamental regression assumption – that the impact of ICT on emissions within each country over time is the same for all countries – into question. We must ask ourselves if ICT has influenced emissions over the entire sample period in the *same way* for a country that focuses on pulp production, a country that concentrates on printing, and a country that has switched focus from pulp to printing. Unfortunately, the answer is most likely "no", forcing us to refrain from interpreting the parametric regression results. All in all, the drastic structural changes within the paper sector over the sample period render both the parametric and the semi parametric analysis for this sector largely irrelevant.

Without the ability to produce meaningful results with an econometric analysis, the most relevant insights with regard to the relationship between ICT and GHG emissions in the paper sector can be found in the case studies and surveys provided in this report. For example, it appears that opportunities for reducing emission intensity of production in the sector in general are not as large as they are in other energy-intensive industries. This could be a result of relatively small opportunities to reduce energy consumption, given the entrenched production processes in certain sub-sectors of the paper industry. The Siemens case study (section 4.1) in particular supports this conclusion, observing that particular energy-savings applications of ICT lead to smaller reductions in the paper-producing sector as opposed to the chemicals sector. In contrast, the majority of experts from the paper sector in the Delphi-style survey (section 5.2) do find "high" or "some" potential for ICT to reduce GHG emissions in the sector. However, one survey participant expressed a strong opinion that further innovation in ICT systems would not improve the sustainability of the sector. A broader base of reliable data, along with further qualitative investigation into the application of ICT for emission-abatement purposes, will help clarify the true impact of ICT on sustainability in the European paper sector.

3.2.4 Glass, cement and ceramic sector

In the **glass, cement, and ceramic** sector (hereafter refered to as the GCC sector), the environmental impact of production is threefold: raw materials extraction (although using recycled raw materials is a major advantage particularly of the glass industry in environmental terms), energy input (especially in furnaces), and emissions from the production process. The average share of the industry in total emissions from the economies of the eleven sample countries is about 3.9%. Similar to the metal and paper industry, the GCC industry has reduced absolute aggregate emissions by 5.8% from 1995 to 2005. With a meagre 5% increase in output over the same period, aggregate emission intensity for the GCC sector has decreased by 10%, the lowest decrease of the five energy-intensive industries.

Table 14: Overview of structural changes in the glass, cement and ceramic sector in the eleven sample countries

	1995	2005	Change
Gross output (million Euros, 1995 prices)	103,923	109,206	5.1%
Energy expenditure (mil. Euros, 1995 prices)	147,81	17,508	18.5%
GHG emissions			
- Aggregate (mil. tons CO2 equivalent)	124	117	-5.8%
- Share in total economy emissions in the eleven countries	4.0%	3.9%	
- Per gross output (tons CO2 equivalent per mil. Euro, 1995 prices)	1,192	1,069	-10%
Real fixed capital stock			
- ICT capital stock (mil. Euro, 1995 prices)	2,051	4,922	140%
- ICT capital intensity, defined as ICT capital stock per gross output (%)	2.0%	4.5%	128%
- Non- ICT capital (mil. Euro, 1995 prices)	75,037	81,842	9%

Source: EU KLEMS, EUROSTAT, DIW econ, 2009.

Industry energy expenditure has increased from 1995 to 2005 by 18%. Despite the reasonable reduction in absolute emissions relative to other energy-intensive industries, this increase in energy expenditures is actually the second largest behind transportation.

In keeping with the trend observed in other energy-intensive sectors, the aggregate industry ICT fixed capital stock increased 140% from 1995 to 2005. With a small increase in non-ICT capital stock by 9% during the same period, the bias toward investment in ICT is again notably strong. The aggregate industry ICT capital intensity increased a corresponding 128%, a result of both this large increase in ICT capital stock and the aforementioned small increase in sector gross output. With a strong decrease in emission intensity and a large increase in ICT capital intensity, an emissions-reducing effect of ICT in the GCC sector is certainly plausible. The parametric and semi-parametric analyses that follow in this section investigate the relationship between ICT and sector sustainability in detail.

Parametric analysis

With important basic processes that draw down large amounts of energy, the GCC sector is dependent on energy-saving efficiencies and innovation in order to reduce the bulk of emissions emitted by the sector. In order to discover the effect of ICT capital on GHG emissions, the relationship between ICT capital intensity and GHG emission intensity is modeled as usual with a linear, log-linear, and a non-linear parametric regression model, with non-ICT capital intensity, energy price, a time trend, and structural effects also included in order to isolating the particular effect of ICT on GHG emission intensity levels in the GCC sector. The results of the first round of estimations on the full data set are shown in Table 15.[79]

[79] A quadratic term was also estimated for non-ICT capital intensity in the non-linear model, but the term was insignificant and did not affect the significance level of the other estimations.

Table 15: Results of the parametric analysis for the glass, cement, and ceramic sector

	Linear Model	Log-Linear Model	Non-Linear Model
Dependent variable: GHG emissions per output			
Independent variables:			
- Energy prices	-0.00128	+0.0695	-0.00177
- ICT capital intensity	+0.00571***	+0.0460	+0.00185
- ICT capital intensity, squared			+0.03024
- Non-ICT capital intensity	+0.00018	+0.1835	+0.00033
- Time	-0.00004**	-0.0163*	-0.00003*
Model statistics:			
Significance of Whole Model	***	***	***
Hausman Test: Are there significant structural effects?	Yes *** (Fixed Effects)	Yes *** (Fixed Effects)	Yes *** (Fixed Effects)
R squared (within)	0.1795	0.2145	0.1840
Significance levels: * = 90%, ** = 95%, *** = 99%			

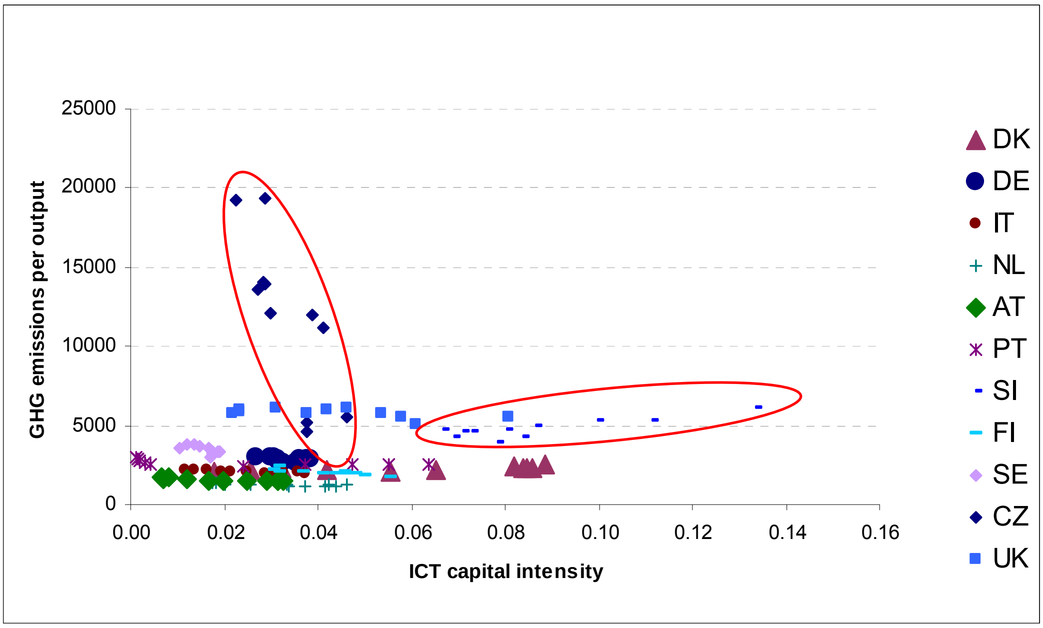
Source: DIW econ, 2009.

The results of the estimation of all three models on a full set of data from the selected eleven countries preliminarily suggest that greater ICT capital intensity increases emission intensity in the European GCC sector. The linear model provides the only significant result, although the direction of the effect is consistent across models and thus supportive of an emissions-increasing effect of ICT capital.

As in all sectors, structural effects are found to be significant. This is the only sector in which structural effects are estimated as fixed effects, demonstrating that the decision about how much to invest in ICT capital stock in the sector is not unrelated to the specific policy or structural characteristics of the country as a whole. The effect of time is also negative and weakly significant, signaling that time-induced exogenous industry change is likely to help counteract the increase in emission intensity due to capital increases. Like ICT capital, greater non-ICT capital is estimated to increase emission intensity in the sector in all models, but the result is inconclusive since no effect is significant. Energy prices are similarly inconclusive and insignificant.

As in other sectors, the conclusions are checked against a visual plot of the data (Figure 16). A re-estimation of the models on a reduced data set, excluding the new Eastern European member states (Czech Republic and Slovenia) to check for robust results, also seems appropriate for the GCC sector. The data for the Czech Republic has a high variance of GHG emission intensity across a small range of ICT capital intensity, as found in other sectors. The data for Slovenia does not immediately stand out, but is also removed for consistency with the analysis of differences between new and older EU member states as performed in other sectors.

Figure 16: Trends in ICT capital intensity and GHG emissions per output in the glass, cement, and ceramic sector



Source: EUROSTAT and EU-KLEMS.

The results of the re-estimation on a reduced data set are shown in Table 16.

Table 16: Results of the parametric analysis for the glass, cement, and ceramic sector (excluding the Czech Republic and Slovenia)

	Linear Model	Log-Linear Model	Non-Linear Model
Dependent variable: GHG emissions per output			
Independent variables:			
- Energy prices	+0.00044	+0.0170	+0.00016
- ICT capital intensity	+0.00008	-0.0086	-0.00141
- ICT capital intensity, squared			+0.01588
- Non-ICT capital intensity	+0.00051***	+0.4337***	+0.00051***
- Time	-5.25e-06	-0.0027	-4.43e-06
Model statistics:			
Significance of Whole Model	***	***	***
Hausman Test: Are there significant structural effects?	Yes *** (Fixed Effects)	Yes *** (Fixed Effects)	Yes *** (Fixed Effects)
R squared (within)	0.3353	0.3606	0.3474
Significance levels: * = 90%, ** = 95%, *** = 99%			

Source: DIW econ, 2009.

The results of the estimation without Slovenia and the Czech Republic place the conclusions from the estimation on the full data set in doubt. The linear model still carries a positive sign on ICT, but the log-linear model now predicts a growth in ICT capital intensity to reduce emission intensity. The non-linear model also predicts an *emissions-reducing* effect of ICT capital intensity, but with diminishing returns up to a turning point.

The effect of ICT in all three models is insignificant, however, so no model is highlighted in blue in Table 16. The lack of significant results attached to ICT in the estimations in Table 16 signals that an emissions-increasing effect of ICT, as found in the estimation on the full data set, is not consistently observed when particular countries are excluded from the data set.

In contrast to the effect of ICT, however, the effect of non-ICT capital gains considerable significance in all three models when new EU member states are excluded. As demonstrated in Figure 16, the high variance in the GHG emissions of the Czech Republic could be at the heart of this change; the removal of the country's data points allows the model to more precisely estimate the effect of non-ICT capital on GHG emission intensity. The decision between models requires further analysis on greater data sets, but the large effect of non-ICT capital in the log-linear model suggests that the type of non-ICT capital used in the GCC sector could be improved in order to help decrease emissions per output of the sector.

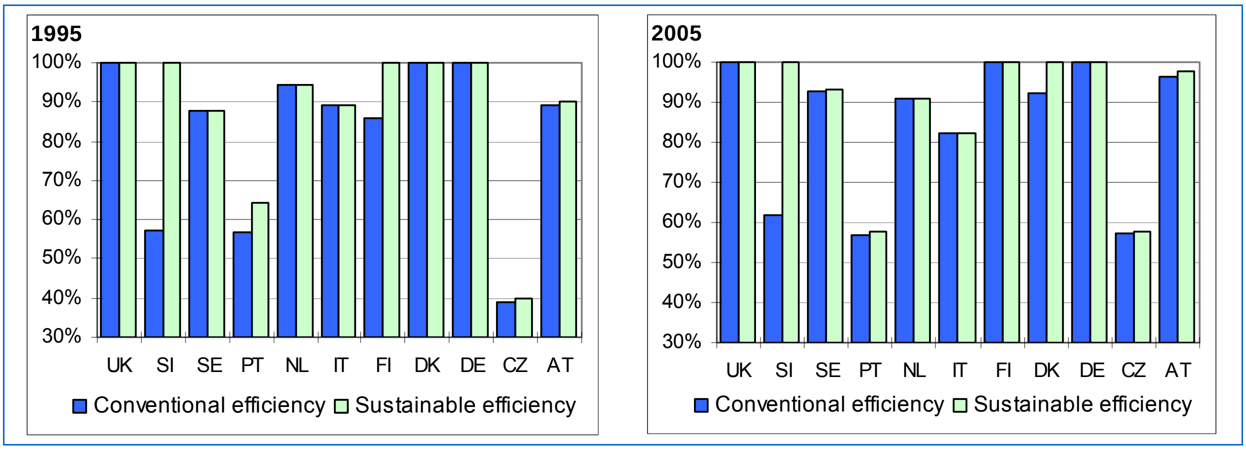
With inconsistent results across old and new EU member states, the effect of ICT capital intensity on emissions per ouptut in the GCC sector cannot be concluded. However, where the effect of ICT capital intensity is insignificant, non-ICT capital intensity plays a significant role in determining emission levels in the sector for older EU member states. This result is somewhat remarkable. Only in the paper sector the effect of non-ICT capital on emission intensity was also found to be positive and highly significant. Together, these estimation results suggest that the role of non-ICT capital in the GCC sector should be more carefully studied, especially in older EU member states, in order to ensure the sustainable growth of the sector. The direct effect of ICT capital on emission intensity is ambiguous, but the following semi-parametric analysis lends insight into the role of ICT capital in the sector's sustainability in general.

Semi-parametric analysis

The semi-parametric analysis addresses the impact of ICT capital share in total capital on measures of conventional and sustainable efficiency. Just as in other sectors, the relationship is estimated through a parametric regression (specifically, a Tobit estimation with random effects). The regression estimates the relationship between ICT capital share and efficiency scores for each country within a given year, allowing for structural differences in the sector to affect efficiency levels differently each year.

Conventional and sustainable efficiency scores for the GCC sector in the eleven countries in the data set are depicted in Figure 17. In 1995, the United Kingdom (UK), Denmark (DK), and Germany (DE) were fully efficient according to both measures, with Slovenia (SI) and Finland (FI) fully efficient only according to the sustainable measure. The Netherlands (NL) was over 90% efficient in 1995 according to both measures, although not fully efficient in either.

Figure 17: Conventional and sustainable efficiency (output-oriented) in the glass, cement and ceramic sector in 1995 and 2005



Source: DIW econ, 2009.

In 2005, the distribution of efficiency scores is quite similar. The UK and Germany remain fully efficient according to both measures, and Slovenia remains fully efficient only with regard to the sustainable measure. Where Denmark was fully efficient in both sustainable and conventional efficiency in 1995, it has slipped in ranking with regards to the conventional measure and now hovers above 90%. In contrast, Finland has gained in conventional efficiency to now define the efficient frontier along with the UK and Germany. The Netherlands remain above the 90% efficiency mark in both measures, with Sweden (SE) and Austria (AT) now also surpassing that level. In addition, total factor productivity gains are estimated to have shifted both the conventional and sustainable efficiency frontier by 1.1% annually.

As discussed above, the parametric regression results regarding the effect of ICT lost significance when Slovenia and the Czech Republic were omitted from the data set, signalling some difference in structure or development pattern with regard to ICT and emissions in these two new Eastern European member states in comparison to the rest of the group. Just as in the chemical sector, the semi-parametric regression is also estimated on full and reduced data sets in order to investigate the possibility of differences between new and old EU member states in the context of efficiency. Only results for the estimation on the full data set are shown (Table 17).

Table 17: Results of the semi-parametric analysis for the glass, cement and ceramic sector

Dependent variable: Efficiency score		
Independent variable: ICT capital share		
	Conventional efficiency	**Sustainable efficiency**
Output-oriented efficiency:		
Marginal effect of ICT capital share	+	+2.58 ***
Significance of the whole model	Insignificant	***
Input-oriented efficiency		
Marginal effect of ICT capital share	+	+0.089
Significance of the whole model	Insignificant	Insignificant
Significance levels: * = 90%, ** = 95%, *** = 99%		

Source: DIW econ, 2009.

The ICT efficiency analysis on all eleven sample countries demonstrates that ICT capital share increases efficiency in the GCC sector. A one percentage point increase in ICT capital share of total capital is estimated to increase output-oriented efficiency by 2.6 percentage points. This corresponds to enabling a given year's output to be increased by approximately 280 million Euros, given constant inputs, *without also increasing emissions levels.*[80]

Just as in the chemical sector, when the new Eastern European member states are excluded from the analysis, the result regarding output-oriented sustainable efficiency is confirmed at the same significance level and similar magnitude. Also in a similar manner to the chemicals sector, the magnitude and significance of all the other efficiency measures increases notably. A one percentage point increase in ICT capital share is now estimated to increase conventional efficiency by 2.4 percentage points and input-oriented sustainable efficiency by 1.8 percentage points. In other words, greater ICT capital relative to total capital allows the GCC sector to actually reduce emissions at constant levels of output. This result can only be interpreted for older EU member states, but are nonetheless indicative and important to note.

Key findings

The parametric analysis does not find conclusive results regarding the direct impact of ICT capital intensity on emission intensity in the GCC sector. Instead, non-ICT capital is found to play an extremely important role in emissions per output in older EU member states. Emissions per output increases significantly with non-ICT capital intensity in the sector for older EU member states, and the same relationship is suggested for new member states as well but not found to be significant.

The semi-parametric analysis offers fresh insight into the role of ICT in the GCC sector in Europe, finding consistent effects of ICT for the sector across all sample countries where the parametric analysis did not. The semi-parametric analysis clearly suggests that countries with higher ICT capital share are better able to increase output at constant levels of emissions. When only older EU member states are considered, higher ICT capital relative total capital is also suggested to help countries reduce emissions at constant levels of output *and* improve conventional production efficiency.

3.2.5 Transport and storage sector

The **transport and storage sector** (hereafter referred to as the transport sector) comprises an extremely large part of the total greenhouse gasses emitted by the economies of the selected eleven sample countries. The sector's annual share averaged 18.5% from 1995 to 2005, actually increasing from around 17% to 19%. This share is over ten percentage points greater than the share of any of the other four energy-intensive industries, indicating that a reduction in emissions in the transport sector is particularly important. Unfortunately, the transport sector appears to not be making much progress in terms of reducing absolute emissions, recording instead a 9.8% *increase* over the period. Aggregate emission intensity for the sector has decreased by almost 17% over the same period, however. This evident decrease in intensity is a result of a much larger increase in gross output relative to emissions, registering an increase of 32.2%.

80 This value was calculated off the data mean gross output of 9723.71 million Euros (1995 prices).

Table 18: Overview of structural changes in the transport and storage sector in the eleven sample countries

	1995	2005	Change
Gross output (million Euros, 1995 prices)	427,275	564,761	32%
Energy expenditure (mil. Euros, 1995 prices)	22,415	32,127	43%
GHG emissions			
- Aggregate (mil. tons CO2 equivalent)	529	581	9.8%
- Share in total economy emissions in the eleven countries	17.1%	19.4%	
- Per gross output (tons CO2 equivalent per mil. Euro, 1995 prices)	1,239	1,030	-17%
Real fixed capital stock			
- ICT capital stock (mil. Euro, 1995 prices)	40,394	85,422	111%
- ICT capital intensity, defined as ICT capital stock per gross output (%)	9.5%	15.1%	60%
- Non- ICT capital (mil. Euro, 1995 prices)	667,468	916,513	37%

Source: EU KLEMS, EUROSTAT, DIW econ, 2009.

The relationship between the growth rates of ICT fixed capital stock and non-ICT fixed capital stock in the transport sector is most closely reflective of that observed in the chemical sector. The differential is the second-smallest of the five sectors, indicating a relatively lesser emphasis on ICT investment in comparison to non-ICT investment. However, this is not to say that absolute capital measures have not increased. Indeed, aggregate industry ICT and non-ICT capital stock across the eleven countries increased 111.5% and 37.3%, respectively. The corresponding increase in industry aggregate ICT capital intensity was also small relative to the rest of the sectors, coming in only above the change in the chemicals sector at just below 60%.

ICT investments are noted in the case studies as the foundation for the optimisation of the transport industry, but the emphasis on investment in ICT capital seems to be less relative to other energy-intensive industries. The following parametric and semi-parametric analyses discover the role that ICT plays in reducing emissions and increasing efficiency in the transport sector.

Parametric analysis

In this section, the role of ICT capital intensity in reducing emissions per output in the transport sector is modelled by a linear, log-linear, and a non-linear model. Each model also includes controls for non-ICT capital intensity, energy prices, a time trend, and structural effects in order to better estimate the true effect of ICT capital stock per output on emissions intensity in the sector. Results from the estimations are shown in Table 19.

Table 19: Results of the parametric analysis for the transport and storage sector

	Linear Model	Log-Linear Model	Non-Linear Model
Dependent variable: GHG emissions per output			
Independent variables:			
- Energy prices	-0.00101	-0.0364	+0.00055
- ICT capital intensity	+0.00151	+0.0614*	+0.00701*
- ICT capital intensity, squared			-0.02354*
- Non-ICT capital intensity	-0.00002	+0.1026	-0.00009
- Time	-0.00003***	-0.0215***	-0.00004***
Model statistics:			
Significance of Whole Model	***	***	***
Hausman Test: Are there significant structural effects?	Yes *** (Random Effects)	Yes *** (Random Effects)	Yes *** (Random Effects)
R squared (within)	0.1500	0.3544	0.1901
Significance levels: * = 90%, ** = 95%, *** = 99%			

Source: DIW econ, 2009.

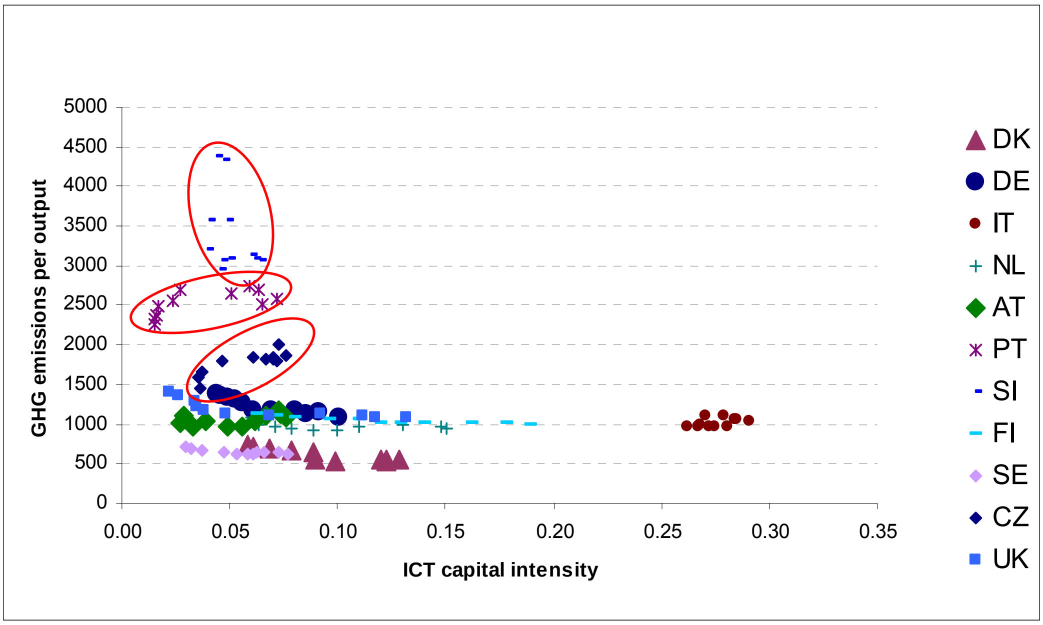
All models estimated on the entire data set offer indicative evidence that the impact of increased ICT capital intensity in the transport sector may increase emissions per output, but the results are only weakly significant (no model is highlighted in Table 19 as strongly significant and appropriate). With little or no significance found regarding the effects of ICT capital and non-ICT capital (and energy prices as well), only the time trend and the estimated structural effects seem to be supporting the significance of the models. The significance of structural effects is intuitive – the structure of transport services operations are likely highly dependent on the geography of a country, subsequently altering the base level of emissions intensity. The negative and highly significant time trend suggests that exogenous changes over time will contribute to a small but important reduction in the emission intensity of the sector.

A graphical view of the trend between ICT capital intensity and emission intensity (Figure 18) helps explain the weakly significant results across all models. Figure 18 suggests that trends in ICT capital intensity against GHG emission intensity might differ significantly for the Czech Republic, Slovenia, and Portugal in comparison to the rest of the countries in this study. The data points for the Czech Republic, Slovenia, and Portugal reside at the high end of GHG emissions per output and are clustered at the low end of ICT capital intensity levels. The data from these countries also seems to display incongruous or indefinable trends.[81]

[81] Italy, in contrast, exhibits abnormally high levels of ICT capital intensity, but GHG emission intensity levels are approximately average. Italy seems not to be a "trend outlier" and thus can reasonably be included in the sample, under the assumption that the high levels of ICT for Italy are not indicative of different measuring or reporting techniques that would affect the results of the regressions. Furthermore, excluding Italy from the regression does not change the significance or direction of the estimated effects.

As in other sectors, we observe a seemingly "split" data set, in which a group of countries exhibits one trend and the other group of countries exhibits another. As mentioned in the metal section, varied data could possibly be explained by EU member status. The Czech Republic and Slovenia are new EU member states, at earlier stage of integration and normalisation with the rest of the EU countries in the study, and could have different transportation sector structures. The clustered high levels of emissions in Portugal could be explained by its lower income level in comparison to other older EU member states. A lower level of national income could affect the quality and structure of the transportation services offered in the country. More basic transportation structures, for example, could interact differently with more ICT capital with regard to emissions.

Figure 18: Trends in ICT capital intensity and GHG emission intensity in the transport and storage sector



Source: EU KLEMS and EUROSTAT, 2009.

As discussed in section 3.1.1, when trends across countries differ, the parametric regressions will not produce significant or meaningful results. In order to ensure that the inclusion of these countries in the regression estimation does not mask the true relationship between ICT capital intensity and emission intensity in older, higher-income EU member states, the regression was re-run on reduced data sets with different combinations of the Czech Republic, Slovenia, and Portugal data excluded. According to these additional estimations, the results regarding ICT in Table 19 seem to be dependent on Slovenia and/or the Czech Republic, with Portugal also strongly influencing the results regarding non-ICT capital.[82] Results of the estimation without all three countries are shown in Table 20.

82 Without just Slovenia and the Czech Republic, the weak significance on the positive log-linear and ICT quadratic trend in Table 19 is reduced to insignificance, the effect of non-ICT is positive and significant at 5% and R squared increases to 24%, 41%, and 25% in the three models. Without Portugal, the impact of non-ICT capital is weakly significant and *negative* in the linear and non-linear model, and the R squared increases to 28.5%, 46.3%, and 30.2% in the three models respectively.

Table 20: Results of the parametric analysis for the transport services sector (excluding the Czech Republic, Slovenia, and Portugal)

	Linear Model	Log-Linear Model	Non-Linear Model
Dependent variable: GHG emissions per output			
Independent variables:			
- Energy prices	+0.00019	-0.0477	-0.00043
- ICT capital intensity	-0.00029	-0.0406	-0.00240**
- ICT capital intensity, squared			+0.00836**
- Non-ICT capital intensity	-0.00003	+0.1277	+9.63e-06
- Time	-0.00001***	-0.0135***	-9.65e-06**
Model statistics:			
Significance of Whole Model	***	***	***
Hausman Test: Are there significant structural effects?	Yes *** (Random Effects)	Yes *** (Random Effects)	Yes *** (Random Effects)
R squared (within)	0.5333	0.5515	0.5582
Significance levels: * = 90%, ** = 95%, *** = 99%			

Source: DIW econ, 2009.

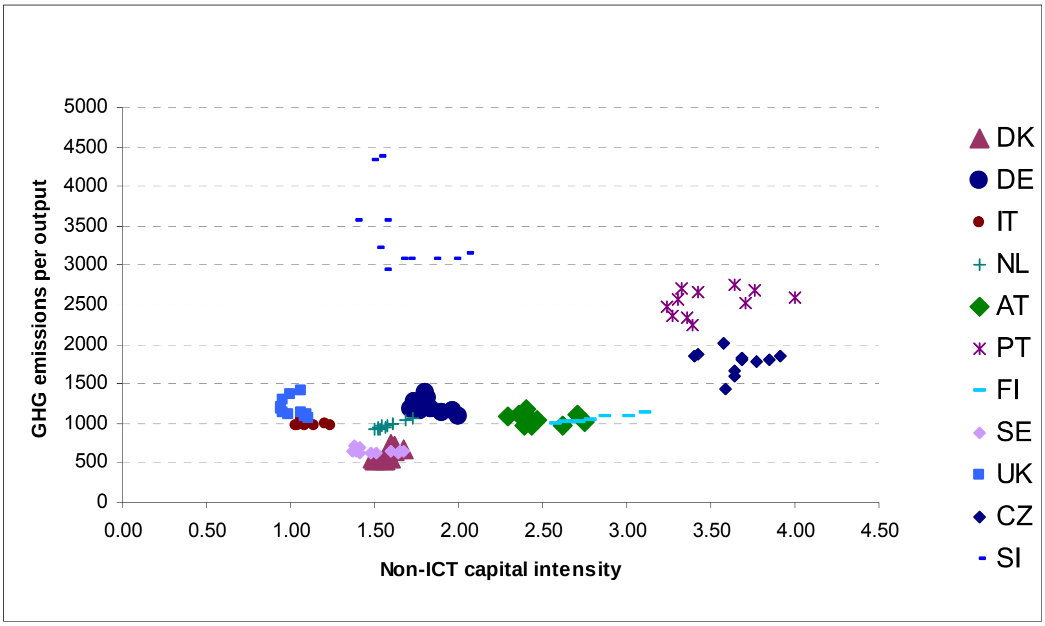
With the three new and low-income member states excluded, the effect of ICT is consistently negative across all models and achieves significance in the non-linear model (column 4) at the conventional 5% level. Notably, the R squared value for this model is more than 30 percentage points greater than corresponding R squared value for the estimations on the whole data set. This difference suggests that the variables in the model explain much more of the variance in GHG emissions per output in older, higher-income EU states that in new Eastern European ones. In higher-income, older EU member states in particular, emissions per output are found to decrease with increases in ICT capital intensity, but with significant diminishing marginal “emissions-reducing returns”. This relationship was also found to be significant in the metals sector, and in both sectors the turning point is beyond the range of the ICT capital intensity levels of most countries (calculated for the transport sector to be a ICT capital intensity level of 14.4%). Assertions about the effect of ICT on emissions beyond the turning point, therefore, are relatively speculative. The important observation is that within the group of older, higher income EU members, ICT has been emissions-reducing, with a decreasing marginal effect, at least from 1995 to 2005.

In addition to providing new insight into the relationship between ICT and emissions, this estimation confirms that structural effects are highly significant for emission intensity levels in the transport sector. The estimation also confirms that time-induced industry change has a tiny but significant effect that reduces emission intensity. The effect of energy prices is entirely insignificant and the direction is not robust to model specification or the size of the data set.

Based on the three models in Table 20, the effect of non-ICT capital also remains insignificant in the reduced data set estimation. As noted in section 3.1.1, however, the non-linear model was also estimated with a quadratic term for non-ICT capital in all sectors, providing for the possibility of different results regarding non-ICT. The results are not additionally informative for other sectors, so the model has not been displayed in the standard results table. However, the inclusion of a quadratic term for non-ICT in the reduced data-set estimation produces significantly different results that are worth noting. First, the significance of the emissions-reducing and non-linear effect of ICT actually improves.[83] The turning point in the relationship is still beyond the range of most data, confirming that ICT has been emissions-reducing in older EU states in the transport sector so far. Second, the new model now finds the relationship between non-ICT capital intensity and emissions per output to be an *inverted U-shape.* This shape has been observed in other econometric studies of emissions patterns, and is discussed further in section 2.4 of this study. Essentially, the inverted parabolic relationship suggests that more non-ICT capital per output increases emissions intensity up to a turning point, after which additional non-ICT capital actually decreases emissions per output. The turning point is estimated to be a non-ICT capital intensity level of 210%, which falls *within* the range of the data, as can be seen in the plot of GHG emission intensity levels and non-ICT capital intensity levels for the entire data set in Figure 19. This predicted ability of non-ICT capital to reduce emission intensity at higher levels is not found in any other sectors. For reference, the full results are included in Table 28 in Appendix II.

Lastly, it is important to note that the R-squared of this new non-linear model jumps to 0.6582 (compare to column 4 in Table 20). This R squared signals that a non-linear effect of both ICT and non-ICT capital intensity, along with time and structural effects, is a strong explanation of the variance of emissions per output in the transport sector – at least for older, higher-income European Union member states.

Figure 19: Trends in non-ICT capital intensity and GHG emission intensity in the transport and storage sector



Source: DIW econ, 2009.

[83] Both the main and quadratic effect of ICT capital intensity become significant at the 1% level, with coefficients of -0.0030 and .0096, respectively. With these coefficients, the turning point at which increased ICT capital begins to increase emissions per output is 15.6%.

The estimated effects of ICT on emissions for the two plausible models (in this case, the non-linear model which includes a non-linear term for ICT and the non-linear model which includes a non-linear term for both ICT and non-ICT) are summarised in Table 21 along with a variety of informative calculations. This table includes the same statistics as the summary table in the metal sector, except the two plausible models are different.

Table 21: Summary table of effects of ICT for the transport and storage sector

Summary Table of Estimated Effects of ICT	
	SI, CZ, and PT excluded
(a) % Change in emissions per output due to 1% increase in ICT capital intensity	
Non-linear model on ICT	-0.1580%
Non-linear model on ICT and non-ICT	-0.2022%
(b) Equivalent absolute *reduction* in GHG emissions from (a)	
Non-linear model on ICT	27,200 tonnes
Non-linear model on ICT and non-ICT	34,800 tonnes
(c) Cost in ICT fixed capital stock of a 1 tonne reduction in GHG emissions	
Non-linear model on ICT	537.30 €
Non-linear model on ICT and non-ICT	419.88 €

Source: DIW econ, 2009.

In the transport sector, for older and higher-income EU member states, a 1% increase in ICT capital intensity is estimated to decrease emissions per output by between 0.16% and 0.20%.[84] In absolute terms, this decrease in emissions intensity corresponds to a decrease in GHG emissions by 27,200 to 24,800 tonnes when gross output is held constant at average levels.[85] The expected "cost" in ICT capital stock required to produce a one tonne reduction in CO2 equivalent in the sector can also be calculated, resulting in an estimated 537 to 420 Euros per tonne.[86] As mentioned in section 3.2.1, this cost is to be used as a reference point for comparison rather than as an exact measure.

Across all metrics, these numbers overlap those calculated for the metal sector (see Table 7), which suggests some consistency regarding the marginal effects of ICT on emissions, irrespective of the absolute gross output, the emissions per output, or the ICT capital stock of the particular energy-intensive sector. As in the metal sector, we also note that these prices per tonne for CO2 are well below market prices. However, additional savings generated from ICT-generated efficiency boosts (including reduced energy consumption) can still make this investment worthwhile for the firm. The following semi-parametric analysis tests the relationship between ICT and efficiency, providing the necessary context for these parametric regression results.

84 These values were calculated off the mean ICT capital intensity level of 3.25% for the data set excluding Slovenia, the Czech Republic, and Portugal.

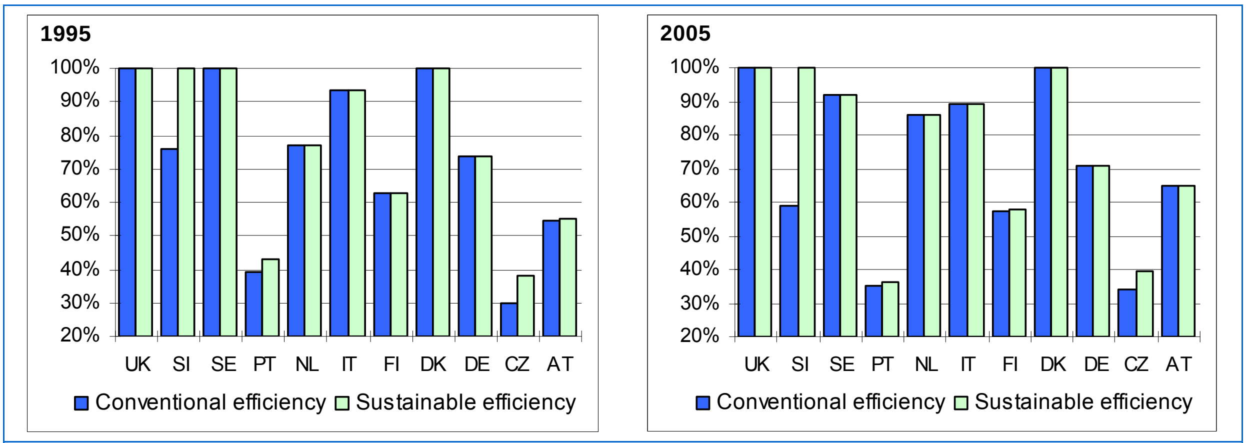
85 These values were calculated off the mean of 44959.49 million Euro (1995 prices) gross output for the data set excluding Slovenia, the Czech Republic, and Portugal.

86 These values were calculated as the absolute change in ICT capital stock that corresponds to a 1% increase in ICT capital intensity off the mean (holding gross output constant), divided by the corresponding absolute change in GHG emissions that is calculated in (b) in Table 21.

Semi-parametric analysis

The semi-parametric analysis as used for all sectors analyses the impact of ICT capital per total capital on different measures of conventional and sustainable efficiency in the European transport sector. Conventional efficiency scores the ability of the sector in a given country to maximize outputs with given inputs, or to minimize inputs with given outputs. Sustainable efficiency includes GHG emissions in the efficiency scoring process, as either an additional (undesirable) output or as an additional input. The calculated efficiency measures for the transport sector are depicted in Figure 20.

Figure 20: Conventional and sustainable efficiency (output-oriented) in the transport and storage sector in 1995 and 2005



Source: DIW econ, 2009.

In 1995, the United Kingdom (UK), Sweden (SE) and Denmark (DK) are fully efficient regarding both conventional and sustainable measures. Slovenia (SI) is also fully efficient with regards to the sustainable measure, and Italy (IT) achives efficiency scores of over 90% according to both measures. In 2005, the distribution of efficiency scores is similar. The UK and Denmark still define the efficiency frontier for both conventional and sustainable efficiency. Sweden drops off the frontier but remains above 90% efficient in both measures. Slovenia still only reaches full efficiency with regard to the sustainable definition, and Italy has dropped in efficiency relative to its peers to barely reach a 90% level. In addition, an analysis of efficiency scores over the full sample period indicates that total productivity has remained largely unchanged for both, the conventional and sustainable efficiency frontier.

Using the calculated efficiency scores, the effect of ICT capital share on efficiency in the transport sector is estimated. The results are displayed in Table 22.

Table 22: Results of the semi-parametric analysis for the transport and storage sector

Dependent variable: Efficiency score		
Independent variable: ICT capital share		
	Conventional efficiency	**Sustainable efficiency**
Output-oriented efficiency:		
Marginal effect of ICT capital share	1.85***	1.24***
Significance of the whole model	***	***
Input-oriented efficiency		
Marginal effect of ICT capital share	1.85***	1.72***
Significance of the whole model	***	***
Significance levels: * = 90%, ** = 95%, *** = 99%		

Source: DIW econ, 2009.

The results of the regression suggest a highly significant positive impact of ICT capital share on conventional as well as on sustainable efficiency, at a greater than one-to-one ratio. In other words, the higher the ICT capital share, the more efficient the production in the transport sector within the entire sample of eleven European countries. The effect of increased ICT on conventional efficiency can be interpreted as follows: a one percentage point increase in ICT capital stock out of total capital allows either output to be increased by 1.85 percentage points, at given input levels, or allows inputs to be decreased by 1.85 percentage points, at given output levels.

With regard to sustainable efficiency, a one percentage point increase in ICT capital relative to total capital in the transport sector is estimated to allow an increase in gross output at constant emission levels, using the same inputs (the output-oriented measure), or a decrease in emissions at constant output levels (the input-oriented measure). These changes are represented by an increase in sustainable efficiency by 1.24 percentage points and 1.72 percentage points, respectively. Both changes can be translated into absolute terms, with a one percentage point increase in ICT capital intensity estimated to allow a 748 million Euro increase in gross output or a 1.19 million tonne decrease in emissions in a given year for the average sector, ceteris paribus.[87] When this decrease in emissions is also translated into a cost measure of the ICT capital necessary to reduce emissions, the cost is 642 Euros per tonne. This figure is similar to those calculated using the parametric regression data (see Table 21), confirming the magnitude of the expenditure on ICT capital stock that corresponds to a one tonne decrease in emissions in the transport sector. Although the market price for emissions in Euros may be much lower, the results from the semi-parametric regression regarding conventional efficiency confirm that such ICT expenditure brings additional revenue with the same value of inputs and/or cost savings at the same output level.

Key findings

Together, the semi-parametric and parametric analyses demonstrate that ICT capital can improve the sustainability of the transport sector. However, not all results are consistent across in sector in all European countries.

[87] These values were calculated off a mean ICT capital share of 0.051, a mean gross output level of 46277.43 million Euro (1995 prices), and average efficiency levels across all countries and periods.

When parametric regressions are employed in order to model and quantify the relationship between ICT capital intensity and GHG emissions per output within a country over time, the results are informative but not conclusive for all countries. Only when the newest and lowest income member states are excluded, do the parametric estimations produce significant results.For older and higher-income EU member states, greater ICT capital intensity is found to reduce emission intensity in the transport sector. This influence of ICT capital is expected to have diminishing returns, but ICT capital has been purely emissions-reducing for the vast majority of analysed countries over the entire sample period.

The emissions-reducing effect of ICT is robust for old EU member states even when non-ICT capital is found to also significantly contribute to an economic explanation of the changes in sector emissions per output. Using the results from non-linear models of the relationship between ICT capital, non-ICT capital, and emissions per output in the transport sector, a 1% increase in ICT capital intensity is estimated to decrease emissions per output by between 0.16% and 0.20%. This corresponds to a decrease in GHG emissions by 27,200 to 24,800 tonnes when gross output is held constant at average levels. The expected “cost” in ICT capital stock is estimated to be 537 to 420 Euros per tonne. While higher than market prices for a tonne of CO2, other efficiency benefits from increased ICT capital stock do not mean that achieving reductions in emissions in the transport sector through ICT innovation will be cost prohibitive.

Newer and lower-income member states may also find ICT to be emission-reducing, but at higher levels of ICT capital to gross output that have not yet been reached in the sector. The effect of non-ICT capital in these states cannot be concluded.

When looking at a different relative measure of ICT – ICT share in total capital as opposed to ICT relative to gross output – ICT is found to significantly improve efficiency for the transport sector in EU member states regardless of member status or national income. The impact of ICT capital share on conventional efficiency measures is significant, suggesting that a one percentage point increase in ICT capital relative to total capital allows the expansion of gross output at given inputs or the reduction of input at given output values, with efficiency levels increasing by 1.85 percentage points.

The impact of ICT capital share on sustainable efficiency measures is also significant. Alternately, a one percentage point increase in ICT capital share is estimated to allow an increase in sustainable efficiency by between 1.24 and 1.72 percentage points. The change depends on how sustainable efficiency is defined: either an increase in gross output, *without increasing emissions* or intputs, or a decrease in emissions at constant ouput. The magnitude of the change in gross output that corresponds to the former definition of sustainable efficieny is estimated to be 748 million Euros. The latter definition indicates that a one percentage point increase in increase in ICT capital relative to total capital is estimated to allow a decrease in emissions by 1.19 million tonnes for the average sector, ceteris paribus. Using these semi-parametric results, the “cost in ICT” per one tonne of CO2 equivalent is calculated to be 642.43 Euros, which is relatively consistent with the same calculation made using results from the parametric regression.

When the quality of capital is improved with more ICT stock, improvements in efficiency – both conventional and sustainable – in the transport sector are found for all countries. The striking changes result when newer and lower-income EU member states are excluded from the parametric analysis, however, suggests that ICT capital cannot be treated equally with regard to emission intensity in all European countries. In the interest of finding results that can be credibly extended to a unified Europe, differences in the structure of the transport sector and patterns of ICT use in new and older member states, or in high and low-income member states, should be further examined.

3.3 Summary of key findings

As the results for the analysed sectors in section 3.2 demonstrate, the relationship between ICT and greenhouse gas emissions in European energy-intensive industries is not straightforward. This section aims to synthesise and summarise the main findings of the semi-parametric and parametric analyses, and the central conclusions that can be drawn.

- **Structural differences and structural change limit the scope of meaningful analysis with available data**

With different production processes and different trends in capital investment and emissions in each sector, it was clear from the beginning that each energy-intensive sector should best be studied separately. Further structural differences within the five sectors –especially between old and new EU member states– force conclusions based on econometric methods to be narrowed to particular sets of countries in most sectors. In the paper sector, differences in output composition within the sector and a lack of detailed data make it impossible to draw any robust conclusions. With limited data availability (or a lack of consistency and unobserved differences across countries and sectors), the chance of discovering robust effects of ICT on emissions was limited from the outset of the econometric analysis. Despite analytical challenges, however, the combination of two different econometric approaches within the empirical analysis *does* reveal certain promising, yet limited, avenues in which ICT can improve the sustainability of European energy-intensive sectors.

- **Greater share of ICT capital in total capital contributes to sustainable industry development**

Setting aside the paper sector, the semi-parametric analysis (see section 3.1.2) consistently finds ICT to have a positive impact on our measure of "output-oriented" sustainable efficiency in European energy-intensive industries. In other words, ICT is helpful to allow the increase of output at constant emission levels. Across four industries, a one-percentage-point-increase in ICT capital share (e.g., fixed ICT capital stock increases from 2% to 3% of total capital) is estimated to increase sustainable efficiency by between 0.79 and 2.64 percentage points. Row (a) in Table 23 summarises these results, which indicate that ICT has a more than one-to-one impact on efficiency in most energy-intensive sectors. Again, excluding the paper industry, the effect of ICT on sustainable efficiency can be quantified. As row (b) in Table 23 shows, a one-percentage-point-increase in ICT capital share can help industry increase gross output – at constant levels of emissions and capital and labour inputs – by between 280 and 1370 million Euros. This analysis demonstrates that the *quality* of total capital is important for the sustainable production growth of energy-intensive sectors in Europe.

For the metal and transport sectors, the effect of ICT capital share on a different measure of sustainable efficiency –the ability of the sector to reduce emissions at given output levels– was also found to be significant. We quantify the effect of a-one-percentage-point increase in ICT capital, in this case, as equivalent to a 0.13 million tonne reduction in emissions in the metal sector and a 1.2 million tonne reduction in emissions in the transport and storage sector. In these two sectors, shifts in overall capital composition from non-ICT to ICT-based capital would allow the sector to reduce the carbon-intensity of current production and actually reduce environmental degredation rather than simply expanding production with the same environmental impact. These two measures combine to provide strong evidence that ICT furthers the sustainability of these two sectors, even with given production processes.

Table 23: Summary table of effects of ICT in European energy-intensive industries

Basic Metal and Fabricated Metal	**Chemicals, Rubber, Plastic and Coke**	**Glass, Cement, and Ceramic**	**Transport and Storage**
(a) *Increase* in sustainable efficiency due to a 1 percentage pt. increase in ICT capital share			
0.79 to 0.89 percentage pts.	2.64 percentage pts.	2.58 percentage pts.	1.24 to 1.72 percentage pts.
(b) Equivalent *increase* in gross output *without additional increase in emissions (1995 Euros)*			
330 million €	1370 million €	280 million €	750 million €
(c) Equivalent absolute *reduction* in GHG emissions *at constant output levels*			
0.13 million tonnes	°°°	°°°	1.2 million tonnes
(d) % Change in emissions per output due to 1% increase in ICT capital intensity			
-0.18% to -0.52%	-0.12%°°	°°°	-0.15% to -0.20%°
(e) Equivalent absolute *reduction* in GHG emissions			
26,400 to 74,000 tonnes	15,000 tonnes°°	°°°	27,200 to 34,800 tonnes
(f) Cost in ICT fixed capital stock of a 1 tonne *reduction* in GHG emissions *(1995 Euros)*			
170€ to 440 €	1,350 € °°	°°°	420 € to 540 €

Notes:

- ° = only applies to old EU member states
- °° = not robust to exclusion of certain countries from the data set
- °°° = results not reported for lack of significance or interpretability

Please see the methodology explanation in section 3.1 for the exact definitions of the variables referred to here. Sections 3.2.1 to 3.2.5 provide further details on the nuances of the interpretation of these effects, as well as other results that were less robust or informative. Section 3.2.3 explains why results from the paper sector are omitted.

Source: DIW econ, 2009.

The range of absolute measures in columns (b) and (c) is to be expected for two reasons. First, production processes across industries will naturally respond differently to changes in capital composition, with some processes being more flexible than others. Secondly, the way in which the efficiency scores are constructed means that the corresponding change in gross output or emissions must be calculated as a relative change off some reference value. The absolute changes reported in Table 23 are calculated off mean output values, which differ considerably across sectors. With a much greater average aggregate emissions level in the transport sector, for example, the greater estimated change in absolute GHG terms in relation to the metal sector is further magnified. The elasticity of gross output and emissions will also naturally change over time, as mean values grow or shrink. In addition, as mentioned at the beginning of this chapter, the use of an aggregated ICT capital stock measure in general means that the quantification of estimated effects will be slightly biased. The measure may capture some ICT that has no use for sustainability, and in turn not all ICT capital stock value with an emissions-reducing potential is included. With these points in mind, the estimated numbers in Table 23 are best used as heuristics for planning purposes rather than as exact figures.

- **Greater intensity of ICT capital in production processes can reduce emissions per output, but the magnitude of the impact on emissions changes with levels of output and ICT capital stock**

When we investigate the form and magnitude of the effect of ICT on greenhouse gas emissions directly (i.e. when we use the parametric approach, see section 3.1.1), the two sectors that reveal the largest scope of efficiency changes as a result of a greater emphasis on ICT capital –the metal and paper sectors– are the same sectors in which ICT delivers the greatest and most significant impact on emissions per output. When the five energy-intensive sectors are viewed as a whole, the effect of ICT on emissions per output is still promising, but not always concretely identified. The quantified impact differs depending on the group of countries treated in the analysis and, of course, on the sector. When ICT has a significant effect on emissions per output, however, it is almost always beneficial.

The impact of ICT is most clearly identified in the metal sector. In this sector, an increase in ICT capital per output is estimated to reduce emissions per output by slightly less than a one-to-one ratio *for all European countries analysed*. At average levels, a 1% increase in ICT capital intensity is specifically estimated to reduce GHG emissions per output by between 0.18% and 0.52%, depending on the model used (row (d) in Table 23). In fact, two basic models of the relationship between ICT and emissions in the metals sector were found to be significant – a model that treats emissions as proportional to ICT capital (i.e. the log-linear model) and a model that simply views ICT to have a non-linear impact on emissions – both of which suggest that ICT is emissions-reducing significant *diminishing returns*. These two models also indicate, suggesting that while ICT has been consistently emissions-reducing over the sample period in the sector, the absolute reductions in emissions achieved by increases in ICT capital will dwindle over time.

In the transport sector, similar dynamics are evident. Increased ICT capital, both relative to total capital and to gross output, is estimated to decrease emissions per output *with diminishing impact*. However, the interpretation of these effects must be confined to older, higher-income EU member states, as results regarding the impact of ICT were inconclusive for the other sample countries.

In the other three energy-intensive sectors analysed, the results regarding the environmental impact of ICT obtained from the parametric regressions are much weaker and narrower in scope. In the chemical sector, we find a 1% increase in ICT capital intensity to reduce emissions per output by 0.12%, a magnitude comparable to the effects found in the metal and transport sectors. Unlike the metal and transport sectors, the relationship between ICT and emissions is assumed to be linear in the most significant model, preliminarily suggesting no boundary to the use of ICT capital for emissions reductions. However, this result is not robust to the exclusion of new Eastern European member states from the analysis. Thus, while ICT may yet be emissions-reducing across the aggregate European chemical sector, the effect of increased ICT capital is likely complex and non-linear and/or differs significantly between old and new member states. The parametric regressions for the GCC sector add no futher conclusions to the semi-parametric results. As for the paper sector, evaluation of the parametric results is not possible given the particular way in which the data is aggregated in the context of substantial sectoral changes over the sample period, as previously mentioned.

- **Changes in the ICT and non-ICT capital structure of the transport sector can particularly improve the climate impact of Europe's energy-intensive industries**

Simply from the observations of energy expenditude and emissions data trends in section 3.2.5, we know that the transport sector comprises the greatest share in total emissions in the eleven sample countries, out of the five energy-intensive industries. Furthermore, the sector has increased absolute emissions over the period, while in other sectors emissions have decreased. Econometric results confirm that increases in ICT capital stock in the transport sector are particularly important for reducing the aggregate emissions of European energy-intensive industries.

A comparison between the metal and transport sectors demonstrates that the effect of increasing ICT capital on absolute emissions –in the transport sector, in particular– depends on how ICT capital stock grows in relation to non-ICT stock. The absolute emissions reductions calculated in row (c) and row (e) of Table 23 are based upon two different ideas of how ICT capital stock changes. In row (c), value is moved from non-ICT capital to ICT capital stock, with total capital stock held constant. WIth these results, we see that an increase in ICT capital stock and a corresponding decrease in non-ICT capital stock reduces absolute emissions at given output. In row (e), ICT capital stock is increased relative to output with non-ICT capital stock held constant. These results suggest that increases in ICT capital stock ceteris paribus reduce emissions per output.

When capital composition shifts toward ICT but total stock remains constant (row (c)), the impact on emissions at constant output is greater in the transport sector than in the metal sector. When non-ICT capital is not reduced with an increase in ICT capital stock (row (e)), the emissions reduction in the transport sector is estimated to be on average smaller and more expensive. This switch in relative impact is explained by a difference in the effect of non-ICT capital on emissions in the two sectors. Non-ICT capital is significantly emissions-increasing[88] in the transport sector but not in the metal sector. Simultaneously decreasing the non-ICT capital stock necessary for production, therefore, boosts the emissions-reducing effectiveness of augmented ICT stock in the transport sector.

The emissions-reducing impact of increasing the share of ICT capital in total capital is, by far, most pronounced in the transport sector, given historical average output and emissions levels. Furthermore, we recall that the impact of greater ICT capital per output on emissions is only conclusive for older member states, and the excluded countries[89] are particularly large contributors to the aggregate emissions of the sector. With these results in mind, it seems that increasing the share of ICT stock in total capital is an effective way to reduce GHG emissions of the European transport sector.

[88] At higher levels of non-ICT capital per output, the dynamics of the effect of non-ICT capital on emissions per output change significantly. Please see section 3.2.5 for details.

[89] In this sector, the Czech Republic, Slovenia, and Portugal are excluded from the sample.

4 Case studies

The econometric analyses provide a means of statistically analysing the effect of ICT capital on GHG emission intensity and efficiency in energy-intensive industries, performed on data from 1995 to 2005, which provides a representative period in which ICT capital stock grew considerably in each sector. Details about the use of ICT capital stock in each sector, both during the analysed period and more recently – reasons for ICT investment, area of implementation in the production process, expected results – are further revealed through the eight case studies in this chapter. These studies cover the use of ICT for production engineering, energy use optimisation, and even emission monitoring programmes. They highlight two distinct avenues through which ICT can influence sustainability in European energy-intensive industries: first, measurement and decision-support, and second, process optimisation.

Case study overview

The first case study, **Siemens**' Energy Optimization Services, illustrates the operations of a leading supplier of energy efficiency equipment and services for firms in all sectors studied. Based on ICT-enabled energy management and control systems, as well as on specific optimisaton tools, Siemens helps its customers increase awareness of energy efficiency matters, realise the potential of various optimisation measures, and finally, reduce energy consumption and GHG emissions by 10-20% on average.

Case 2: **Deutsche Post World Net** develops and implements Intelligent Transport and Carbon-Accounting Systems to fullfill its commitment to reduce greenhouse gas emissions by 30% by 2020. The Intelligent Transport System helps Deutsche Post reduce fuel consumption and GHG emissions during delivery trips. The Carbon-Accounting System enables the company to monitor the emissions generated by internal and external projects and to offer customers the possibility of offsetting emissions caused by their orders.

Case 3: **Corus Rail**, a French metal producer, has managed to reduce its energy consumption by 11% and the number of defects due to the uneven heating in its furnaces by more than 10% during the last four years by using several ICT-based systems.

Case 4: **Due Torri**, a small Italian logistic company, has successfully developed its own software to conduct shipping orders more efficiently and to reduce its fuel consumption and GHG emissions by about 25%.

Case 5: The Danish **A.P. Moller – Maersk Group** improves energy efficiency of its shipping operation. In particular, the company uses ICT-based systems to reduce energy consumption of its cool reefers and to enable vessels' crews to choose fuel-efficient routes and propeller revolution speeds.

Case 6: The Swedish firm **Eka Chemicals** has managed to reduce energy consumption by using an ICT-based monitoring system. This system benchmarks current consumption levels to that of previous periods and offers solutions for reducing consumption levels once they exceed their benchmark levels.

Case 7: **Solvay**, a Belgium procer of pharmaceuticals, chemicals and plastics, reports that the potential to increase energy efficiency in its current production processes has been largely realised. While ICT has helped to increase energy efficiency over the past

20 years, additional contributions are declining and the firm worries about the impact of additional regulations on GHG emissions on its competitiveness.

Case 8: **Oracle**'s Transport Management system has helped one of its users, Kraft foods, to optimise route planing for compex shipping orders.

Table 24: Case studies and business examples evaluated

Case	Company	Sector	Country	Topic(s)
1	Siemens	All five	Germany / Europe	Leading supplier of ICT-enabled energy efficiency equipment and services for firms in all five sectors
2	Deutsche Post World Net	Transportation	Germany / global	Large logistics operator with ICT-enabled *Intelligent Transport System* and *Carbon-Accounting* scheme
3	Corus Rail	Metal industry	France	Rail manufactuer with ICT-based systems that increase energy efficiency during steel processing
4	Due Torri	Transportation	Italy	Small logistics operator with self-developed logistics software that optimises shipping orders
5	A.P. Moller – Maersk	Transportation	Denmark	World's largest liner shipping company that has implemented ICT-enabled initiatives to reduce energy consumption
6	Eka Chemicals	Chemical industry	Sweden	Use of an ICT-based Production Information System to monitor and analyse energy consumption
7	Solvay	Chemical industry	Belgium	Demonstrated potential for ICT-enabled optimisation over the past 20 years.
8	Oracle	Transportation	USA	Implemented Oracle Transport Management System to optimise logistics of a globally-operating food producer

Case study key findings

Each of the eight case studies conveys the clear message that ICT systems can be used to reduce emissions, either through energy management systems, process optimisation, or emissions management systems. Each company has a different take on prospects for current and new ICT systems, depending on its stage of ICT adoption and its subsectoral market, but certain projections of GHG reductions are notable. Siemens, a supplier of energy optimisation analysis and technology, expects chemical companies in general to achieve a reduction of about 20%; the cases of Eka Chemicals and Solvay in this industry, however, indicate a reduction of 1-2% per year and argue that major ICT-based efficiency gains have been already made. For the paper and steel industries, Siemens expects that GHG emissions can be reduced by 10%. Corus Rail (metal industry) reports a reduction of GHG emissions by 14% between 2006 and 2008 at one plant, but sees this as atypically high relative to other plants in its company group, Tata Steel. Lastly, the transport industry reveals a high potential for ICT today. Due Torri, a small logistics company, decreased CO_2 emissions by 25% on certain delivery routes and Maersk Line, the world's leading liner shipping company, reduced emissions through ICT-supported route planning by 1% (121,000 tonnes) in 2008. Companies like Deutsche Post Worldnet and Maersk are also currently working on improving their ICT based systems in order to reduce GHG emissions, indicating a remaining high potential for ICT in the future.

4.1 Siemens' energy optimisation services

Abstract

Siemens, a German-based supplier of equipment for industry, energy and healthcare, offers an integrated approach to increase energy efficiency and decrease greenhouse gas emissions. ICT is used to assess awareness of energy efficiency matters based on interviews conducted with the help of the software "One-2-Five Energy". Furthermore, ICT in the form of the standard Microsoft Excel software is used to calculate the impacts of different production optimisation measures. An ICT-enabled knowledge management system amasses information on comparable optimisation measures implemented in plants worldwide. Finally, a newly introduced ICT application in production has led to an increase in energy efficiency and a decrease in greenhouse gas emissions of 10-20%. Siemens emphasises that industry consciousness of sustainable production is a recent development and is often driven by marketing purposes. The Emissions Trading Scheme, for example, is not perceived by Siemens to have had a significant impact on attention to sustainable production among its clients.

Case study fact sheet

■ *Full name of the company:*	*Siemens AG*
■ *Location (HQ / main branches):*	*HQ: Berlin, Munich, Germany; Branches worldwide*
■ *Main business activity:*	*Equipment producer for Industry, Energy, Healthcare*
■ *Year of foundation:*	*1847*
■ *Number of employees:*	*400,000*
■ *Turnover in last financial year:*	*77.3 billion Euros*
■ *Primary customers:*	*Enterprises within Industry, Energy, Healthcare*
■ *Most significant geographic market:*	*Worldwide*
■ *Main ICT applications studied:*	*Energy optimisation*
■ *Case contact person(s):*	*Claus Blankert, Head of CoC Industrial Energy and Environment Management*

Company background

Siemens is a German supplier of equipment and systems and divides its operations among the Industry, Energy and Healthcare sectors. Moreover, Siemens offers IT-solutions to cross-sector businesses regarding equity investments and cross-sector synergies. With about 400,000 employees worldwide and a turnover of 77.3 billion Euros in 2008, Siemens is one of the leading companies in its field. Additionally, the company is number two in regards to patent holdings in Germany, number three in Europe and number eleven in the USA. These numerous patents highlight Siemens' commitment to innovation.

Siemens offers energy services in its product range. Through an integrated approach of analysing energy efficiency, planning specific implementation concepts for production sites and modernising plants with the help of its own products and external suppliers, Siemens occupies an exceptional role in the field of energy consultancy. While there are numerous firms that provide energy consultancy services based on the pure assessment of the potential of new technology, Siemens is one of the few that can provide this new technology itself. Siemens operates in a niche and barely faces competition.

Siemens has provided energy-related services since the late 1990s. The demand for such services in most industries was previously lacking, with the steel and paper industry being the exceptions – the first to demand Siemens' services. This situation has changed within the last three years, and other industries such as chemicals, food and beverages have increased their demand. Nevertheless, environmentally-friendly approaches are still often used only for marketing purposes, especially by producers of consumer goods, rather than to achieve better production sustainability. According to Siemens, the introduction of the Emission Trading System (ETS) has not yet induced a significant change in demand for its services in this field.

Use of ICT to reduce energy consumption / GHG emissions

The energy optimisation services offered by Siemens are based on two different processes. The first step is the "Energy Health Check", followed by the second step: the actual "Energy Optimisation Service". Both services can be purchased separately; about 40% of the customers only use the "Energy Health Check".

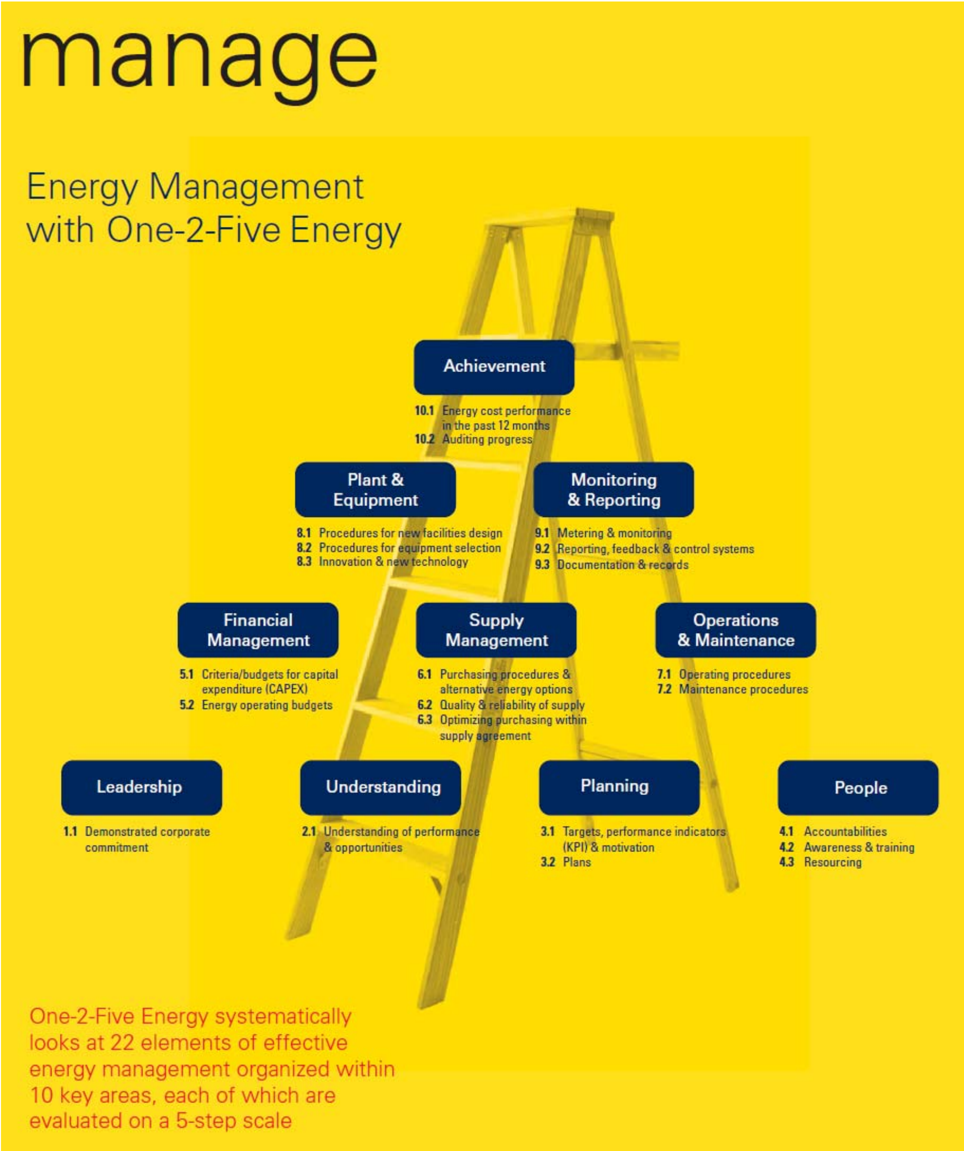
"Energy Health Check"

The "Energy Health Check" consists of a computer-based interview, conducted by an experienced and certified auditor, lasting 2-4 hours, depending on the involvement in sustainable practices. During the interview, representatives from different areas of the company such as senior managers, plant managers, facilities and/or maintenance managers, chief financial officers, and environmental and/or energy managers respond to simple yes or no questions in a standardised questionnaire. The questions, in turn, represent 10 key areas that break down to 22 elements as displayed in Figure 21. These areas cover not only the production of a firm, but also awareness and attitude towards sustainability.

Both the questionnaire survey and the analysis are conducted with support of the software "One-2-Five Energy", which is provided by Envinta, a US-based developer of energy and environmental products and services. A final report is generated based on the company's answers. This report shows overall performance in terms of energy efficiency, as well as the level of development for each of the 22 categories. In addition, a database in "One-2-Five Energy" that includes about 2,100 firms enables the auditor to benchmark the company in comparison to other firms in the same industry or country. Based on these results, specific recommendations can be provided on how to increase the company's energy efficiency, and first estimations of the annual savings potential from increased energy efficiency can be made.

According to Siemens, the results of such analyses show no significant differences across different (energy intensive) industries. However, there appear to be differences among regions. Northern and Western European firms typically perform much better with regard to energy management benchmarks. The USA has only recently caught up, according to the available data. Other regions, such as Asia, are still lagging behind. After having conducted the Energy Health Check, 40% of Siemens' client companies drop out for reasons such as a lack of potential, deciding to pursue other actions or simply inaction. The remaining 60% continue with Siemens' "Energy Optimisation Service".

Figure 21: Overview of Siemens' Energy Management System



Source: EnVINTA

"Energy Optimization Service"

The "Energy Optimization Service" is based on three phases: analysis, feasibility and implementation. In the first phase, a technical analysis takes place on-site to determine the specific possibilities of increasing energy efficiency. Within this analysis all forms of energy supply and distribution and energy data collection and archiving are reviewed. In addition to the optimisation potential, required investments are measured. In the second phase, economical and technical feasibility are assessed and measures of improvement are prioritised by the customer. The result of the second phase is a detailed technical and economic feasibility study, an overview of yearly energy savings and an implementation concept designed according to the customer's priorities. In the third and final step, the agreed measures are implemented with products from Siemens and external suppliers.

ICT is widely used within the "Energy Optimization Service". Standard spreadsheet calculation software such as Microsoft Excel is used to calculate the energy saving potential of various measures. Knowledge management systems are also used. This system enables the Siemens auditors to distribute information for similar applications and make use of best practice solutions. By making use of the experiences taken from numerous plants world wide, the auditing process and feasibility study yield better results and can be conducted faster. Further ICT applications that save a significant amount of energy directly are then implemented at the production site.

This "Energy Optimization Service" identifies various possibilities for saving energy, which are mostly industry-specific. The following examples, as discovered by Siemens through provision of the service, are illustrative:

- In the **metal** industry, energy can be saved by introducing ICT systems in production, such as in the rolling process of steel. During that process, the steel lies on several rollers driven by electric motors. ICT-based control techniques make it possible to turn off the rollers that have no contact with the steel at a given moment during the rolling process. As a consequence, there are fewer motors running, which saves energy.
- The **paper** industry can save energy in the production by turning off part of the production equipment as well. When a paper roller stops working during production, it must be fixed before production can be resumed. In the meantime, ICT can be used to power down the machines as necessary, which leads to energy savings.
- In the **logistics** industry, ICT is used to systematically monitor processes and quickly power down engines in case of a break in the conveyor machinery.
- **Chemical** and **glass or cement** producers can save energy with a load management system. ICT measures the loads and manages the demand, driving the system and helping to avoid using resources at peak demands.

Siemens emphasizes that the "Energy Optimization Service" must be a recurring process in order to produce the most optimal energy use reductions. The effect of the implemented measures needs to be evaluated and technological progress needs to be taken into account when a company is interested in constantly producing at the highest efficiency. As Siemens sees it, ICT applications such as the "Energy Health Check" are needed to provide an up-to-date benchmark of the current production characteristics and the awareness of sustainability issues in all processes.

The costs for such ICT-based services differ. The "Energy Health Check" is offered at a package price of 5,000 Euros, irrespective of the industry. The "Energy Optimisation Service" costs vary, however, depending on the customer's priorities. Optimisation costs can be understood through the amortisation period associated with optimisation initiatives, which also differs by industry. Siemens estimates an amortisation period of 2-3 years in the basic metals, paper, and glass and cement industries and a period of up to 4 years in the chemical industry. For comparison, amortisation periods in other industries like automotive manufacturing or food and beverages are typically only one year. Thus among a broad range of sectors, energy optimisation initiatives typically hold their value the longest in energy-intensive industries. The process of analysing, planning and implementing, however, can add additional costs. It takes about one year when the process flows smoothly, but can otherwise take about two years.

Impacts

In Siemens' experience with customers, energy-saving applications based on ICT can lead to significant reductions in energy consumption. On average, these applications can lead to an **energy use reduction of 10-20%.** However, reductions of up to 30% or down to less than 10% can occur, depending on project-specific conditions. Within this range, Siemens estimates that chemical companies typically reach a 20% decrease in energy use, whereas **paper or steel producers typically achieve smaller reductions** of about 10%. Interestingly, Siemens has not found significant differences in the energy use reductions achieved among firms of different sizes within a given industry.

Siemens' estimation of the possible **decrease in emissions is comparable to the size of the reduction in energy consumption** in a given sector. Hence, the largest emissions reductions are expected to be achieved in the chemicals industry, with (relatively) smaller reductions expected in the paper and steel industries. In the production of glass, Siemens notes that the energy use (and emissions) reduction potential is limited by further factors. Energy is most often used in its primary form, but companies in the glass and cement industry tend to concentrate on the side effects of production to save energy. Furthermore, for all industries, Siemens observes that information about reduced greenhouse gas emissions is sometimes used more for marketing purposes rather than to satisfy an internal demand for sustainability. This bias increases as the proximity to end-consumers increases. Lastly, no significant effect of the ETS on the demand for energy consumption information has been noticed by Siemens.

Some related effects of increased awareness of energy consumption are worth noting. Unsurprisingly, productivity rises and market shares can increase due to cost leadership induced by reductions in energy consumption. However, the size of the effect depends on the share of energy cost in production. Another positive effect can be an improvement in quality of products or services due to the implementation of certain production technologies that also induce reductions in energy consumption.

Lessons learned

Siemens' clients often realise after implementing the new system that they could have achieved many of the efficiency savings earlier. Siemens suggests that this late-coming revelation is linked to the fact that in some industries, the awareness of energy efficiency and sustainability has just developed within the last two to three years.

Regarding the optimisation process itself, the efficiency and sustainability awareness level of the particular management team in the client company is often crucial to the success of the new system. Participating decision-makers, who were not previously aware of the benefits of the new systems, tend to slow down implementation processes or even the use of a newly-implemented system.

Apart from internal factors, the extent to which the regulatory framework stimulates further advances in energy efficiency plays an important role. In Germany, for example, two specific laws[90] determine feed-in tariffs for electricity generated from combined heat and power plants or renewable energies. These laws directly influence the incentives for companies to implement such combined plants or new energy technologies as part of Siemens' energy optimisation system.

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[90] Kraft-Wärme-Kopplungsgesetz (KWKG) and Erneuerbare Energien Gesetz (EEG).

References

Research for this case study was conducted by Jano Costard, DIW econ. Sources and references used include desk research plus:

- Interviews with Claus Blankertz, Head of CoC Industrial Energy and Environment Management, Siemens AG
- Information from the brochure “SIMAIN Energy Optimization- for industry and infrastructure”.
- Websites: http://envinta.com/products.htm

4.2 Deutsche Post World Net’s Intelligent Transport System and Carbon-Accounting

Abstract

The Deutsche Post World Net is a world-leading logistics company, offering its services within the brands of Deutsche Post and DHL. Its commitment to sustainable development is characterised by a greenhouse gas emissions reduction target of 30% by 2020 based on the year 2007. This case study presents two elements that play an important role in the achievement of the goal. Deutsche Post World Net is currently implementing an Intelligent Transport System, called SmartTruck, aimed at reducing certain delivery characteristics such as kilometres per hour and the amount of stops per hour. One of the new elements is a permanent dialogue between vehicles and a central optimisation system that, among other things, takes current traffic data and new incoming orders into account, leading to a more efficient delivery process in terms of fuel consumption and greenhouse gas emissions. Furthermore, an ICT-based Carbon-Accounting scheme is in the implementation phase and will be finalised in 2010. The Carbon-Management system manages the production of carbon credits arising from internal and external projects and allows customers to offset the emissions caused by their deliveries. Finally, a high potential for ICT can be found in regards to the reduction of greenhouse gas emissions, especially in the SmartTruck project.

Case study fact sheet

■ *Full name of the company:*	*Deutsche Post World Net*
■ *Location (HQ / main branches):*	*Bonn, Germany*
■ *Main business activity:*	*Mail, Express, Global Forwarding/Freight*
■ *Year of foundation:*	*1995 (Privatisation)*
■ *Number of employees:*	*500,000*
■ *Revenue in last financial year:*	*€ 54,474 m*
■ *Primary customers:*	*Various customers worldwide*
■ *Most significant geographic market:*	*Worldwide*
■ *Main ICT applications studied:*	*Intelligent Transport System, Carbon-Accounting*
■ *Case contact person(s):*	*Dr. Winfried Häser, Vice President Environment Strategy and Policy;* *Boris Paul, Project Manager SmartTruck, DHL Innovation Center*

Company background

The Deutsche Post World Net offers integrated services and customised solutions for the processing and transport of goods and information on a global scale. It emerged when the federal authority “Deutsche Bundespost” was privatised in 1995 and offers its services now within the brands Deutsche Post and DHL. Deutsche Post transports mail within Germany and to more than 140 other countries around the globe. DHL provides courier and express services to businesses and private customers and reaches about 220 countries and territories. Moreover, Deutsche Post World Net carries goods by rail, road, air and sea and is the world’s largest air and ocean freight operator and one of the leading overland freight carriers in Europe. Their “Supply Chain/Corporate Information

Solutions” division is world-leading. It offers contract logistics, warehousing and ground-based transport services, among other services.

As the world’s largest provider of logistics, which is an energy-intensive industry, Deutsche Post World Net is aware of its environmental impact. It was the first global logistics company to set a clear CO_2 efficiency improvement target of 30% by 2020 and an interim target of 10% by 2012 based on the year 2007. To achieve these aims, different measures were introduced and new ones will be implemented in future. Among these systems are: the **SmartTruck** Project, which is an **Intelligent Transport System** (ITS), and a **Carbon-Accounting** scheme, which includes a **Carbon-Management** system. The latter two programmes improve management efficiency and the transparency of processes with regard to emissions. All initiatives make use of ICT.

Use of ICT to reduce energy consumption / GHG emissions

The **SmartTruck** technology aims to reduce greenhouse gas emissions by determining the most efficient route for delivery, saving fuel and reducing CO_2 emissions. The planning phase began in January 2008, and a pilot scheme in Berlin has been running since the beginning of 2009.

SmartTruck is not an entirely new approach. Deutsche Post World Net used route planning in their vehicles even before consumers used navigation systems in their cars. This legacy system enabled the company to reduce the average mileage per delivery district by more than 12% between December 2001 and December 2003, with the number of items delivered being only slightly lower. In addition, a further decrease of 2% in average mileage per delivery was realised between 2003 and 2006, at constant numbers of delivered items. This system has been improved further and is now able to consider prevailing traffic conditions and take into account new orders during the delivery process. The role of ICT in SmartTruck becomes clear by looking at the information flow that enables the dynamic route planning.

The planning of the work day’s routes starts in the night, even before the goods arrive at the shipment centre. Making use of foresighted delivery data, a central server calculates an initial planning of the day, including the allocation of parcels on vehicles and initial routes of the vehicles. Those routes can change daily due to varying delivery characteristics. These calculations are stopped 5 minutes prior to the sorting of parcels. Parcels are then sorted and loaded according to the optimised delivery model. In parallel, pick-ups are virtually planned and remain subject to optimisation for the whole day because of changing routes and new incoming orders. During the loading, the freight list is controlled by comparing it via RFID (Radio Frequency Identification) with the default from the initial optimisation. After leaving the shipment centre, the on-board unit guides the driver to his first calculated stop. Consequently, the route planning system is still running and optimising the route based on new data such as traffic or new pick-up deliveries. The management of pick-up and delivery itself takes the truck’s current position, determined by GPS (Global Positioning System), the routes of vehicles, vehicle capacity, and traffic data into account. All of this information is sent to a central computer system that then calculates new routes and provides the on-board units of the vehicle with the new route characteristics. All that leads to a constant dialogue between the vehicle and the central optimisation unit made possible only by ICT.

One of the new key elements is the use of current traffic data to optimise routes. For that purpose, data from more than 500 taxis are used in the pilot scheme in Berlin. Via the Floating Car Data System (FCD), location and speed of the taxis is revealed by GPS.

Figure 22: Elements of SmartTruck

Source: DHL Innovation Center

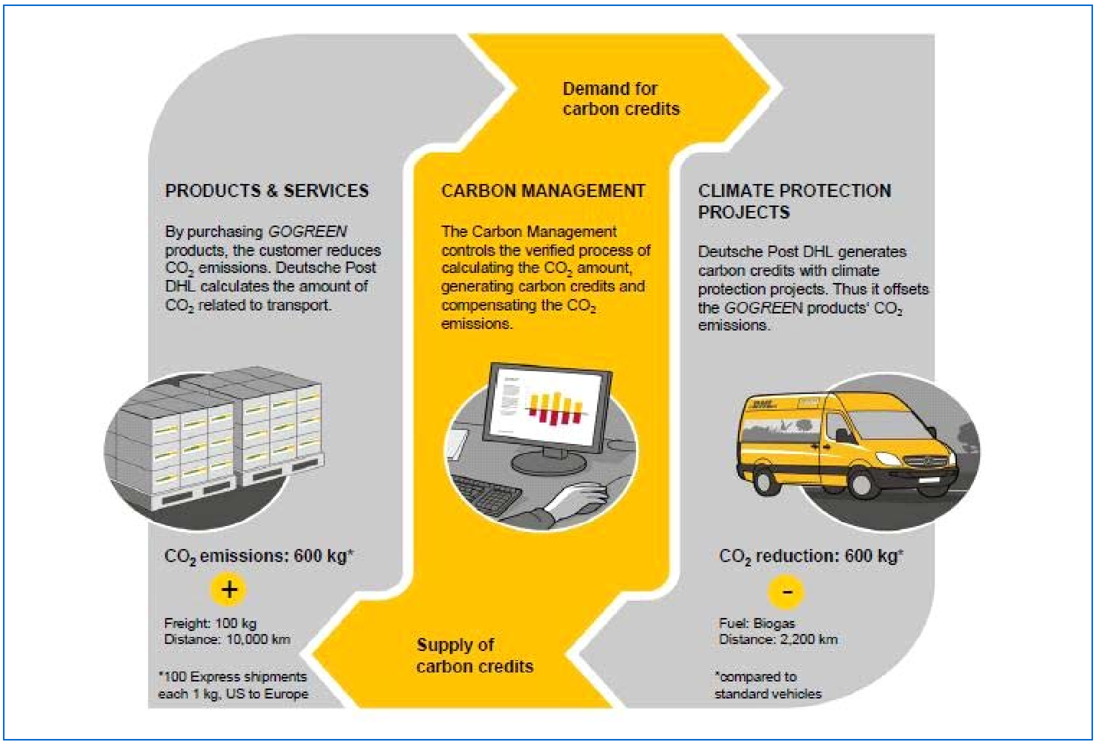
By comparing the actual data with historical means, the current traffic situation can be determined. Additionally, data about construction sites or demonstrations are added.

Many different companies were involved in planning and implementing the Smart Truck project since its start in the beginning of 2008. The main contributors were the German Aerospace Center (DLR), the Institute for Information Systems (IWi) at the German Research Center for Artificial Intelligence (DFKI), Motorola, a US-based telecommunications company, and Quintiq, a Dutch based IT-solutions provider. The DFKI provided the IT-architecture and system integration and the DLR provided the FCD and planning of the hardware. Motorola provided the on-board unit as well as the necessary software to run it and Quintiq provided the actual ICT-based optimisation model that calculates optimal routes.

In addition to the SmartTruck approach, which reduces greenhouse gas emissions directly, indirect measures are taken that support emission-reducing management decisions. Such a system, called **Carbon-Accounting**, is in the implementation phase and is expected to be finalised in 2010. Carbon-Accounting determines the CO_2 emissions in every enterprise process. By uncovering the CO_2 emissions for every business activity, a first step is taken to reduce the overall emission of greenhouse gases. The Carbon-Accounting system is based on the ICT-enabled Financial-Accounting system in use at Deutsche Post.

The Carbon-Accounting system is used for internal as well as external purposes. Within Deutsche Post World Net's management system, Carbon-Accounting provides information on current CO_2 emissions, which provide the basis for better management and strategic decisions with regard to Deutsche Post's reactions to climate change policy. This is especially important with regard to the introduction of a cost of emissions, which the Deutsche Post World Net expects in the near future. The management of emissions is thus used to prepare for future emission costs introduced by the political environment. Deutsche Post World Net is convinced that Carbon-Accounting is needed to accurately measure the reduction of greenhouse gas emissions and to evaluate achievements concerning emission-reduction targets, both for Deutsche Post itself and for Deutsche Post's customers.

Figure 23: Carbon Management



Source: DHL Innovation Center

In addition, Carbon-Accounting can be used to offer customers a “carbon footprint” of different products, offering them the chance to choose the product that best fits their preferences concerning emissions and other qualitative criteria. Customers can also use Deutsche Post’s carbon-footprint information when assessing their own individual carbon footprint. These multiple applications of one technology suggest that the implementation of ICT-based carbon-accounting systems can have a positive ripple effect across industries.

Within the Carbon-Accounting framework, another ICT based system helps to reduce greenhouse gas emissions. The **Carbon-Management** system is responsible for the accounting of carbon credits, monitoring the “GoGreen” production scheme, ensuring that the supply and demand of carbon credits is matched, and documenting when used credits are retired. The supply of carbon credits is supported by emission savings generated by Deutsche Post World Net or through projects that belong to the UN’s Clean Development Mechanism (CDM). Examples of internal savings are the use of alternative fuel vehicles (biogas), more efficient technologies like SmartTruck or the increased energy efficiency of buildings. Externally, projects like a hydroelectric power plant in Brazil and wind farms in North-Central and East China generate emissions savings.

Impacts

Although final results from the SmartTruck pilot scheme in Berlin are not yet available, Deutsche Post World Net characterizes the system as a significant improvement on other solutions in use today. SmartTruck reveals a strong potential for ICT to contribute to emission reductions, even though it is still in the pilot phase and it will take some time to finally spread to other German or European cities and even worldwide. Furthermore, the real-time dialogue between the vehicle and the central planning system offers a variety of opportunities for further technological development. Judging by Deutsche Post World

Net's example, ICT plays an important role in today's transport sector, and this role can increase with further innovation.

As stated above, the **Carbon-Accounting and Carbon-Management** systems used by Deutsche Post World Net do not directly reduce greenhouse gas emissions. However, they **enable reductions in emissions** through other schemes. For instance, the GoGreen scheme, managed by the Carbon-Management project, **increased the amount of offset CO_2** from over 1,000 tonnes in 2006 to more than 16,000 tonnes in 2008. This was achieved by delivering 5.5 million parcels and more than 100 million mail items using carbon-neutral options in 2008. Deutsche Post World Net's GoGreen is also used by other big companies within their environmental strategy. The Deutsche Post World Net's mail division's largest GoGreen client is the Allianz insurance group, for example.

Lessons learned

The case indicates that ICT has a high potential in the transport sector for reducing greenhouse gas emissions. This holds true for the SmartTruck project in particular as well as for the use of ITS in general. Furthermore, ICT used in accounting and managing emissions is important to illuminate the status quo in GHG emissions and to provide a solid basis for the functioning of concrete schemes to reduce greenhouse gas emissions. It is important to note that Carbon-Accounting is not limited to the transport industry, and can be used in any sector.

The political environment has an influence on the success of carbon-related measures within Deutsche Post World Net. For example, the SmartTruck project is supported by the German Federal Government and the Federal Ministry of Economics and Technology as part of the initiative "Intelligent logistics in goods and commercial transport - innovation offensive for tomorrow's markets". Despite the benefits from political support experienced by Deutsche Post World Net, the company contends that further support is needed. An important factor in the development of Carbon-Accounting schemes, for example, is suggested to be an agreement on accounting standards. According to Deutsche Post World Net, worldwide standards are needed in order to provide the industry with certain criteria and to make the results from Carbon-Accounting comparable between firms.

References

Research for this case study was conducted by Jano Costard, DIW econ. Sources and references used include desk research plus:

- Interviews with
  - Dr. Winfried Häser, Vice President Environment Strategy and Policy, Deutsche Post
  - Boris Paul, Project Manager SmartTruck, DHL Innovation Center
- Websites:
  - Website of the Deutsche Post DHL: http://www.dp-dhl.de
  - Website of the DHL Innovation Center: http://www.dhl-innovation.de

4.3 Corus Rail's approach to increase energy efficiency[91]

Abstract

This case study focuses on a plant in Hayange, France, operated by Corus Rail, which is part of the Corus Group and Tata Steel. The plant produces a wide range of rails for the French, European and world market. Among them are special rails for high speed tracks or urban transport. The production is characterised by the conversion of purchased blooms into rails. To increase energy efficiency in production, several ICT-based systems were applied to the process of reheating the blooms in a natural-gas-fired furnace. These systems include a database, which is used to document the optimal temperatures of the bloom and the furnace for different products, an automation package to ensure an optimal air to gas ratio for the furnace, and a computer system to optimise the temperature in different areas of the furnace. All measures together resulted in an 11% drop in energy consumption during the last four years and a decrease of more than 10% in the number of defects due to uneven heating of the blooms. Space for further improvement is limited and would involve a new furnace or major changes in the plant's physical structure.

Case study fact sheet

■ *Full name of the company:*	*Corus Rail*
■ *Location (HQ / main branches):*	*France and UK*
■ *Main business activity:*	*Production of Rails*
■ *Year of foundation:*	*1892*
■ *Number of employees:*	*440*
■ *Turnover in last financial year:*	*€ 250 m*
■ *Primary customers:*	*SNCF (French National Railway)*
■ *Most significant geographic market:*	*France, Europe, World*
■ *Main ICT applications studied:*	*Optimisation of production via ICT*
■ *Case contact person(s):*	*David Walker Project and Process Development Manager;* *Michel Parizel, QA and Environment Manager*

Company background

The Corus Rail plant in Hayange, France, is part of the Corus Group, Europe's second largest steel producer, based mainly in the UK and the Netherlands. The Corus Croup itself is part of Tata Steel, one of the world's largest steel producers.

Corus Rail produces rails and special rails, such as for high speed tracks or urban transport, in the Hayange plant. In that process, blooms of typically 254mm x 330mm in width, 5-8.5m in length, and about 5 tonnes in weight are purchased, reheated in one of two identical natural-gas-fired furnaces and rolled into rails.

300,000-320,000 tonnes are produced annually at the Hayange plant, making Corus one of the top tow rail producers in a group of six main suppliers in Europe. Corus' main competitors in terms of output as well as product range and quality include the Austrian-

[91] The case study and the case study fact sheet are based solely on the Corus Rail plant in Hayange, France.

based Voestalpine. The form of competition among companies varies. On the one hand, the home market is relatively easy to protect. Because the transportation of rails is rather expensive due to their size and the logistics are complicated, producers tend to have a cost advantage in their home market. Corus Rail's main customer in Europe is consistently the French National Railway (SNCF), for example, showing the strength of Corus Rail on its home market. On the other hand, there is quite fierce price competition on an international level. For example, Corus Rail faces competition by up to 20 other suppliers in South America. In light of strong international competition, it is not surprising that one third of Corus Rail's production is typically sold in France, another third is sold in the rest of Europe and the rest is sold in other parts of the world. Corus' share of customers in each country also varies. This is partly due to changes in exchange rates, which alter prices of the in- France produced rails and influence the competitiveness of Corus Rail in many non-Euro countries where dominating price competition dominates.

With price strong competition internationally, Corus Rail has taken considerable steps to reduce costs in the Hayange plant. With an annual spending of 5.5 million Euros for gas[92] and 3.0 million Euros for electricity in the last year, energy is one of the company's major costs. Within the last 5 years, studies were conducted and measures implemented to increase energy efficiency. Corus Rail sees ICT systems as integral to these measures.

Use of ICT to reduce energy consumption / GHG emissions

An important factor in the quality of the rail is the equal heating of the whole bloom, as well as equal temperatures within all reheated blooms. Furthermore, the temperature needs to be optimal for the rolling process. The bloom should not be too cold for rolling, but a temperature higher than needed causes higher energy use and thus greater greenhouse gas emissions and costs. ICT plays an important role in the heating and rolling process.

At the Hayange plant, a database is used to manage the different bloom and furnace temperatures. A detailed documentation of important production characteristics is conducted and provides a basis for current and reference-value comparisons. This leads to the detection of the optimal temperature of both bloom and furnace. In addition, this database makes it easy to manage temperatures for a variety of different kinds of rails and dimensions. The database is also used to manage several other operating figures in the production such as quality measures and other production parameters. The database has been used for this purpose since 2005 and was implemented by the internal IT-department. As techniques and products change, it is consequently adjusted.

Another important factor for efficient production is an optimal air to gas ratio in the furnace. Gas cannot be burned without sufficient oxygen, and with a lack of gas temperatures in the furnace will be lower. Therefore, the old and unstable flow transmitters were replaced with new ones to control and stabilise the air to gas ratio. This investment was complemented by an automation and regulation package created by the Swiss-based ABB, a producer of power and automation technology. With new transmitters, energy is saved due to the more exact measurement of operating figures and a better regulation of input factors air and gas.

In addition to the database and transmitters, another measure was taken to increase efficiency with regard to the furnace. CMI, a Belgium-based mechanical engineering and

[92] Including transport, excluding VAT.

plant construction firm, provided the new optimisation model created specifically for the Hayange furnace. This computer system replaced an old system and calculates the temperature in different zones of the furnaces. It makes it then possible to optimise the production by avoiding too high of temperatures in some zones, saving energy. Further, it achieves equal temperature along the bloom.

Both the new flow transmitters and the new optimisation and automation system were implemented as a total concept in 2008. The time to study the case, plan and approve the project and implement it exceeded 12 months and cost approximately 500,000 Euros. The renewal of flow transmitters and automation concerning the air to gas ratio, as well as the new optimisation model to regulate the temperature in different zones of the furnace, were a major investment for the plant and are planned to last for about 15 years, with slight modifications according to technological development.

The new system works very well today, especially due to the involvement of stakeholders such as production managers, engineers, the technical department and operators from the beginning. Since energy consumption is a very current topic in the Hayange plant, burdens for achieving awareness and acceptance for new measures were low. Another factor for success has been the training of employees with regard to the new systems. In that case, the operators and the rolling mill manager were not only trained at the plant, but received a more formal training on furnace efficiency by an external trainer.

Today, most improvements have already been implemented so that there is little room for further increases in energy efficiency. Next big steps would concern the physical structure of the plant such as the purchase of a new furnace, which would cost about 15-20 million Euros, or an enlargement of the production site to produce rails of 108m length, compared to a maximum of 80m today. This would not only lead to new products, especially for high speed tracks, but also to a more efficient production of shorter rails. The cost for that project would amount to approximately 35 million Euros.

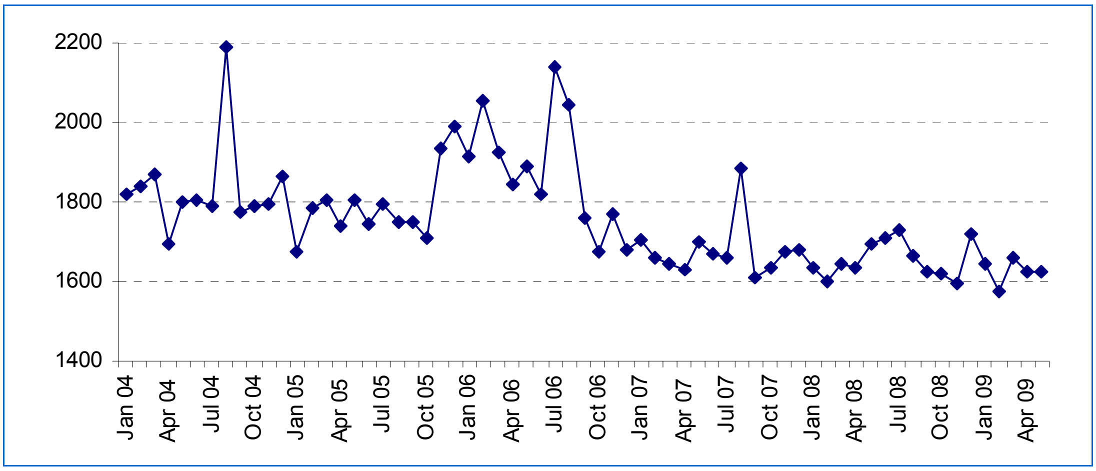
Impacts

The described measures, as well as a technical change in the waste heat recovery system, led to a **decrease of energy demand** by approximately 11% over the last four years. As Figure 24 shows, average energy use has fallen from 1800 MJ per tonne of output to 1600 MJ per tonne of output. The volatility in energy demand that is shown in the figure can be explained by the varying energy demands for different products and variation in plant loading. According to a benchmark within the Corus Group, the Hayange plant is among the world leaders in their sector with regard to energy efficiency, even though their furnace dates from 1972.

With regard to **CO_2 emissions**, a **reduction** of about 14% between 2006 and 2008 was achieved (see Figure 25). In absolute terms, the emissions of $C0_2$ per tonne of output fell from 110.5 kg per tonne in 2006 to 95.3 kg per tonne in 2008.

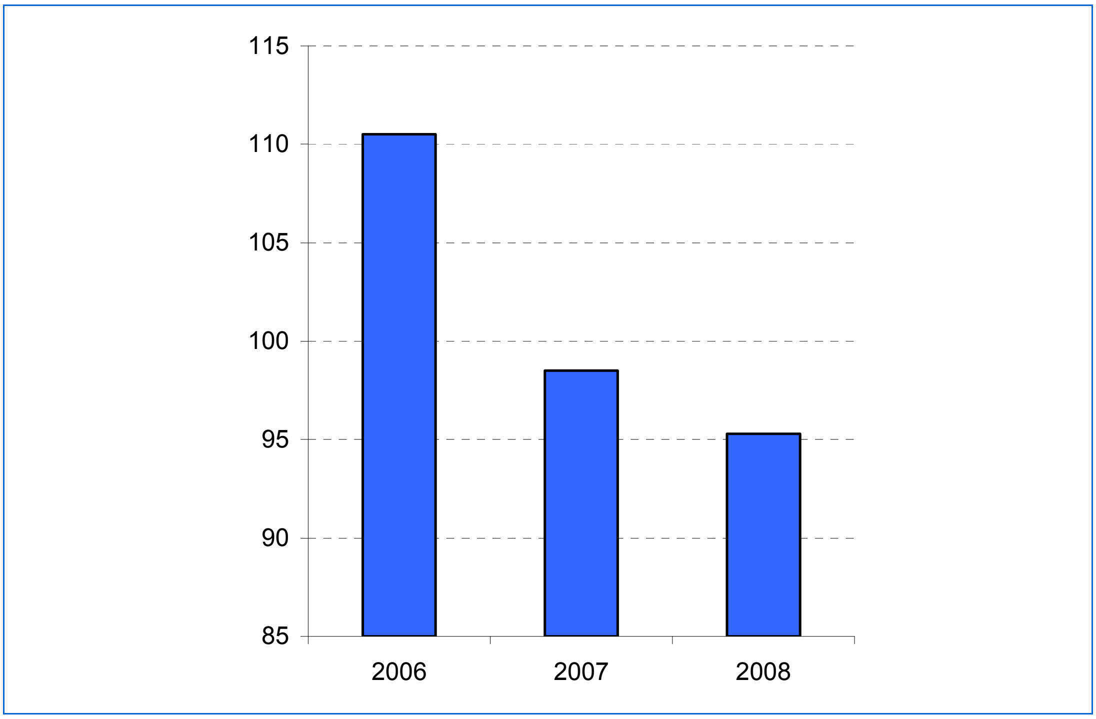
The cost-reducing measures have had no significant impact on indicators of business success such as turnover or market share. Turnover, for example, is far more driven by market demand, the applied strategy and the ability to find businesses. Nevertheless, positive product effects can be noticed. The improved control of temperatures along a bloom led to a **reduction of dimensional defects** of more than 10%. Therefore, the implemented measures have had no downsides and have been successful in reducing costs and greenhouse gas emissions, despite a lack of change in turnover or market share.

Figure 24: Monthly average energy consumption (MJ/t), Jan 2004-May 2009



Source: Corus Rail

Figure 25: Emitted kg CO2 per tonne Output (2006-2008)



Source: Corus Rail

Lessons learned

Concerning the planning and implementation process, no major obstacles arose when implementing the new system. At best, it could have been done earlier.

A crucial element of the planning and implementation process was the choice of accurate parameters for the optimisation model of furnace zone temperatures. This issue was addressed by having the old system run parallel, with the possibility to switch between the systems, until it was ensured that correct parameters where chosen.

A factor that has fostered the improvement in energy efficiency is the French research and development (R&D) aid "crédit d'impôt recherché", a scheme that offers the opportunity to credit R&D expenditure against a firm's tax liabilities.

Finally, ICT plays an important role for increasing energy efficiency and decreasing greenhouse gas emissions. Nevertheless, the improvements possible at the current level of technological development have almost been achieved. So, further improvements need to be backed by further innovations in ICT or new non-ICT capital such as a new furnace.

References

Research for this case study was conducted by Jano Costard, DIW econ. Sources and references used include desk research plus:

- Interviews with
  - David Walker, Project and Process Development Manager, Corus Rail
  - Michel Parizel, QA and Environment Manager, Corus Rail
- Information from: Corus Rail Products- Technical Handbook.
- Websites:
  - Website of Corus Rail: http://www.corusrail.com/en/

4.4 Self developed logistic software of Due Torri S.p.A.

Abstract

The Italian logistic company Due Torri S.p.A. offers many kinds of logistics services. It is located close to Bologna (Italy) and has 20 permanent employees. In 2007, it implemented a special logistics software that helps conduct shipping orders much more efficiently. The system was developed internally over six months. The effect of the implemented system was a decrease in gas consumption. For example a shipping order from Bologna to Milan now demands about 25% less fuel. The effects on greenhouse gas emissions are equivalent. Productivity also rose about 20%, as the procedures are much more efficient. Due Torri is very satisfied with the system and looks to further improve it.

Case study fact sheet

■ *Full name of the company:*	*Due Torri S.p.A.*
■ *Location (HQ / main branches):*	*Minerbio (Bologna), Italy*
■ *Main business activity:*	*Logistics*
■ *Year of foundation:*	*1974*
■ *Number of employees:*	*20*
■ *Turnover in last financial year:*	*€ 11 m*
■ *Most significant geographic market:*	*Italy*
■ *Main ICT applications studied:*	*Special logistics software*
■ *Case contact person(s):*	*Nicola Borghi, Operations Director*

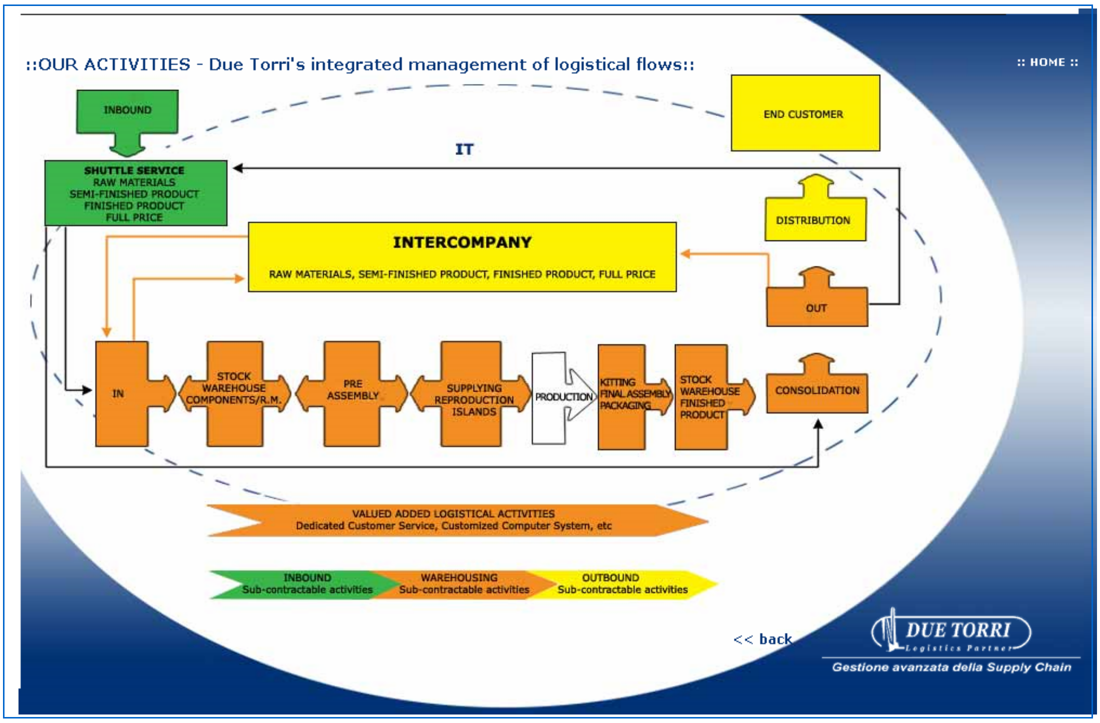
Company background

Due Torri S.p.A. is an Italian logistics company located in Minerbio, close to Bologna. It has 20 regular employees and works with about 100 subcontractors, mostly truck drivers who own or provide a truck. The services that Due Torri offers are basically all activities concerned with logistics and are fairly broad: inbound service, warehousing, distribution and outbound service (see Figure 26). The core service Due Torri offers is warehousing; currently (in 2009), Due Torri owns three warehouses. Most of the products which get stored and transported by Due Torri S.p.A. are books, cosmetics, food and products from the medical and mechanic sector.

Due Torri S.p.A. faces tough competition as it has to compete with much bigger companies. Being a relatively small company, there competitive advantage is their flexibility which enables them to offer special customer-focused solutions. Besides strong competition, another challenge for Due Torri is the fact that outsourcing in Italy is not very popular. Many companies prefer to ship their goods themselves.

e-Business activities are seen by Due Torri S.p.A. as a very important element in this sector. The decision to implement an IT system to ease the logistic process was made mainly to reduce costs.

Figure 26: Business activities of Due Torri



Source: http://www.duetorrispa.com/english/company/cosa2.asp

Use of ICT to reduce energy consumption / GHG emissions

Due Torri has two ICT systems that help to facilitate logistical processes and are partly able to reduce greenhouse gas emissions. The first system is a radiofrequency system, which enables the automatic identification and localisation of goods via radio waves. It enables very efficient packing of trucks and visibility for customers. The possibility for customers to see the movement of their products in real time is very practical, but the feature which actually helps to save energy is the efficient packing. With this feature, products must be moved less, which saves energy. The second system, which helps to reduce greenhouse gas emissions, is a special SQL logistic software. This system calculates the most efficient route for the truck drivers. Inputs about goods that have to be inserted into the system are: quantity, weight, volume, destination, date of delivery, etc. This information is complemented by the type of and number of trucks that are available and the optimised route is then calculated.

Before the introduction of the logistic software and the radiofrequency system, no special system or software for optimising the logistical process was used. An internal team in Due Torri developed the currently used software. The duration of planning and implementing the system took about six to seven monthes and after the implementation a two to three month control period was set. The implementation costs amounted to about 40,000 Euros. To maintain the system, expenses of about 5,000 Euros must be paid each year.

For adapting the new system, new computers and new servers had to be acquired. Furthermore, the employed people had to be trained.

Today Due Torri S.p.A. is very satisfied with the system and has seen enormous value from its implementation.

Impacts and lessons learned

The introduction of these IT systems, mainly the special logistic software, has helped to reduce energy demand at Due Torri. The **biggest savings** were **in gas consumption**, as the new system reduced the number of kilometres driven. A total figure of energy savings is not available, but, as an example, the gas reduction of a transport drive from Bologna to Milan (distance of 220 km) amounts to about 25% and from Bologna to Florence (distance of 130 km) about 15%. Since savings are made in gas consumption, the effect on greenhouse gas emissions can be directly computed.

The cost reduction of the reduced gas demand affects Due Torri indirectly, as the savings are made by the subcontractors, the truck drivers. But they pass the **reduced costs** on to Due Torri via their invoice. Furthermore, Due Torri's internal costs were reduced by about 10% and the **productivity increased** about 20% as a result of their IT systems. The number of employees remains the same, but the working time can be used much more efficiently.

Furthermore, as the quality of the logistic processes improved, the precision of delivery time was improved. Since the system has been in use, 99.4% of deliveries are on time, compared to 97% without the system. This is an important factor for staying competitive.

In general, Due Torri S.p.A. is very satisfied with the logistic software system. If they had to implement the system again, Due Torri would try to have a longer preparation time and place even more emphasis on customising the software 100% to their specific needs before implementing it. Due Torri reported that some significant changes had to be made during the implementation period, which created an unnecessary slow-down in the implementation process.

References

Research for this case study was conducted by Marianne Leitzke, Analyst at DIW econ. Sources and references used include desk research plus:

- Interviews with Nicola Borghi, Operations Director, Due Torri S.p.A.
- Websites:
  - http://www.leduetorri.it/

4.5 A.P. Moller – Maersk's approach to make shipping more efficient

Abstract

A.P. Moller – Maersk Group is the world's largest liner shipping company, running about 550 self-owned and chartered vessels and more than 1,900,000 20-foot-long containers, of which 200,000 are reefers in which the load can be cooled. Maersk is currently working on sustainable and environmental friendly solutions in many projects to reduce the environmental "footprint" of its transport business. This case study focuses on two of these initiatives: the first example presented is QUEST, a method of decreasing the energy demanded to cool reefers by 50% and is solely based on ICT. The second example is VES, a system that enables a vessel's crew to choose fuel-efficient routes and propeller revolution speeds and has resulted in a 1% drop in fuel consumption that added up to 121,000 tonnes in 2008. In addition to the implementation of these two programmes to increase the company's sustainability, Maersk supports the formation of a global approach to regulate greenhouse gas emissions.

Case study fact sheet

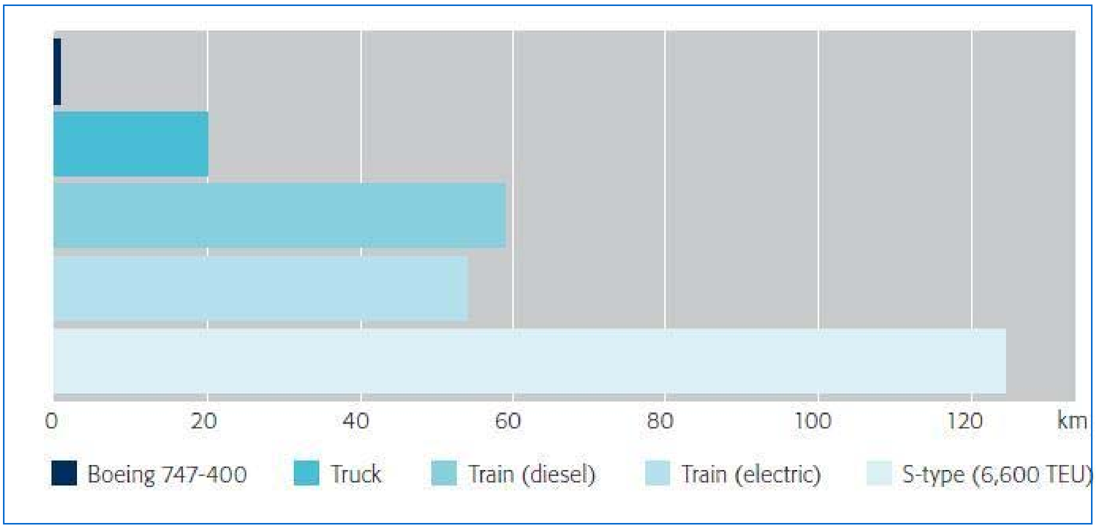
■ *Full name of the company:*	*A.P. Møller – Maersk A/S*
■ *Location (HQ):*	*Copenhagen, Denmark*
■ *Main business activity:*	*Transport, energy, industry*
■ *Year of foundation:*	*1904*
■ *Number of employees:*	*120,000*
■ *Revenue in 2008:*	*311,821 m DKK (approx. € 41,883 m)*
■ *Most significant geographic market:*	*Worldwide*
■ *Main ICT applications studied:*	*QUEST, VES*
■ *Case contact persons:*	*Mads Stensen, Environmental assistant general manager in the sustainability department; Henrik Lindhardt, Head of reefer operations, Technical sales and innovation; Kristian Bendix Nielsen, Senior specialist in the performance department*

Company background

A.P. Moller Maersk Group offers a wide range of services and products within transport, energy and industry. Maersk Group's Maersk Line and Safmarine together run 551 vessels indicating that they are among the world-leading liner shipping companies. The Maersk Line fleet alone, with about 500 vessels, handles more than 1,900,000 20-foot-long containers. Maersk Oil, which is part of the energy division, is a midsize international oil and gas company that operates at an oil production level of about 650,000 barrels per day and a sales gas production of up to some 1,000 million cubic feet per day. Maersk Group is completed by its industry segment, home to Dansk Supermarket, Denmark's largest retail conglomerate, Maersk Container Industry, which makes reefer and dry cargo containers, and Star Air, an air cargo fleet of 12 aircrafts, among others.

As the world's largest container shipping company, and with subsidies active in the energy segment, Maersk has a significant environmental impact even though shipping is one of the most efficient modes of transport (see Figure 27). As such, Maersk is aware of its obligation to contribute to sustainable solutions and has therefore been a leader in environmental practices. The importance of this environmental leadership is increasing today as the public interest in environmental issues also rises. In addition to Maersk's environmentally-friendly company policies, Maersk supports global regulation of green-house gas (GHG) emissions. This global approach is also essential to avoid competition distortions.

Figure 27: Distance covered with 1 tonne of cargo and the emission of 1 kg CO_2



S-type indicating a vessel with 6,600 20-foot-equivalent units
Source: A.P. Moller – Maersk

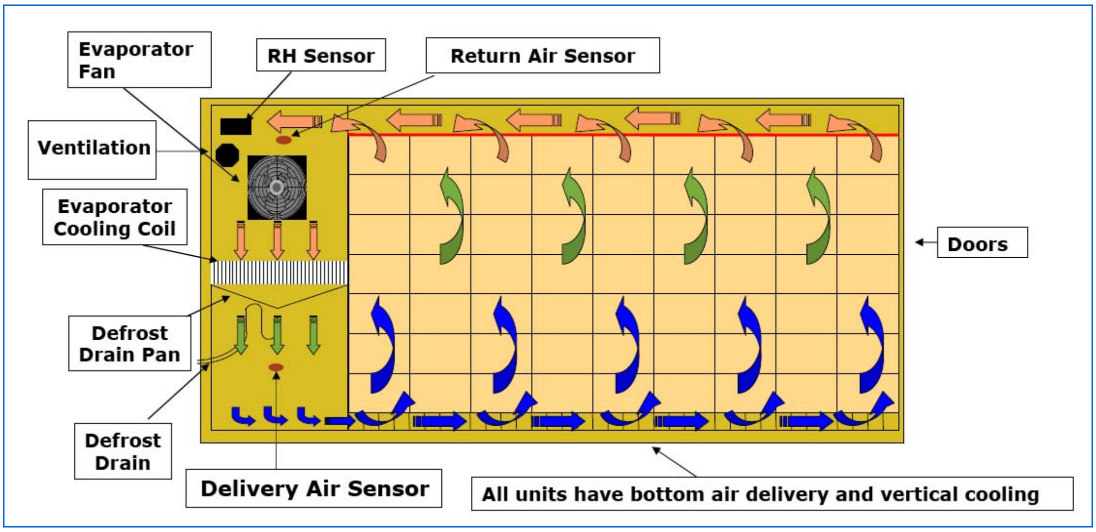
Maersk's transport segment uses two central systems which are part of a whole set of projects used to decrease the environmental impact of Maersk's business activities. The first system, called **QUEST** (Quality and Energy Efficiency in Storage and Transport), reduces the energy demanded by cool reefers by applying information and communication technology (ICT). The second system, called **VES** (Voyage Efficiency System), uses ICT to help find the most fuel efficient route and propeller setting.

Use of ICT to reduce energy consumption / GHG emissions

Maersk owns about 200,000 reefers to handle temperature-sensitive goods. The functioning of reefers is comparable to ordinary refrigerators, where the equipment consists of a compressor, a condenser, and an evaporator coil. All the equipment is arranged in the back of a standard sized container, and the cargo is then cooled down by cool air flowing in from the bottom of the container. The cool air absorbs the thermal energy of the cargo, heats up, and then flows back into the cooling system above the cargo (see Figure 28 and Figure 29).

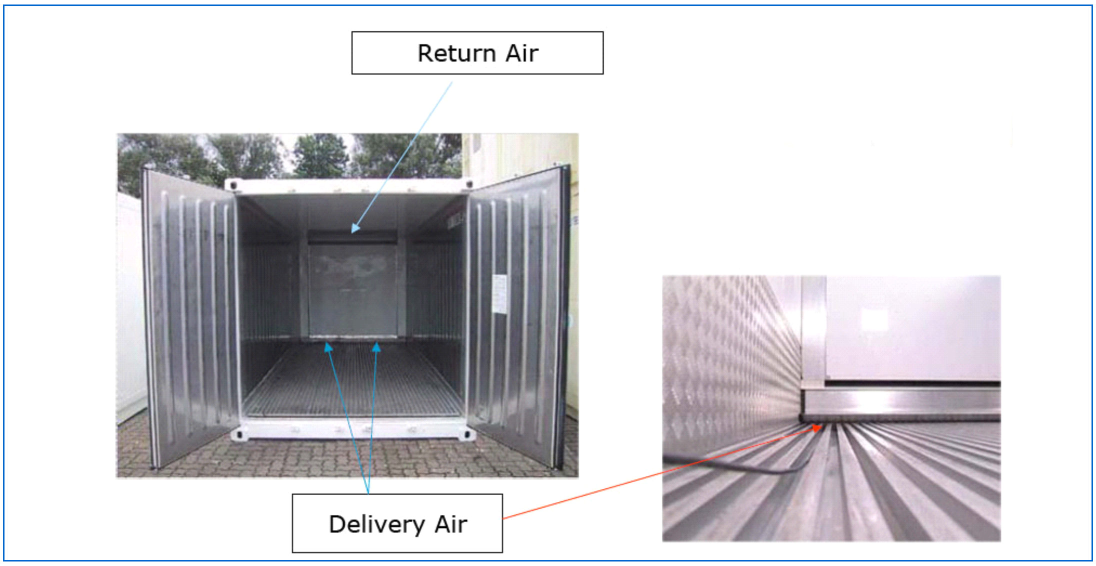
In a normal system, the compressor is continuously running, resulting in a constant temperature of the cold delivery air. The improvements made to the normal system by **QUEST** are solely based on the use of ICT, so the actual technical equipment remains the same. Only the software was changed in such a way that the compressor is not running all the time. Nevertheless, the freight needs to stay within a certain temperature range. To achieve this range, the delivery air is cooled to 2°C below the target temperature of the freight and the compressor is then turned off for 10-15 minutes, which saves energy. For example, if the target temperature of the load is 2°C, the delivery air would be cooled down to 0°C. This process is controlled by the delivery air sensor and processed in the cooling unit. Afterwards, the compressor is turned off automatically, until the sensor recognises that the air temperature is reaching a pre-defined threshold. When that occurs, after approximately 10-15 minutes, the processor starts working again to cool the delivery air down to 0°C.

Figure 28: Air flow and cooling principles in Maersk's reefer containers



Source: A.P. Moller – Maersk

Figure 29: Return- and delivery air in reefer container



Source: A.P. Moller - Maersk

In July 2009, Maersk was running this system in about 75% of its reefers and expected to implement QUEST in all reefers by the end of 2009. The implementation process has gone relatively quickly so far, as it demands only a software update, taking a total of about two years. To implement the system, Maersk needed to cooperate with the suppliers of reefers, who had to rewrite the software to make it work with Maersk's specific reefer model. Carrier Transicold, a supplier of heating, ventilation, air-conditioning and refrigeration (HVACR) systems, based in the United States, was an important partner and was involved since the beginning of the implementation phase in 2007. In the following years all other unit manufacturers made the reefer software available so that all reefer unit types in the Maersk Line fleet can be QUEST-enabled.

Maersk began to implement QUEST in 2007, but the main work developing the system was done before. Research started in 2002 at Wageningen University and Research Centre, in the city of Wageningen in the Netherlands. There, the researchers first came up with the idea to cool down the air below target and then turn off the compressor. As successful as the technology is now, the Maersk team was originally interested but in doubt as to whether the QUEST system would work or affect the quality of transported goods. Although it took some effort to convince customers that the quality of their goods will not be negatively affected, today Maersk is absolutely convinced about the merits of the system. The company is so pleased with the results that it is currently working on further improvements of QUEST.

The second system, the **Voyage Efficiency System** (VES), was introduced in 2004. VES differs in many ways from QUEST, which is a fully automated system and was improved by a pure change in software. In contrast to Quest, VES was initiated by a practitioner, a captain of one of Maersk's vessels. In principle, the system is designed to gather all relevant information to advise the crew with regard to the optimal route, speed, or revolution of the propellers. It is not an autopilot, but a device to help or discipline the captain and navigator to take all relevant information into account and provide a suggestion for optimal decisions. The suggestions of VES can be altered by the captain, who may have access to more information than is considered by the system.

Put in precise terms, VES is an onboard decision support system. It requires the crew to provide an input consisting of the distance, certain points that need to be reached during the route and the desired estimated time of arrival (ETA). Furthermore, VES contains tools to share information between ships, such as on current speeds, wind, weather, or the fuel consumption of other vessels on the same route. The role of ICT in this system is to measure parameters like wind speed, realise the communication between ships, and process all the information. As a result, VES provides the crew with suggestions for a route and for optimal propeller revolution. It does not, however, suggest a specific speed. The most efficient travel is determined by a constant revolution of the propellers, while a constant speed would require the adaptation of the engine performance to wind and current situations. With a constant revolution of the propellers, the speed of the vessel may change, but it is more fuel efficient.

The development of VES was successful due to collaboration among many actors. As mentioned before, the VES innovation was initiated by a captain. The captain took part in the development of VES, which started in 2003. Maersk also has a PhD program, which contributes to the development and improvement of VES. External sources have made further contributions to VES's development.

The improvements planned for VES include the consideration of additional information such as weather within the VES system, for example, or the connection of VES to Maersk's vessel performance system where information is collected for every route. These enhancements would broaden the information available to VES and improve the quality of VES' suggestions.

Impacts

QUEST has successfully decreased greenhouse gas emissions though a **reduction in energy consumption** by 50% compared to the old system. At the end of 2009, this 50% reduction is equivalent to more than 300,000 tonnes of CO_2 that will not have been emitted. Furthermore, QUEST has a **positive impact on the quality of goods** that are transported. The legacy (previous) system cooled the air down to the temperature the goods should have, even though the crucial temperature is that of the goods rather than the air. Cooler delivery air has more capacity to absorb thermal energy, so the cooler air used with QUEST holds the goods more efficiently in their temperature range. With these efficiency gains, QUEST can be seen as a success. In the coming years, it will be further developed and Maersk expects it to lead to further deceases in energy demand.

Table 25: Energy consumption 2007-2008

Energy consumption	Fuel oil		Diesel		Natural gas		Electricity		Energy intensity	
	1,000 tonnes		1,000 tonnes		1,000 tonnes		1,000 MWh		MJ/USD turnover	
	2008	2007	**2008**	2007	**2008**	2007	**2008**	2007	**2008**	2007
Transport	**11,985**	13,067	**256**	110	**0**	1	**838**	66	**17.6**	18.6
Energy	**1,022**	781	**113**	163	**874**	897	**17**	5	**5.4**	6.8
Industry	**10**	0	**53**	304	**12**	10	**726**	666	**0.2**	1.5
Maersk Group	**13,017**	13,848	**422**	577	**886**	908	**1,581**	737	**10.9**	12.2

Source: A.P. Moller – Maersk

Table 26:Energy consumption and greenhouse gas (GHG) emissions in the transport segment 2007-2008

Energy consumption		**2008**	**2007**
Fuel oil	1,000 tonnes	11,985	13,067
Diesel	1,000 tonnes	256	110
Natural gas	1,000 tonnes	0	1
Electricity	1,000 MWh	838	66
Energy intensity	MJ/USD turnover	17.6	18.6
GHG emissions		**2008**	**2007**
GHG emissions	1,000 tonnes CO2 eq	38,931	42,600
Direct GHG emissions			
CO2	1,000 tonnes	37,865.4	41,076
CH4	1,000 tonnes CO2 eq	138.1	23
HFC	1,000 tonnes CO2 eq	0	n/a
N20	1,000 tonnes CO2 eq	448.5	911
Indirect GHG emissions			
CO2	1,000 tonnes	450.7	590
GHG intensity	kg CO2/USD turnover	1.2	1.5
Other air emissions			
SOx	1,000 tonnes	607.6	616
NOx	1,000 tonnes	892.4	1,026
VOCs	1,000 tonnes	17.14	n/a
PM	1,000 tonnes	28.9	45

Source: A.P. Moller - Maersk

Like QUEST, VES reduces emissions through energy use reduction. The introduction of VES caused an approximate 1% drop in fuel consumption, which is a significant amount. As can be seen in Table 25 and Table 26, the annual fuel oil consumption in the Maersk's transport segment was 11,985,000 tonnes in 2008, which indicates that the potential of VES to reduce fuel oil consumption was about 121,000 tonnes in 2008. This reduction is based on different achievements. VES allows the speed of the vessel to be lower and run at the appropriate fuel-efficient speed, due to better planning. VES also facilitates better route planning by requiring information about all relevant factors for route planning to be gathered in one data system. It is important to note that the potential of VES is dependent on the crew's abilities, however.

The better and more experienced the crew, the lower the potential to decrease fuel consumption, as VES is "just" a decision support system. In that respect, VES has a strong educational effect for younger crews.

Overall, Table 25 and Table 26 and show that energy consumption within Maersk's transport segment has decreased in most cases. Accordingly, both direct and indirect GHG emissions have decreased. Furthermore, all segments within Maersk Group have reduced their energy intensity from 2007 to 2008, indicating a more efficient business activity group-wide.

Lessons learned

The results of QUEST show that a pure change in ICT (in this case, the software) can have a huge impact on reducing greenhouse gas emissions. The process of QUEST's development also suggests that ICT can be used to increase energy efficiency further if one leaves known paths and draws on outside sources of knowledge. Academic researchers originally developed the system, for example, which Maersk would never have initiated on its own. Cooperation between enterprises and researchers (who are able to work more freely and are not bound to profit) can be very fruitful according to the Maersk example.

VES demonstrates that ICT can be used to boost the quality of employee decision-making. Even without introducing a fully-automated system, the introduction of VES has produced a percentage decrease of 1% in energy demand. This decrease has already paid for the investment.

In addition to the gains already achieved, the initiatives indicate that there is potential to further improve the systems.

References

Research for this case study was conducted by Jano Costard, DIW econ. Sources and references used include desk research plus:

- Interviews with
    - Mads Stensen, Environmental assistant general manager in the sustainability department, Maersk Line
    - Henrik Lindhardt, Head of reefer operations, Technical sales and innovation, Maersk Line
    - Kristian Bendix Nielsen, Senior specialist in the performance department, Maersk Maritime Technology
- Information from "The Maersk Voice" December 2007.
- Websites:
    - A.P. Moller – Maersk Group: http://www.maersk.com/en/Pages/Welcome.aspx

4.6 Eka Chemicals' strategy for reducing energy consumption

Abstract

The Swedish company Eka Chemicals, a business unit of Akzo Nobel, develops and produces chemicals for the pulp and paper industry. Eka Chemicals faces tough price-based competition. Energy costs are an increasingly important factor in this context. The company therefore has a strong interest in increasing its energy efficiency. In the 1990s, a standardised Production Information System from GE Fanuc was introduced in many production processes. This system constantly monitors and analyses the energy consumption of a certain process and compares it to the historical energy demand of this specific process. In case of unusual increases in energy use, an alarm gets triggered. The problem is then addressed and solved either manually or automatically, depending on the complexity of the production process. The energy reduction that resulted from using this system is estimated to be about 1% of the energy consumption of the previous year. The system is constantly improved, but further significant energy reductions are seen to be reachable only through new technologies.

Case study fact sheet

■ *Full name of the company:*	*Eka Chemicals (business unit within Akzo Nobel)*
■ *Location (HQ / main branches):*	*Sweden / globally active*
■ *Main business activity:*	*Developing and producing chemicals for the pulp and paper industry*
■ *Year of foundation:*	*1895*
■ *Number of employees:*	*2700 (in 2007)*
■ *Turnover in last financial year:*	*€ 991 m (in 2007)*
■ *Most significant geographic market:*	*Globally active*
■ *Main ICT applications studied:*	*Production Information System*
■ *Case contact person(s):*	*Magnus Davidsson, Global Technology Manager*

Company background

Eka Chemicals' headquarters are located in Bohus/Göteborg, Sweden, and the company employed about 2,700 people in 2007. It is a business unit within the chemical company Akzo Nobel which is based in the Netherlands. Akzo Nobel is one of the world's leading industrial companies and the largest global paint and coating company.

Eka Chemicals itself is one of the world's leading manufacturers of bleaching and performance chemicals and offers a wide range of products and services to the pulp and paper industry. In fact it is among the top three leading companies within the pulp and paper chemical industry. Its main products are bleaching chemicals, paper chemicals and speciality products. Its market areas and customers are spread worldwide.

Since Eka Chemicals is acting globally, it has to compete worldwide. Competition in the field of pulp and paper chemicals is fierce and mainly price based. The main competitors of Eka Chemicals are Nalko (USA), Kemira (Finland) and BASF (Germany).

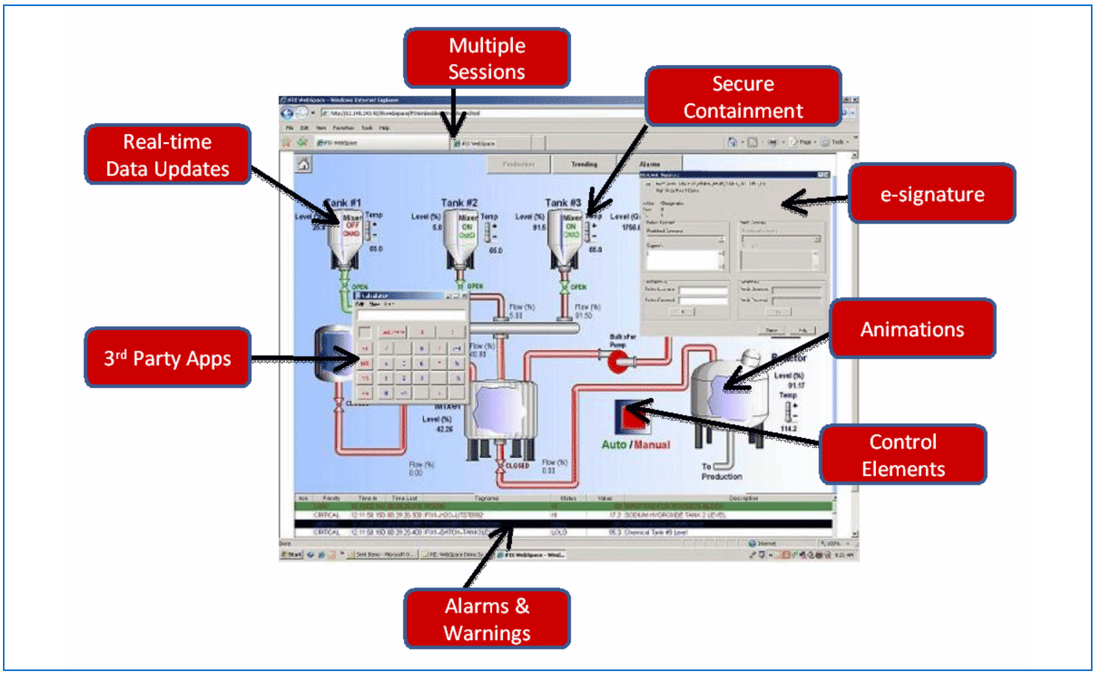
ICT and e-business are seen as important instruments, in particular in the production process. Eka Chemicals uses IT support in nearly every process.

Energy costs are the main cost factor in many processes. Any opportunity to decrease energy consumption is therefore highly relevant to reduce production costs and strengthen the company's competitiveness.

Use of ICT to reduce energy consumption / GHG emissions

Eka Chemicals uses ICT to reduce the energy demand in production processes. The so-called **Production Information System** is an engineering tool which is used in different production lines. It constantly monitors and analyses the energy consumption of a certain process. The system collects production data and calculates the current energy consumption per tonne. The collected data is then compared with historical production data and if the current energy consumption exceeds the historical consumption on a certain level, it triggers an alarm. It can then be checked what the reason is for the high energy consumption and the lack of efficiency. After the alarm is triggered, there are two different possible reactions, which depend on the production line and the complexity of the production process. If the production process is very complex, an already installed automatic reaction model comes into force. In contrast, if the production process is very simple, the problem is resolved manually. An example of the functioning of a real time application produced by GE Fanuc can be seen in Figure 30.

Figure 30: Example of real time application from GE Fanuc



Source: http://www.gefanuc.com/webspace

The Production Information System is a commercial product, which Eka bought from GE Fanuc, a joint venture between General Electric and the Japanese company Fanuc Ltd., headquartered in the United States. Among other products and services, GE Fanuc provides computer boards, system and software packages to control and report on factory production lines and other types of applications. The Production Information System used by Eka Chemicals was implemented about 15 years ago. Before that, the optimisation was done manually and was not as efficient. The new system operates continuously and is constantly being improved. For comparing the current energy consumption with the historical data, no special inputs are needed, except detailed historical production information and a transfer of the current data to the system.

The costs of the Production Information System, i.e. installation, software, licences, programming and setup, are more than equalled by the reduction of energy consumption and staff; the break-even point was reached after about a year. For implementing the system, no major organisational changes in the company were necessary.

The Production Information System works very well and definitely helps to save energy. According to Eka Chemicals, significant improvements regarding energy savings are only possible with new production technologies. For optimising the energy efficiency of these new technologies, an ICT system is indispensable.

Impacts

The impacts of the implemented Production Information System are diverse. Using the Production Information System, energy consumption is reduced. The **reduction of energy consumption** per tonne is estimated to be about 1-2% every year, and the implemented ICT and new technology has been estimated to be responsible for about half of the energy reduction. Total figures or percentages of energy savings since the implementation of the program are not available, however. A direct effect on greenhouse gas emissions cannot be measured either, since the electricity that Eka Chemicals uses is “CO2 neutral” (it is created from hydropower and nuclear power plants, which have no direct CO2 emissions). Nevertheless, an indirect effect from the usage of e-business on greenhouse gas emissions can be measured. Since Eka Chemicals is using less CO2 neutral energy, more CO2 neutral energy is left for other energy customers. Furthermore, less energy from conventional power plants, which does produce CO2, is demanded.

The Production Information System does not have other significant effects on Eka Chemical’s turnover or market share. However, **productivity has increased** due to the implementation of the system. In the last five years, the number of engineers was reduced by about 25%. Despite these reductions, the quality of the products remained constant. In the near future the quality of the products is even expected to improve due to the Production Information System.

A new department was launched to support issues arising from the use of the Production Information System. A core team of four employees develops, manages and implements the system for global use within Eka Chemicals; in total, ten people take care of the system.

Lessons learned

A very important issue regarding the Production Information System is the access to and the availability of current and historical data. Hence a responsible way of measuring and collecting data is essential to enable use of the system.

A second important issue is standardisation across the company. Introducing the Production Information System was a top management commitment; the same system runs globally in Eka Chemical plants and partially also in their customer factories. This facilitates the company-wide implementation, as well as the development and the correction of errors.

Eka Chemicals is very satisfied with the Production Information System and would not make any changes to its implementation process.

References

Research for this case study was conducted by Marianne Leitzke, DIW econ. Sources and references used include desk research plus:

- Interviews with Magnus Davidsson, Global Technology Manager, Eka Chemicals
- Websites:
  - www.eka.com
  - www.akzonobel.com
  - www.gefanuc.com

4.7 Solvay: The changing role of ICT in production processes

Abstract

Solvay is a Belgian company that produces pharmaceuticals, chemicals and plastics and is a world leader with some of its products. Solvay points out that the role of ICT has diminished in recent years. This observation is especially based on characteristics of the chemical industry, which is very much limited in its production by underlying physical and chemical laws. According to Solvay, the only way to increase energy efficiency is to reduce the standard deviation of optimal production parameters. As it has worked on this issue for about 20 years now, Solvay sees not much scope for further improvements by means of ICT. Solvay maintains that additional costs of GHG emissions imposed by related policies would ulitmately reduce the firm's competitiveness, because the increase in production costs cannot be compensated through higher efficiency. Solvay actually considers relocating production facilities to non-EU countries, if additional levies on GHG emissions are introduced in the chemical industry in Europe.

Case study fact sheet

■ *Full name of the company:*	*Solvay S.A*
■ *Location (HQ):*	*Brussels, Belgium*
■ *Main business activity:*	*Pharmaceuticals, chemicals, plastics*
■ *Year of foundation:*	*1863*
■ *Number of employees:*	*29,433*
■ *Operating result in 2008:*	*€ 1 billion*
■ *Most significant geographic market:*	*Worldwide*
■ *Main ICT applications studied:*	*ICT-based production control systems*
■ *Case contact person(s):*	*Joao Gouveia, Production Manager*

Company background

Solvay was founded in 1863 with the creation of Mr. Solvay's first plant for soda manufacturing in Couillet, Belgium. Since then, Solvay has developed into a world wide player in the production of pharmaceuticals, chemicals and plastics. Today, Solvay employs 29,433 people in 50 countries and 400 sales and production facilities. Their chemicals division is world leading in the production of soda ash, sodium bicarbonate and hydrogen peroxide, as well as one of the leading producers of caustic soda, and is the focus of this case study. Nevertheless, competition is tough in these markets, and Solvay's leadership only reflects the situation on a firm-level. With regard to countries and regions, China is world leading in the mentioned products, followed by the USA and Europe. In addition, this competition is not only price based, but also stems from the increasing quality of Chinese products.

Evolution of production processes

Beginning in the 1960s, production processes were controlled manually by the plant's operators. In the following decade, pneumatic control was introduced and enabled a higher distance between operators and machines, making process control more efficient.

In the 1980s, plants began to implement electronic equipment to run machines and enabled single loop control. Later, in the 1990s, more advanced electronic systems, including ICT-based systems, were introduced. Those systems were characterised by complex mathematical models and double, as well as, multi loop control. They enabled operators to control all processes simultaneously from a central controlling room. Furthermore, ICT systems made it possible to control not only direct parameters, such as pressure or temperature, in the production process, but also enabled operators to control for quality characteristics directly.

Impact of ICT on production

To understand the role of ICT in the production process, it is important to be aware of the specific characteristics of the chemical industry. It is limited by three major factors: chemical reactions, thermodynamics and the control system. Chemical reactions determine the input factors and the amounts which need to be used. One of these input factors is energy. As the amount of energy needed for a specific chemical reaction is fixed, there is no room for improvement in reducing the amount of energy used in the processes. The second issue, thermodynamics, reveals limits as well. In this context, the production of steam for the production processes can be mentioned. Again, physical and chemical laws apply, which determine how much energy is needed to produce a certain amount of steam. So there is no possibility to directly save energy within that process. If there is a chance to make production more efficient, it is by manipulating the control system. This gain in efficiency is achieved by reducing the deviation of production parameters from their optimum.

However, as mentioned before, ICT systems have been in use for about 20 years at Solvay, and they have been continuously improved and renewed. After all these years, the potential for the company to further reduce the standard deviation of parameters is very limited. Solvay estimates that, today, a further reduction of up to 1% of energy consumption can be achieved through new ICT systems. Even though the effect is small, Solvay continues to invest in ICT, but these investments are mainly driven by the need to optimise in the face of fierce competition and not by the chance to further decrease greenhouse gas emissions. In conclusion, the time when ICT was a major tool for improving energy efficiency is over.

Lessons learned

Solvay believes that the scope for further increases in energy efficiency and decreases in greenhouse gas emissions is small. Therefore, further costs for emissions, e.g. if imposed by European Union policy, cannot be offset by companies through increased efficiency. If it should be the case that additional charges result from the climate summit in Copenhagen in December 2009, Solvay is prepared to make a decision regarding whether or not to move production to non-European countries.

References

Research for this case study was conducted by Jano Costard, DIW econ. Sources and references used include desk research plus:

- Interviews with
    - Joao Gouveia, Production Manager (Chemicals Sector), Solvay

4.8 Oracle Transport Management

Abstract

Oracle Corporation is the world's largest enterprise software company. Oracle's product range includes databases, middleware and application solutions and services. This case study focuses on the "Oracle Transport Management" (OTM) solution. OTM is a complex software package that consists of several products, one of which is the Oracle "Fusion Transportation Intelligence" (FTI). This system transforms transportation data into logistics information and therefore into an optimal route for complex shipping orders. The case study demonstrates the potential by focusing on one user company: Kraft Foods, a food manufacturer with an enormous shipping demand, implemented the system in 2007. Since Kraft foods has been using the system, it has reduced its shipping costs by about 3-5%. As these are mainly gas costs, the savings can be directly transferred to a decrease in CO2 emissions. With rising awareness of greenhouse gas emissions, OTM is seen as a product of increasing importance.

Case study fact sheet

■ *Full name of the company:*	*Oracle Corporation*
■ *Location (HQ / main branches):*	*Redwood Shores, California (USA)*
■ *Main business activity:*	*Develop, manufacture, market, distribute and service database, middle software and application software*
■ *Year of foundation:*	*1977*
■ *Number of employees:*	*84,233 (31.05.2008)*
■ *Turnover in last financial year:*	*US$ 7,515 m (approx. € 5,271 m)*
■ *Most significant geographic market:*	*America, Europe*
■ *Main ICT applications studied:*	*Oracle Transport Management*
■ *Case contact person(s):*	*Steven Hagner, Director, EMEA Governance, Risk & Compliance Solution Sales*

Company background

Oracle Corporation is the world's largest enterprise software company, operating world wide, with about 85,000 employees (2008) and headquarters in Redwood Shores, California, United States. Oracle is organised into two businesses; software and services. These represent about 80% and 20% of the total revenues, respectively. The software business is divided into the segments "new software licences" and "software licenses updates and product support". The service business unit of Oracle has three operating segments: "consulting", "on demand" and "education". The most well-known Oracle product is its database, named the "Oracle database". Oracle has about 80,000 customers; none of them accounted for more than 10% of revenues in the past three years. This case study focuses on the "Oracle Transport Management" (OTM) solution and its potential to help decrease energy (gas) consumption in logistics processes.

Use of ICT to reduce energy consumption / GHG emissions

"Oracle Transportation Management" (OTM) is an application of the Supply Chain Management system of Oracle that helps to reduce greenhouse gas emissions. One part of the OTM is the Oracle Fusion Transportation Intelligence (FTI) option that transforms transportation data into logistics information. Therefore it creates a transportation and logistics dashboard or cockpit for operational and strategic planning and execution needs. By taking operational data and converting it into a concrete shipping route, companies can conduct their shipping much more efficiently and make real-time changes to plans that are not going as expected. It is also possible to monitor key performance indicators while also allowing navigation between historical and current operational information. From an operational point of view, FTI also enables planners to utilise historical carrier performance data to make decisions on current orders and shipments. The results of the transportation operations can be seen in a dashboard view. With this up-to-date information, it is possible to modify existing formulas and/or report specific customised values according to the customer's needs.

The Oracle Transportation Management system also enables more than one company to work and ship together. This has an enormous savings potential as well. OTM can easily calculate the optimal route while separating the costs and savings for each company.

Figure 31: Dashboard of transportation metrics (including graphs of statistics, utilisation, costs and benefits)

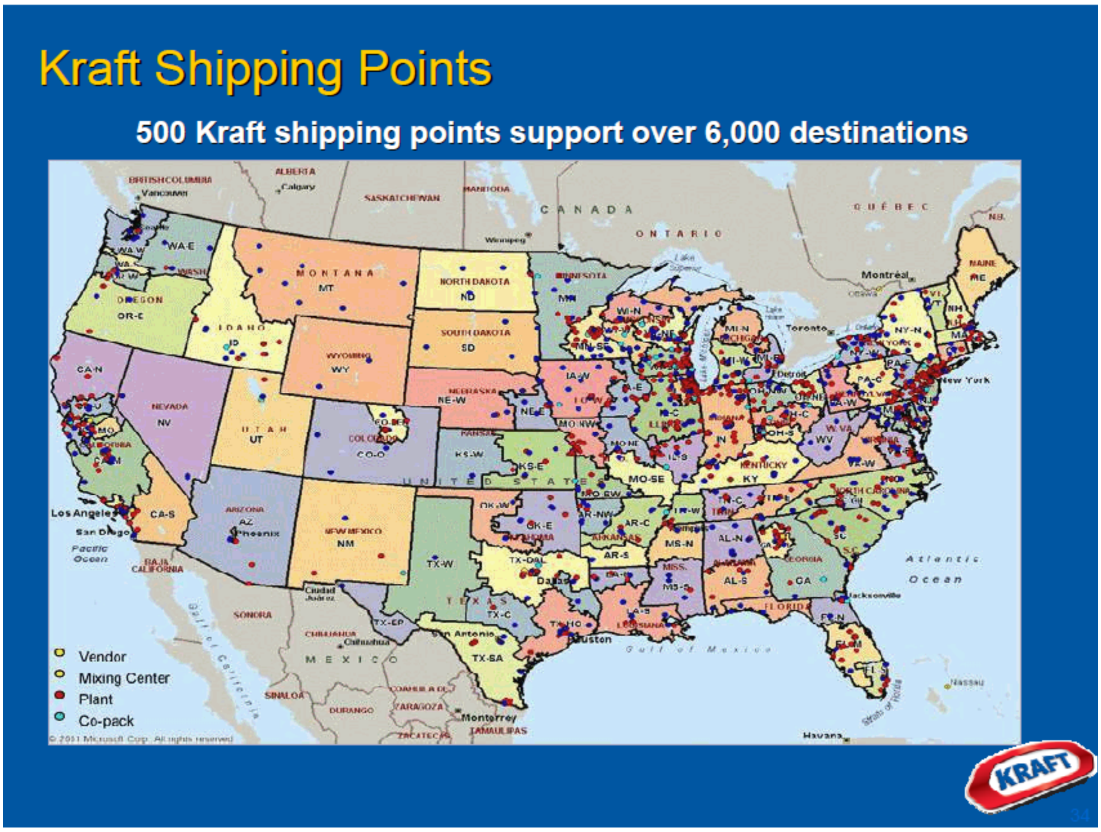
Source: http://www.oracle.com/applications/scm/transportation-management/fusion-transportation-intelligence.pdf

One of the customers that use the OTM system is Kraft Foods, one of the biggest food companies worldwide. Kraft has an enormous demand for shipping goods, as it sells products in more than 150 countries and has ground operations in more than 70 countries. Kraft Foods implemented OTM in 2007, mainly to cut costs. Kraft Foods wanted, among other things, to optimise the routing and to increase the ability to model network changes and cooperate with other companies. In Europe, for example, 25% of the trucks on the street drive empty. These are costs which could be reduced by cooperating and optimisating the shipping routes. For optimising the routes, the inputs into the system are information about the products that are sold, the locations and the schedule. Another important question that can be solved by using OTM is whether to ship the goods by boat plane or truck.

In the case of Kraft Foods, OTM is further supported by the Oracle Inventory Management, which provides an electronic simulation of the optimised arrangement of loads in a truck.

Kraft Foods implemented a Transport Management System (TMS) in 1997, which was developed by Kraft itself. In 2001 the system was extended with two further solutions. In the future Kraft wants to further continue and improve its use of OTM and cooperate with partners who also participate in the company's shipping process.

Figure 32: Overview of Kraft shipping points and destinations



Source: Oracle

Impacts and lessons learned

The carbon foot print of the logistic and transport sector is estimated by the World Economic Forum to be about 2,800 mega tonnes each year. This equates to 5.5% of the total greenhouse gas emissions made by humans.

The Orcale Transport Management solution can help reduce gas consumption. Due to much **more efficient routing**, less empty driving (Kraft Foods has 500,000 miles less of empty driving a year) and the cooperation among companies, Kraft Foods was able to save 3-5% of the original costs. Most of the **cost reductions** result from saving gas. This has a direct effect on the production of green house gas emissions so at the same time the logistic operations of Kraft produce about **3-5% less CO2**. Since shipping costs have been reduced and the shipping is much more efficient, Kraft and Oracle report that productivity has increased. Exact figures for that increase are not available, however.

References

Research for this case study was conducted by Marianne Leitzke, DIW econ. Sources and references used include desk research plus:

- Interviews with Steven Hagner, Director, EMEA Governance, Risk & Compliance Solution Sales, Oracle
- Internal PowerPoint presentations from Oracle
- Websites:
  - www.oracle.com

5 Surveys of industry perspective

Through the case studies presented in chapter 4, the econometric analysis in this report is grounded in the specific experiences with ICT of eight companies in Europe's energy-intensive industries. However, further knowledge of industry attitude toward greenhouse gas emissions and reactions to environmental and emission regulation is necessary in order to fully take advantage of the previous chapters' lessons for environmental policy purposes.

In order to provide up-to-date insights into the interaction between environmental policy and industry business practices, and to understand the extent to which ICT has been implemented to reduce emissions in energy-intensive industries, the findings of two surveys are presented in this chapter.

- A pilot survey among companies from the glass, cement, and ceramic industries examines the use of ICT for saving energy and monitoring GHG emissions (see section 5.1).
- A Delphi-style survey poses questions about the potential of ICT for reducing GHG emissions to experts in relevant companies, industry associations and research institutions. The survey also investigates the perceived effect of environmental policy on European energy-intensive industries (see section 5.2).

5.1 Pilot survey in the glass, cement and ceramic sector

This section explores the extent to which companies in energy-intensive industries use ICT systems for managing and reducing energy consumption and emissions, and the potential they attribute to ICT in these areas. The data presented are mostly based on a **pilot survey** about these issues among companies from in the **glass, cement and ceramic** industries.[93] This survey was comprised of 676 companies (with at least 10 employees) from six EU countries (Germany, France, Italy, Poland, Spain, UK). The interviews were conducted as computer assisted telephone interviews (CATI method) in March 2009 with ICT decision makers in the company. The sample drawn was a stratified random sample of companies from the population, with the objective of fulfilling minimum strata with respect to company size-bands.[94]

The manufacture of glass, ceramics and cement (GCC) constitutes only a segment of the energy-intensive sectors, but all of these sectors are process manufacturing industries.

93 The term "glass, ceramics and cement (GCC) industries" as used in the survey and in this study refers to business activities specified in NACE Rev. 2 Division 23 as the "manufacture of other non-metallic mineral products", covering Groups 23.1 to 23.6. According to Eurostat, this sector employed more than a million people in the EU (in 2005) and comprised about 65,000 enterprises. The questions on ICT usage for energy and emissions management were part of a larger survey about ICT usage and e-business in this sector, conducted as part of another Sectoral e-Business Watch study.

94 More information about the methodology, including information about the participation rate and the statistical accuracy that can be expected for the results is available in a specific methodology report, published as Annex 2 of the Sectoral e-Business Watch study on the glass, ceramics and cement industry (2009). Researchers who want to use the raw (case level) data for their own statistical analysis can send a request to receive the data via an online form on the website of the Sectoral e-Business Watch (www.ebusiness-watch.org). (the conditions for use are also specified there).

The general trend in the usage and assessment of ICT for energy and emissions management in the GCC sector is at least indicative for other sectors as well.

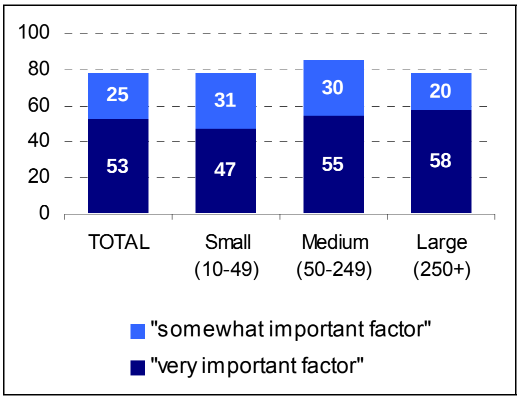
5.1.1 The importance of energy costs and emissions management

Rising energy costs – a critical issue

Rising energy costs are a business concern in all energy-intensive industries, as energy is a highly relevant cost factor with an impact on competitiveness. If energy costs are significantly higher in one region or country than in another, companies producing in this region/country face a competitive disadvantage. This holds certainly true for the GCC isector. In the cement industry, for example, energy costs account for more than 30% of total production costs.[95] Each tonne of cement produced requires about 105 KWh of electricity.[96]

This survey clearly confirms the importance that GCC companies attribute to the issue of rising **energy costs**. More than 50% of the companies interviewed said that energy costs represented a "very important" factor for their competitiveness; another 25% said that it was a "somewhat important" factor (see Figure 33). Thus, energy costs are perceived as a relevant issue by close to 80% of all companies. This holds true for companies from all sub-sectors and size-bands. For large companies, energy costs appear to be an even more important issue than for small ones.

Figure 33: % of companies saying that energy costs are a very / somewhat important competition factor



Source: e-Business Survey in the GCC sector

To counteract rising energy costs, the industry has made enormous efforts to become **more energy efficient** in production. The glass industry, for example, has significantly decreased its energy consumption levels since the 1970s. The German industry association has calculated that energy efficiency has increased by 77% since 1970, mostly due to continuous innovation in production technologies.[97] British Glass, the manufacturers' confederation, reports that the amount of energy required to melt a tonne of glass has fallen from 3.18MWh per tonne to 1.47MWh between 1979 and 2003, i.e. by more than 50%.[98] The technological progress in production procedures has also led to reduced CO_2 emissions (in relation to the output). The efforts to reduce CO_2 emissions are documented in regular monitoring and inspections by independent institutes.

[95] bdz: "Themes: Energy intensity and energy efficiency", http://www.bdzement.de/75.html?&lang (March 2009)

[96] CEMBUREAU: "Main characteristics of the cement industry." www.cembureau.be (March 2009)

[97] Information by BV Glas (the association of the German glass industry), http://www.bvglas.de/umwelt-energie/energie-klimaschutz/ (accessed in May 2009)

[98] "Glass: Society and the Environment", brochure by British Glass

Production processes in the cement and ceramics industry have also become much more energy efficient.

There are different opinions regarding the **potential for further improvements** in energy efficiency, irrespective of the role that ICT could play in this context. Although the various industries of the GCC sector continue to seek new ways of further reducing their emissions and energy consumption, industry associations question whether there is much further potential in the foreseeable future. Representatives of the ceramics industry believe that the remaining potential to further bring down energy costs in production is only about 5%.[99] In the cement industry, the co-processing of alternative fuels (e.g. used tyres) might be one way of recovering energy and material from waste.[100]

Perceived relevance of the EU Emissions Trading System

Industrial activities account for more than half of global greenhouse gas (GHG) emissions, which are commonly believed to be a major cause of climate change. Energy-intensive sectors such as the GCC industries contribute significantly to emissions. In the past 5-10 years, international efforts to reduce industrial emissions have significantly gained support and momentum. Europe is particularly committed to take a lead in this field. The major initiative in this area is the EU Emissions Trading System (EU ETS),[101] which became effective in 2005 (see section 1.5). Most of the EU ceramics and cement installations are covered by the ETS Directive.

The GCC industry has expressed **major concerns** about the impact of the EU ETS on the competitiveness of the European industry. A study by the Boston Consulting Group, requested by CEMBUREAU,[102] concludes that clinker and cement production in the EU will be seriously affected by carbon leakage, leading to an acceleration of the **relocation** of clinker production to countries with no carbon constraints from 2013 onwards.[103] The industry stresses the importance of taking appropriate measures to prevent unfair competition from products (e.g. cement and clinker) imported into the EU from regions with no carbon constraints and, therefore, no CO2 costs.

The intensive debate about the impacts of the EU ETS for companies from the sector – all of the major industry federations pay great attention to this issue – indicates that regulation related to the ETS should be a priority issue for many companies. The survey results do not fully confirm this at first sight; at least, the share of companies that say they are affected by ETS regulation is lower than the share that considers rising energy costs as a critical issue.

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99 Interview with Renaud Batier, Managing Director, Cérame-Unie, April 2009.

100 See "Sustainable cement production: Co-processing of alternative fuels and raw materials in the European cement industry", brochure by CEMBUREAU. In 2006, the European cement industry used an energy equivalent of about 26 million tonnes of coal, a non renewable fossil fuel, for the production of 266 million tonnes of cement. Alternative fuels constituted 18% of this across Europe, saving about 5 million tonnes of coal.

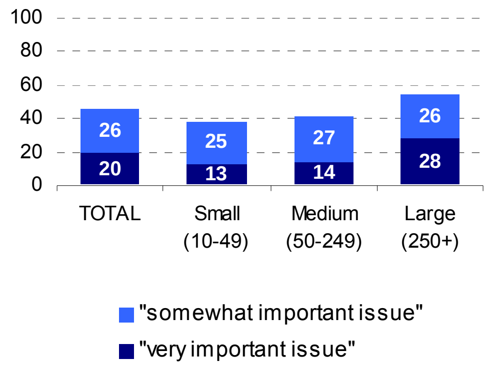
101 In 2003, the European Commission had published Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community, stipulating that the ETS was to start in January 2005.

102 "Assessment of the impact of the 2013-2020 ETS Proposal on the European cement industry". Study by BCG (2008).

103 Quoted from: "Carbon leakage: European cement industry at risk", press release by CEMBUREAU, 7 October 2008

In total, companies representing about 20% of the sector's employment say that the EU ETS is a "very important issue" for them, and another 26% say that it is "somewhat important" (see Figure 34). Among large companies, the percentage is higher than among SMEs. ETS compliance is probably more of an issue for those manufacturers that produce the basic materials in large volumes (e.g. flat glass, ceramics bricks and tiles, clinker, cement) than for companies producing specific applications requiring smaller volumes of the raw materials such as tableware or technical ceramics.

Figure 34: % of companies saying that regulation related to the EU ETS is a very / somewhat important issue for them



Source: e-Business Survey in the GCC sector

5.1.2 ICT usage for energy management

As shown above, energy costs are a concern for the broad majority of companies in the GCC sector, and companies make great efforts to bring their energy consumption to the lowest possible level. There is hope that innovation in ICT systems for monitoring and analysing energy consumption might enable companies to further increase their energy efficiency, i.e. reduce their energy consumption at given output or increase production with the same amount of energy. This section explores the current **diffusion** of such ICT systems and their **perceived effectiveness**.

Energy management / control systems (EMS / ECS)

The term "energy management systems" (EMS) initially referred predominantly to systems used by energy supply companies (in particular operators of electric utility grids) rather than by energy consumers. For them, EMS are ICT-enabled tools used to monitor, control, and optimise the performance of the generation and transmission system. Today, the terms **EMS** or **ECS** (management / control systems) are equally used for systems used by energy consumers in industry for monitoring, analysing and improving their energy consumption patterns. In more advanced forms of application, EMS/ECS automate energy consumption processes within a facility. EMS can include different modules and devices, ranging from a relatively simple time clock controlling a single circuit to sophisticated direct digital controls (DDC) that manage all of the energy intensive systems in a building.[104]

There are several **objectives** which companies typically pursue with support of EMS/ECS, including improved control, quality assurance and reduced costs:

- The principle function of these systems is certainly to facilitate transparency and control over a company's power distribution network.

[104] Cf. product description of EMS solutions by Energy Conservation & Supply, Inc., see www.enerconsupply.com (accessed in June 2009)

- Improved control over the power network contributes to safety and quality assurance. Faults and their source are faster and more easily detected. This includes an early warning in case of energy losses.
- EMS/ECS enable companies to allocate power costs more precisely, e.g. to different production units. This information is valuable for cost accounting. It is also important for the optimal procurement of energy, as it can help improving the accuracy of consumption forecasts. Procurement agents have better evidence and can then, ideally, purchase the required power at a better cost.
- The data gained from EMS/ECS is also an important basis for calculating, monitoring and documenting (greenhouse gas) emissions.
- In many cases, the EMS/ECS is also expected to enable the company to improve its energy efficiency. In this respect, these systems can be expected to have their highest potential in energy-intensive manufacturing industries, where energy-related costs –and thus, possibly, savings– tend to be substantial.

It is not possible in the context of this study to describe and analyse in detail the supply side for EMS. It is likely that the EMS market has considerable growth potential in the years to come. A market study for the USA by BCC Research estimates that the market for energy management information systems increased from approximately USD 10.4 billion in 2003 to 17.6 billion in 2006. The study forecasts that revenues will reach nearly USD 23 billion by 2011, representing an average annual growth rate (AAGR) of 5.4% from 2006 to 2011.[105] Suppliers of such systems include many of the large electrical companies such as Siemens or Oracle (see the case studies in sectons 4.1 and 4.8).

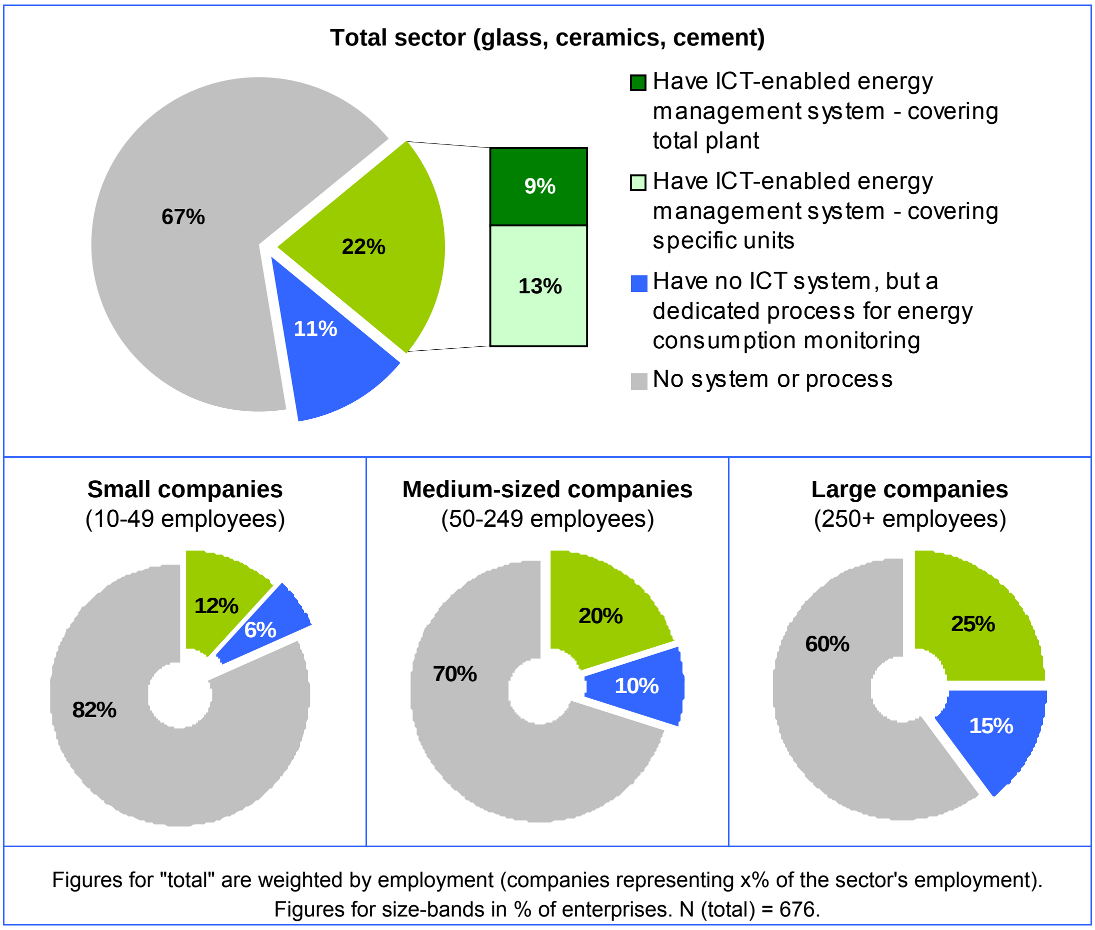
Adoption of ICT-enabled EMS / ECS

In total, companies representing 22% of the GCC industry said they have an ICT-enabled EMS. A further 11% say they do not have an ICT solution for this purpose, but have implemented a dedicated process for systematically monitoring and analysing their energy consumption. This leaves two thirds of the companies which apparently have no systematic approach to energy management. As can be expected, relatively more large companies have ICT-enabled management systems. Adoption rates increase by firm-size, from 12% among small companies to 20% of medium-sized and 25% of large ones.

Figure 35 summarises the adoption of ICT-enabled EMS and ECS in the glass, cement and ceramic sector.

[105] BCC Research (2006): The Global Market for Energy Management Information Systems. Analyst: Sarah LoPrinzi. More information: http://www.bccresearch.com/report/EGY052A.html (accessed in June 2009).

Figure 35: % of companies using an ICT-enabled system or a dedicated process to monitor and analyse their energy consumption

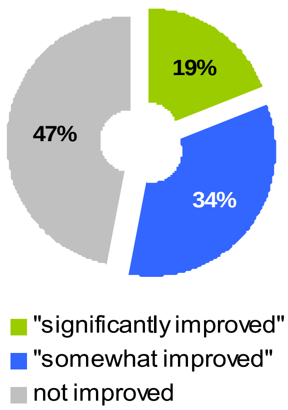


Source: e-Business Survey 2009 by the SeBW

Perceived effectiveness of EMS / ECS

Companies that said that they had used an energy management system for at least one year were then asked for an assessment of the system's effectiveness. About 20% believed that the energy efficiency of their company had "significantly improved" due to the system in place, about a third of the companies said the efficiency had "somewhat improved" (see Figure 36).

Figure 36: Share of companies saying their energy efficiency has ... due to their EMS



Source: e-Business Survey 2009

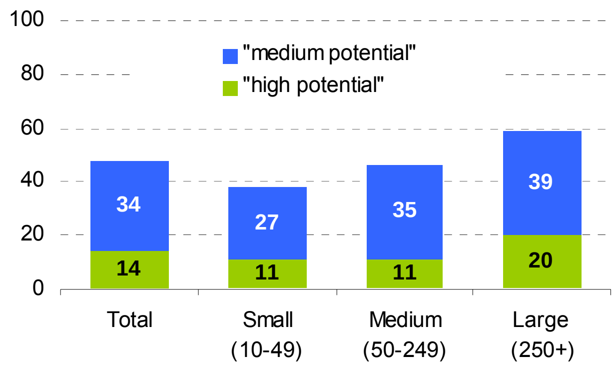
Nearly a 50% share[106] of the EMS-using companies have not yet observed any impact on the energy efficiency. While this might look like a disappointing result; two factors must be considered.

First, as stated above, improving the energy efficiency is often only an indirect objective that companies may pursue with EMS. The basic functionality of an EMS is to ease the control and overview of the energy flows in the company, with a view to safety and quality control in energy-intensive production processes. The smaller benefits to energy efficiency, then, are not necessarily indicative of small benefits to the firm from EMS.

Second, it can take some time before an EMS becomes effective in terms of energy savings. The better evidence about the energy consumption patterns that are gained from such systems needs to be transposed into new processes, such as improved planning and production, in order to have a real impact.

The actual experience of EMS users corresponds largely to the wider expectations which companies have towards ICT in this respect. About half of the companies interviewed (by their share of employment) believe that ICT have a medium or high potential for energy efficiency, only 14% see a "high potential", however (see Figure 37). Larger companies are slightly more optimistic than small ones; about 60% of the large companies attribute potential to ICT in this respect.

Figure 37: % of companies thinking that ICT has a high / medium potential for energy efficiency



Figures for "total" are weighted by employment (companies representing x% of the sector's employment).
Figures for size-bands in % of enterprises. N (total) = 676.

Source: e-Business Survey 2009

Energy efficiency as an objective for ICT investments

The links between ICT and a company's energy efficiency are not restricted to EMS. ICT can also help to reduce energy consumption by making production processes more efficient. Finally, ICT systems consume energy themselves; this is often an aspect when companies make investments in new ICT infrastructure ("Green IT").

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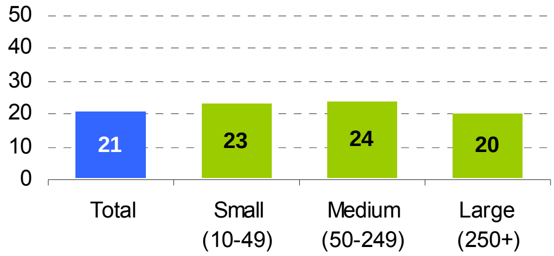
[106] Weighted by employment (= companies representing x% of the sector's employment). N (total) = 86

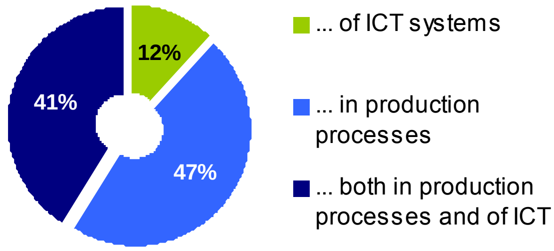
A few questions in the survey explored how relevant energy-related aspects are for ICT investment decisions in general. In total, about 20% of the interviewed IT decision-makers from the GCC sector said that energy efficiency has been a relevant objective in their ICT investments in recent years (see (a) in Figure 38). There is hardly a difference between size-bands in this respect. These companies were then asked whether the focus was on improving the energy efficiency of production processes or of the ICT systems themselves. In Figure 38, (b) confirms the role of ICT as a general purpose technology in this respect: nearly half of the companies with an energy-focus in their investments said that the main goal was to reduce energy demand indirectly by improving production processes through ICT.

Figure 38: Energy efficiency as an objective for ICT investments

(a) % of GCC companies for whom energy savings have been a relevant objective in ICT investments in recent years



(b) of those: % of companies whose main objective in ICT investments was to improve the energy efficiency ...



Source: e-Business Survey 2009

Another 40% of companies said that they aimed to achieve both energy-efficiency gains in production and "Green IT" advancements, i.e. to improve the energy-efficiency of the ICT systems themselves. Only about 10% of the companies said that their focus was mainly on Green IT (and not on production processes).

5.1.3 ICT usage for the management of greenhouse gas emissions

To cope with regulatory requirements such as the EU ETS, an increasing number of enterprises will be obliged to identify, understand and manage its carbon footprint. This footprint can encompass all emitted greenhouse gases which are then converted into CO2 tonnes equivalent. Emissions can result from different direct and indirect sources, including energy, transport, waste, water supply chain and other indirect contributors.[107]

In larger companies, collecting and monitoring data about CO2 footprints will probably become a normal part of the overall **enterprise resource planning** (ERP) process. The integration of this domain is a relatively new development, however, and a real structural novelty, because the type of data to be collected is quite different from other resources. ERP system providers are currently developing add-on tools to their solutions that shall

[107] cf. Energy Management Solutions: Carbon Management and Carbon Footprinting. http://www.ems.org.uk (accessed in June 2009)

help companies tracking their carbon footprint and thus complying with emerging regulatory requirements (see example in box). In addition to solutions that are fully integrated with an ERP system, there are also software solutions that are linked with energy management systems as well as specialised stand-alone solutions for monitoring the carbon footprint.

Example of an ICT system to manage carbon footprint

IBM's "GreenCert" – a web-based system to quantify emissions

IBM has developed a web-based Enterprise Content Management System to accurately quantify Greenhouse gas (GHG) emissions and certify these environmental improvements as carbon credits.

Sources: IBM[108]

Example of an ICT system to manage carbon footprint

Microsoft software to manage carbon footprint

The "Environmental Sustainability Dashboard", an add-on module to Microsoft's ERP software "Dynamics AX" offered at no additional charge, shall enable medium-sized companies to track their environmental impact and energy consumption from within their ERP solution. It allows companies to capture auditable data needed to measure key indicators related to energy consumption and greenhouse gas emissions as part of everyday business processes, thus helping them to comply with the emerging regulatory environment. Microsoft believes that this evidence will also help companies pinpoint ways to cut their energy consumption and costs.

Sources: Microsoft[109]

All in all, the market for emissions management tools is still in an early phase. As it is likely, however, that tracking the carbon footprint will be a new market for software applications, the software giants are currently planning their approach and have started developing solutions. Oracle, for example, has a solution called "Business Activity Monitoring" that tracks a company's carbon footprint back to its supply chain. IBM has developed an emissions monitoring and certification software called "GreenCert" (see box) and has also partnered with Oracle on carbon data management.[110] It can be expected that the large vendors will try to buy small software companies that have specialised in this area as part of their efforts to develop their own service portfolio in this new market.

108 See http://www.ibm.com/developerworks/wikis/display/im/GreenCert, accessed in June 2009

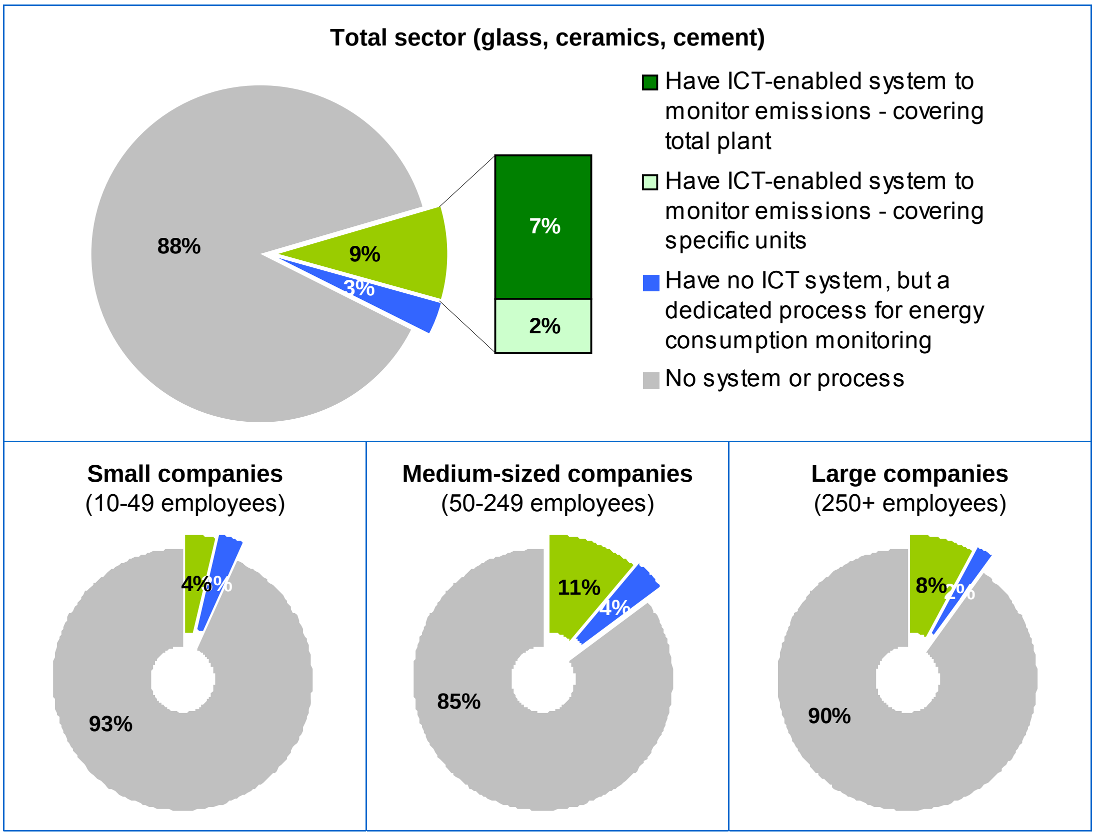
109 "Microsoft Helps Businesses Manage Their Carbon Footprint and Identify Cost-Saving Opportunities", press release, 9 February 2009 (http://www.microsoft.com/presspass/press/2009/feb09/02-09JDTPR.mspx, accessed in June 2009).

110 "With Carbon Regulation Looming, SAP to Buy Carbon Software Startup", written by Katie Fehrenbacher, published at earth2tech (http://earth2tech.com/2009/05/11/with-carbon-regulation-looming-sap-to-buy-carbon-software-startup/, accessed in June 2009).

Adoption of ICT systems for GHG emissions management

Specific systems or modules for monitoring and measuring GHG emissions are **not yet widely diffused**. In the GCC industry, less than 10% of the companies interviewed said they had an ICT-enabled application to systematically monitor GHG emissions. A further 3% said they did not have an ICT solution for this purpose, but had implemented a dedicated process for systematically monitoring and analysing their emissions. This leaves close to 90% of the companies which apparently have no systematic approach to emissions management (see Figure 39). In contrast to the wider-diffused EMS, there is hardly a difference between companies of the various size-bands in this respect. Even among large companies, only few use currently ICT systems to track their emissions.

Figure 39: % of companies using an ICT system or a dedicated process for monitoring their greenhouse gas emissions



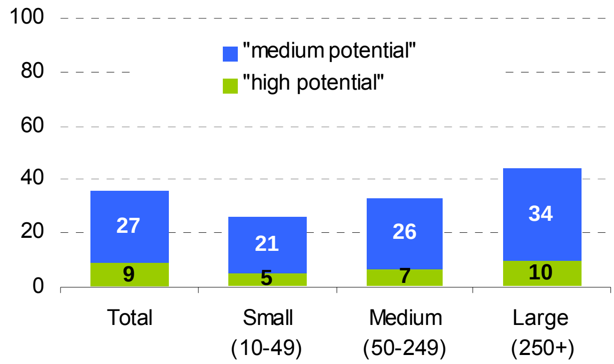
Source: e-Business Survey 2009 by the SeBW

Perceived potential of ICT systems for reducing emissions

Because of the small installed base of such ICT systems, it was not possible to obtain statistically meaningful results from users about the effectiveness of these systems from users. The last question in the GCC survey, however, provides evidence of the expectations of companies in the sector regarding the potential of ICT for reducing emissions. In general, companies are rather sceptical whether ICT holds a significant potential for reducing GHG emissions. The full results are included in Figure 40.

Only about 10% of all companies –and notably the larger ones– see a "high potential" of ICT in this respect; about 27% see at least a "medium potential" (see Figure 40). Larger companies are slightly more optimistic; about 45% attribute at least some potential to ICT in this respect. Thus, companies are more convinced about the potential of ICT for increasing energy efficiency (60%) than for reducing emissions.

Figure 40: % of companies thinking that ICT has a high / medium potential for reducing emissions



Figures for "total" are weighted by employment (companies representing x% of the sector's employment).
Figures for size-bands in % of enterprises. N (total) = 676.

Source: e-Business Survey 2009

5.2 Delphi-style survey

In order to provide further context for the results from the econometric analysis, a Delphi-style survey of experts in the five analysed energy-intensive industries was conducted. A traditional Delphi survey requires that a selected group of experts is posed certain questions in two rounds: the second round involves the same set of questions as the first round, but the experts are presented with first round results and are given the opportunity to change their answers. When answers change from the first and second round, the dynamics of expert opinion are better understood.

This survey addressed three areas of the intersection between ICT and emissions in energy-intensive industries – the perceived impact of emissions regulation on industry business practices, the use of greenhouse gas emissions monitoring systems, and the potential for ICT to reduce greenhouse gas emissions – through six questions. The results of the survey are explained and reported in this section.

5.2.1 Survey method

The survey conducted in this study was executed based on Delphi principles, although not strictly according to the Delphi method, so the survey is denoted “Delphi-style”. In order to find relevant interview subjects, three pools of experts were considered: representatives from companies in the five energy-intensive industries, representatives from industry organisations for these industries, and representatives from research institutions on the dynamics of these industries.

Representatives from companies were those determined to be the closest to the pulse of corporation opinion regarding ICT and environmental policy, e.g. technology managers, environmental policy managers, and in other cases press representatives. Since the econometric analysis in this study is confined to eleven European countries due to data limitations, the pool of possible respondents was enlarged to the EU-15 plus the Czech Republic and Slovenia in order to cull qualitative insights from areas that could not be analysed quantitatively. Respondents were also informed that their personal or company information would be maintained confidential.

The experts that finally participated in the survey were selected according to their expected ability to contribute knowledge on the topic and to their willingness to do so. The assembled group of twenty-three respondents aims to be indicative rather than statistically representative, with seventeen representatives from companies, five from industry organisations, and one from a research institution. At least four representatives from each industry were presented with the questions in this survey, with six from the metal sector and five from the transport sector. The respondents come from companies of various sizes, with representatives from the largest players (based on output) specifically sought out and utilised when possible. Representatives come from nine different countries within the EU-15 and from the Czech Republic.

In the first round, survey questions were posed through an online questionnaire or in a telephone conversation, depending on the convenience of the expert respondent. The questions were exactly the same no matter the medium. In the second round, questions were posed through e-mail versions of the online questionnaire, with the results from the first round attached in graphic form. Respondents were asked to respond with any changes to their opinion based on knowledge of the attached results. In each round of questions, respondents were also given the opportunity to write or speak any further comments on the topic as they wished.

The results of the six survey questions are reported in aggregated form, designed to give an overview of energy-intensive industries in Europe as a whole. However, important differences in regulation across these industries and countries must be kept in mind, and particularly interesting trends within specific sectors are also reported. The aggregated results are transformed so as to place equal weight on responses from each industry, even though certain industries provided a disproportionate amount of participants.

5.2.2 Impact of emissions regulation on business practices

The first two questions of the survey were designed to illuminate the broad effect of environmental policy (both EU ETS and general regulations regarding carbon emissions) on industry business practices. Especially in the context of the present study, the extent to which industry responds to environmental policy is key information for policymakers.

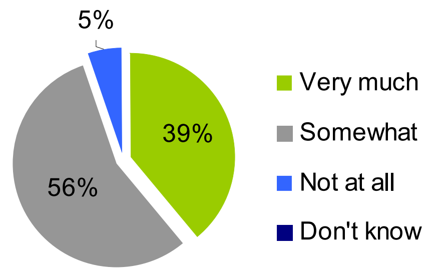
As noted in section 1.5, European regulation is not yet fully harmonised in this regard. The Europe-wide EU ETS system was introduced in 2005 to allow carbon trading. The EU ETS is being implemented in distinct phases or "trading periods" (EU Emissions Trading Scheme, 2009). Phase 1, from 1 January 2005 to 31 December 2007, was a three-year pilot phase in which a price for carbon and necessary infrastructure was established. During Phase 2, from 1 January 2008 to 31 December 2012, the volume of national emission allowances permitted was reduced below the 2005 level in order to ensure actual emission reductions. This phased-policy programme is likely to have a large impact beginning in Phase 2, in which national caps are actually implemented.

Aside from the EU ETS, national regulations are sparse. Only Sweden, Denmark, Finland, and the UK currently levy carbon taxes. The extent to which industry experts will view business practices as changed due to regulations related to carbon emissions in general is likely based upon geographic location as well as industry, therefore, an effect that has not been captured by this survey. Nonetheless, results regarding the impact of greenhouse gas emission policy on business practices in energy-intensive industries provide a promising indicator of the ability of European policy to alter business practices in the industry (see Figure 41).

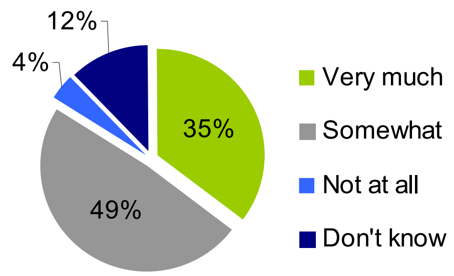
Industry decisions on ICT use can be a function of a variety of elements: firm production processes, need for coordination among business units, and state or European regulation and incentives. According to this study's Delphi-style survey, both national regulation and the EU ETS have a large impact on business practices in European energy-intensive industries. A total of 95% of experts questioned responded that business practices in their company and/or industry had changed "very much" or "somewhat" due to environmental regulations regarding carbon emissions. A total of 84% responded in the same way when questioned about the impact of the EU ETS. As EU ETS moves further into the second phase of its implementation, it is not unlikely that industry business practices will continue to change.

Figure 41: Policy impact on business practices

(a) Extent to which industry business practices have changed due to environmental regulations regarding carbon emissions



(b) Extent to which industry business practices have changed due to the European Union Emissions Trading Scheme (EU ETS)



Source: DIW econ, 2009.

The results presented in Figure 41 are somewhat surprising given the results from the similar question posed in the Pilot survey in the glass, cement, and ceramic sector where only 46% of the respondents (ICT decision makers in the glass, ceramic, and cement industry) said that EU ETS was a "very important issue" or "somewhat important issue" for them (section 5.1). This difference is possibly due to the aggregation of responses across industries in the Delphi-style survey. Moreover, it might also be due to the type of survey respondent. While the pilot survey questioned representatives of companies from different size-bands within the sector, the Delphi-style survey targeted representatives from the largest players who were willing to participate. Furthermore, ICT managers were the primary subjects in the pilot survey, while environmental managers, ICT managers and spokespersons were all participants in the Delphi-style survey. This broader range of expert subjects has probably a better knowledge of the interaction between firm practices and European emission regulation. To some extent, the difference in results across surveys may also be indicative of a disconnect between ICT business units and environmental policy units, in which ICT managers are less focused on the evolution of the firm with regard to environmental regulation and more focused on the implementation of ICT systems for firm efficiency.

As mentioned, the Delphi-style survey gave participants the option to provide any other comments at the end of their response process. A few of these responses are particularly informative regarding the survey's investigation of the impact of GHG policy on industry business practices:

> ***Comments on the impact of emissions regulation***
>
> ***In the chemicals, rubber, plastic and coke sector:***
>
> *"Quite a few companies have been putting up windmills in order to reduce energy use [to] comply [with EU ETS]…[there have been] big investments in combined heat and power as well, although that is not rewarded as it should be in the latest draft of the EU ETS."*
>
> ***In the glass, cement, and ceramic sector:***
>
> *"How you produce is always dependent on what laws are in place there. In Austria, there are strict regulations and we are always checked by the government, which affects our business practices."*
>
> *"We already made a lot of changes to business practices for efficiency reasons even before regulations were in place [including] a group-wide [carbon] monitoring system."*
>
> *Source: Delphi-style survey (respondents anonymous)*

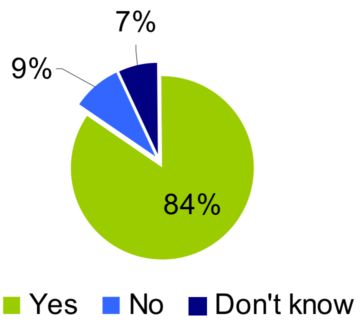
These comments provide insight into the range of industry opinions regarding the impact of carbon emission policy on business practices. A respondent from Austria affirms a strong and direct impact on business practices due to policy. A respondent from the chemical sector in the United Kingdom provides some examples of how business practices have changed due to EU ETS specifically: new investments in large non-ICT capital stock that is designed to reduce energy and thus emissions. In contrast, the third respondent (from the GCC sector) opines that emission regulations do not necessarily have a drastic impact on firm business practices. Business decisions made because they are profitable for the company – such as investments in capital or changes in processes to increase efficiency – can often coincide directly with changes desired in order to reduce environmental degradation. In this sense, ICT capital can be particularly instrumental.

5.2.3 Adoption of ICT systems for GHG emissions management

ICT has been touted as instrumental for efficiency improvements in the overall production process as well as for enabling the implementation of carbon emission-monitoring systems. The next three questions of the Delphi-style survey investigate the implementation of greenhouse gas emission monitoring systems in energy-intensive industries. The first question inquires about the decision to implement a monitoring system, the second about the scope of the system, and the third about the integration of ICT into the system. Results are shown in Figure 42.

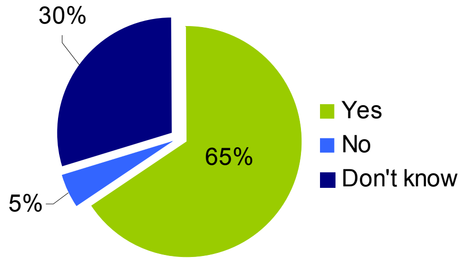
Figure 42: ICT use for emissions management

(a) Use of a dedicated process for systematically monitoring greenhouse gas emissions

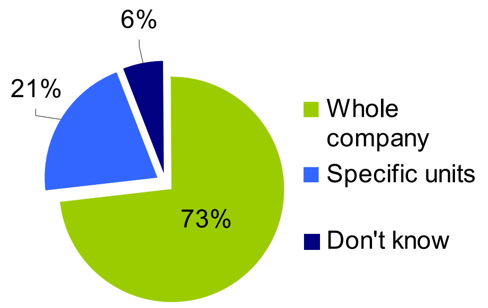


Source: DIW econ, 2009.

(b) Utilisation of an ICT-enabled system for the emission-monitoring process



(c) Coverage of emission-monitoring process



Across all five energy-intensive industries analysed, response regarding the implementation of systematic processes for monitoring greenhouse gas emissions is impressive. Of the experts questioned, 84% attested to the implementation of such a system in their company and/or industry. These experts are primarily from the largest European corporations and industry groups in the five sectors, and thus may be biased toward implementing monitoring systems in order to stay ahead of the curve. This bias could be reflected in the difference between this high number and the results from the GCC pilot survey (section 5.1) in which 91% of companies in the glass, cement, and ceramic sector surveyed *did not* have a dedicated system for monitoring emissions.

Interestingly, the results from question (c) in Figure 42 on the coverage of the emission-monitoring process are in line with the results from the pilot survey. The pilot survey found the emission-monitoring processes implemented in the whole company versus specific business units at a similar 7:2 ratio to that in the Delphi-style survey. When companies in European energy-intensive industries implement emissions-monitoring systems, they are almost three times more likely to implement the system in the whole company as opposed to specific business units.

Further comments from experts interviewed in the Delphi-style survey provide insight:

Comments on the use of ICT in emissions-monitoring systems

In the chemicals, rubber, plastic and coke sector:

"Yes to monitoring, because under the UK climate change agreement, we have to [monitor greenhouse gas emissions] in order to get a rebate. There are complex rules about how far up the line a subsidiary goes to its parent, or how many subsidiaries are covered by the parent [in order to determine where the carbon reduction commitment applies]."

In the glass, cement, and ceramic sector:

"We use a group-wide monitoring system based on SAP, then we have an integrated group data-base, and I can click on the bottom and see the carbon status."

In the basic metal and fabricated metal sector:

"Our automated and information system is on a very high level. We are monitoring what is possible and controlling automatically what is possible to control."

Source: Delphi-style survey (respondents anonymous)

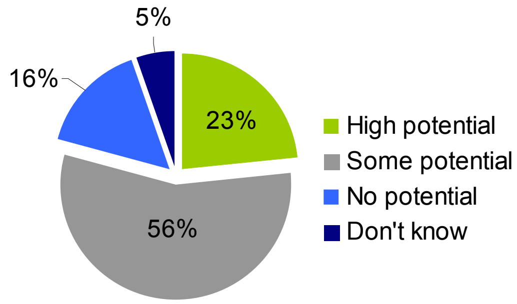
As the expert from the chemical sector attests, the decision to monitor carbon emissions is likely a result of a cost-benefit decision in the frame of European carbon regulation. The second two expert comments illuminate the complexity and scope of monitoring systems. In both instances, ICT is specifically mentioned as a key component of the system. ICT seems to enable the use of emissions-monitoring systems through improvement in the user interface and scope of system-user interactions, provision of real-time information that can be used by managers for decision-making, and the control of various aspects of production in order to optimise output and emissions.

5.2.4 Potential of ICT for reducing emissions

The last question of the Delphi-style survey addresses the broad potential of ICT to reduce greenhouse gas emissions in energy-intensive industries (see Figure 43). The results from this survey are more promising than in the pilot survey in section 5.1, but not overwhelmingly supportive of ICT's role in *reducing* emissions.

Just over three-quarters of experts interviewed find ICT to have "high potential" or "some potential" for reducing GHG emissions. The percent of respondents asserting "no potential" (16%) is discomforting, but these responses must be contextualised by further comments submitted by respondents, which emphasised the role of ICT in monitoring, but not necessarily reducing, greenhouse gas emissions.

Figure 43: Potential of ICT systems for reducing greenhouse gas emissions in energy-intensive industries



Source: DIW econ, 2009.

When interviewed experts responded with further comments, they highlighted the importance of ICT in monitoring carbon emissions:

Comments on the potential of ICT for reducing GHG emissions

In the glass, cement, and ceramic sector:

"The potential of ICT to reduce emissions is nothing, but to monitor – yes."

In the transport and storage sector:

"In order to gain the largest reduction in CO2, ICT systems need to be supplemented with various other measures and systems."

In the basic metal and fabricated metal sector:

"I would say a high potential, but I would have to say some potential because I do not think the implementation [of such systems] is that easy."

In the paper, pulp, printing, and paper products sector:

"I don't see any benefit to special new ICT systems. Present ones are enough."

Source: Delphi-style survey (respondents anonymous)

A respondent from the paper sector emphasised that the state-of-play in the industry was sufficient with regards to ICT systems, suggesting that firm knowledge of ICT use for efficiency gains and monitoring systems was already high in his sector. In the opinion of industry representatives, further gains to emission reduction will not stem from ICT but from other improvements in business practices, such as the implementation of abatement systems or changes to chemical and production processes in order to reduce emissions at the outset. When ICT systems are difficult to use or integrate with other business processes, their potential to reduce greenhouse gas emissions seems to be lower.

5.2.5 Conclusions

The Delphi-style survey provides a broader perspective on the opinion of experts from energy-intensive industries, including company representatives, industry group members, and researchers, on emissions and ICT systems. In contrast to the specific sector survey in the glass, cement, and ceramic sector (section 5.1), the experts questioned were emphatic about the strong impact that both the EU ETS and general emissions regulation has on business practices in their five industries. Interviewees revealed that large capital investments in renewable energy technologies as well as investments in ICT-based emission monitoring systems had been made as a result of these emissions regulations.

Carbon-emission monitoring systems were found to be relatively common. Only 5% of systems were reported to be non-ICT based, with almost three times as many companies implementing these systems over the whole company (or even group) as opposed to specific business units. The motivation for the implementation of such systems and the decision regarding their scope are based on a cost-benefit analysis that is strongly influenced by the frame of emission regulation. The system of rebates in the UK was reported to be particularly comprehensive, while at least one respondent complained that benefits for energy-reducing investments were not sufficient under the current EU ETS.

Lastly, the opinion of industry experts regarding the potential of ICT systems seems to be split. ICT systems are reported to be integral to emissions monitoring systems, but achieving actual reductions seems to require a more comprehensive production overhaul.

6 Conclusions and policy recommendations

With the goal of discovering the impact of ICT on greenhouse gas emissions in energy-intensive industries, this report has employed a combination of econometric estimation techniques, case studies, and surveys. In the first section of this chapter (6.1), we provide an integrated review of the main results and discuss the implications for the role of ICT in improving the sustainability of European energy-intensive industries. In the second section (6.2), we provide policy suggestions in order to assist European policymakers in putting the results in this report to good use.

6.1 Putting econometric results in context

The econometric analysis in this study discovered a significant effect of ICT capital share on the sustainable efficiency –the ability to increase output with given inputs and at constant levels of emissions, or to reduce emissions at constant levels of output– of most European energy-intensive industries. In addition, we discover additional beneficial roles for ICT in the basic metal and fabricated metal sector and in the transport and storage sector, where increases in ICT capital bring non-linear decreases in emissions per output and allow reductions in aggregate emissions at current output levels. Highly significant structural differences across sectors, within sectors, and over time, however, significantly affect our ability to observe a consistent and interpretable effect of ICT capital on various measures of sustainability and emissions impact across the five sectors. In light of these variations, our surveys and case studies provide essential context and validation for the econometric results.

- **Industry experience with ICT-based production optimisation systems explains ICT's statistically-proven ability to enhance industry sustainability**

Our most robust econometric conclusion is that increased ICT share in total capital allows increased aggregate production without emissions increasing at the same rate.[111] As all case studies demonstrate, ICT-based production optimisation systems are at the heart of these efficiency gains. ICT is used for improving the time and fuel-efficiency of transport routes and optimising furnace temperatures in steel processing, for example.[112] Various quality and service improvements as additional benefits as a result of the implementation of ICT-based optimisation systems are also worth noting. In turn, these firm-level observations on the usefulness of ICT to achieve efficiency and sustainability gains provide support for our econometric estimations despite concerns about the aggregated nature of the ICT measure used.[113]

- **Monitoring and feedback systems can enable reductions in GHG emissions that have not yet been captured by the econometric analysis**

Both surveys indicate the necessity of using ICT in order to build an effective emissions-monitoring system. Monitoring is the first step toward achieving reductions. The Deutsche Post/DHL case study provides the consummate example of how ICT can be extensively

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[111] We refer to the output-oriented measure of sustainable efficiency in the semi-parametric analysis. See sector results in section 3.2 and 3.3.

[112] See case studies for Deutsche Post World Net and Corus Rail.

[113] See section 3.1 for further discussion on the use of aggregated data.

employed to enable a spectrum of emissions monitoring systems. ICT capital investments for emissions-monitoring also enable Deutsche Post/DHL to offer monitoring services and carbon offset opportunities to its customers, creating a multiplier effect. This cross-sectoral link between ICT capital and emissions reductions was not directly captured by the economic analysis. Furthermore, the case studies indicate that the most significant realisation of efficiency benefits and emissions reductions through ICT within energy-intensive industries took place after 2005, which is beyond the range of the data set. The spread of ICT-based emissions-monitoring systems has been particularly weak within the period covered by available data.[114] The estimated effects in this study (which are based on the period from 1995 to 2005) should thus be taken as descriptive of *historical* trends. Wider implementation of ICT-enabled energy-efficiency and emissions-monitoring systems is likely to strengthen the direct link between ICT and emissions intensity discovered by econometric methods in the coming years. Our estimations may well be the lower bound of the true effect of ICT on sustainability in energy-intensive industries, especially when an ICT investment has the dual effect of reducing emissions through production efficiency and "enabling" further reductions through its monitoring and feedback function. However, the future dynamics of returns to ICT capital growth cannot be expressly concluded with available data and the applied methods.

- **Specific policy and structural environments in each country are important determinants of the emissions intensity of production, and can make or break the effect of ICT**

Across all econometric analyses, structural effects –such as static differences in policy, geography, the regulatory framework and culture– are highly important determinants of emissions intensity. Industry opinions confirm a strong influence of such climate change policies and regulation on industry business practices. Industry investments in energy efficiency and emissions monitoring systems were also reported to be a direct result of national or international incentives.[115] These incentives differ considerably across the range of countries in our econometric sample, partially explaining the significance of structural effects in the econometric results. Some countries have imposed a cost on emissions through carbon tax regimes, others have implemented incentive systems to support renewable energies, and others lack climate change policies altogether. As further support, the Siemens case study observes that industry demand for ICT-based monitoring technologies increases with the environmental-consciouness of the industry's customers. Varying levels of concern for sustainability in European countries, both on the part of end users and manufacturers, translates into significantly different patterns of ICT adoption and GHG emissions per output. All in all, the policy and culture of the country in which an industry operates forms a highly varied and complex structure which can hinder or enhance the deployment of ICT for marginal reductions in emissions.

- **Improvements in awareness and changes in the type of marginal ICT investment are crucial for further improvements in climate impact**

The significant relationships between ICT capital and emissions per output discovered by our econometric analysis are also *significantly non-linear*, especially in the form of an emissions-reducing but diminishing impact of ICT. Diminishing returns to ICT investment, at least for a firm in the chemical sector, are supported e.g. by the Solvay case study. To be sure, an advanced firm with knowledge of all available ICT technologies is likely to see

[114] See the pilot survey in the glass, cement, and ceramic sector in section 5.1.

[115] See sections 5.1 and 5.2.

diminishing returns to ICT investment. As efficiency potential is realised and remaining emissions elasticity becomes entirely tied to input composition, ICT is less important for climate impact. However, firm-level dynamics are much different from sector-level dynamics, and our econometric methods likely do not capture the exact dynamics of the effect on GHG emissions from ICT deployment.

When more "Solvay-like" firms (that quickly adopt current technology) exist in a sector, our econometric analysis is more likely to capture a significant and diminishing link between ICT and emissions at the sector level. However, we only find this link in the metal sector, and for older, higher-income EU member states in the transport sector. The lack of consistent sector-level relationships that reflect firm-level opinions is a general problem in the analysis of the impact of ICT based on sector level data, because the visibility of ICT impact very much depends on the distribution of firms in the sector between "early adopters" of ICT and those that lag behind.[116]

Energy experts at Siemens observe that the awareness of energy-efficiency concerns and demand for production optimisation technologies has only grown strongly in the past two to three years for most energy-intensive industries.[117] The level of awareness also differs by industry, which helps explain the strongly varied econometric results in this study. The steel industry, cited as an early-adopter of energy-mangement technology by Siemens, is also the sector in which we find the most conclusive link between increased ICT and lower emissions intensity.[118] An emissions-reducing impact of ICT that is not statistically significant at the sector (as in the chemical sector, for example) could be a result of weak sector-level *adoption* of ICT rather than evidence against the *potential* for these technologies to improve sector sustainability. Indeed, Siemens finds that awareness of ICT-based efficiency systems has only recently increased in the chemical sector and estimates particularly large potential savings from ICT systems, despite the pessimistic outlook of the early-adopter Solvay.

Structural homogeneity (within a sector and across sectors) is also likely to determine whether the econometric analysis finds significant evidence for an emissions-reducing effect of ICT. A larger set of homogenous firms increases demand for a particular ICT solution within a sector, making it more likely that this service is developed and implemented – and subsequently magnifying the emissions reductions generated by industry ICT capital stock. Homogeneity in processes among sectors (such as use of a standard electricity generation technology) similarly enables increased investment in ICT capital that increases efficiency and reduces emissions, increasing the likelihood that econometric analysis finds a consistent and meaningful relationship between ICT and emissions in all sectors.

When currently available technologies produce significant reductions in emissions, but these technologies are not adopted industry-wide (for reasons of low awareness, low economic returns or because of structural/technical complications), the industry econometric analysis will not find significant emissions-reducing effects of ICT. As marginal increases in ICT capital stock at the industry level are comprised more of investments in process optimisation and emissions monitoring systems, future econometric analyses will

[116] For example, see e-Business W@tch (2008 b):

[117] See Siemens case study in section 4.1.

[118] The paper sector was also cited as an early adopter, but subsectoral structural differences have prevented us from obtaining meaningful econometric results with which to compare this observation. See section 3.2.3.

probably confirm a more significant role for ICT in all energy-intensive sectors. In the case where ICT has truly reached its potential for producing efficiency gains (this is more likely for a particular firm than for the sector as a whole) a revamping of production processes and non-ICT capital structures in addition to the implementation of ICT-based emissions monitoring systems will be necessary to reduce GHG.

6.2 Policy recommendations

In principle, recommendations that are applicable to all EU member states would be desirable in order to facilitate policymaking. However, ICT and emissions policy should be carefully designed to consider the significantly different nature of the relationship among sectors, among European countries, and even in a given industry over time. With this in mind, we offer the following set of recommendations in order to fully realise the restricted but distinct potential for ICT to reduce emissions in European energy-intensive industries.

Strengthen economic incentives for reducing greenhouse gas emissions

While ICT can be significantly emissions-reducing, it is not the "silver bullet" for greenhouse gas emissions abatement. When we calculate the cost of an ICT investment needed to achieve a one tonne GHG emission in a given sector, it is much more expensive than the current market price per tonne CO2 equivalent.[119] ICT is also expensive compared to other possible abatement technologies.[120]

WIth a range of different technologies that can reduce emissions at varying costs, the most efficient way to discover the least-cost technologies for reducing GHG emissions is a cap-and-trade system which imposes a cap on total emissions while leaving the choice of specific abatement technologies to the market. With the EU ETS, such a scheme has been introduced in Europe in 2005. For this system to work effectively, the cap must be sufficient enough so that the price for carbon emissions is notably high. A high cost on emissions will induce the implementation of various technologies to monitor, manage and reduce emission levels.The EU ETS is the state-of-the art instrument to internalise externalities caused by GHG emissions (i.e. climate change) into the decision-making process of individual firms, since it incentivises firms to reduce their emission levels while still allowing the choice of the most cost-efficient abatement technology. Hence, policies should be mainly focused on imposing sufficiently high prices on carbon emissions by setting reasonalby restrictive caps within the frame of EU ETS, rather than directly supporting specific abatement technologies. Nevertheless, it can be expected that the technologies that different firms will select will largely be ICT-based even without direct

[119] See discussions in the metal and transport sector results (sections 3.2.1 and 3.2.5, respectively) and in the key findings of the econometric analysis in section 3.3. As also noted in these sections, the quantified cost in ICT should not be taken as an exact number, but reference point for the cost of deploying ICT for emissions reductions. The ICT cost calculated in this report is based on the available EU KLEMS measure of fixed ICT capital stock. This measure ignores e.g. the personnel and training costs associated with the implementation and effective use of an ICT-based system, while possibly including costs that would not be incurred if the unit of ICT investment were designed only for the purpose of e.g. efficiency gains or an emissions-monitoring system.

[120] See McKinsey & Company, Inc. (2007).

policy support, as exemplified by the implementation of ICT systems for energy management.

Various evidence suggests that the price of carbon under the EU ETS has not been sufficient in the past. By the end of the first trading period of the ETS in 2007, the price for emission permits had fallen to almost zero, demonstrating that the current cap did not impose a binding constraint on the activity of affected firms. For the second period, from 2008 to 2012, the impact of the approved caps on carbon prices remains to be seen. The empirical investigations in this report find mixed evidence on the impact of EU ETS on firms. On one hand, over 75% of experts in the Delphi-style survey find that EU ETS has influenced business practices in their industries. On the other hand, most firms in the case studies do not cite EU ETS as a driver of ICT implementation decisions. Futhermore, only three (metal, paper and GCC) of the five energy-intensive sectors addressed in this report are actually covered by the EU ETS, while two (transport and chemical sectors) are not.

Given that the theoretical economic potential of the EU ETS has not yet been realised, the most central policy recommendation in the context of this report is that economic incentives to reduce GHG emissions should be strengthened. Above all, this requires setting emission caps more restrictively throughout all member states. This policy move is the crucial foundation for generating permanent market-based incentives for reducing emissions, both with ICT systems and without. Optimising the EU ETS framework will minimise the overall economic costs for realising a given emission cap, and thus is clearly prefereable to all different measures of direct support to specific abatement technologies, including ICT.

Foster the development of ICT-based process optimisation systems that integrate energy and emissions management systems

Capital stock data and the case studies clearly demonstrate that firms are investing in ICT for process optimisation. While our calculated "ICT cost"[121] for a reduction in emissions suggests that these investments were not largely financed with savings from emissions reductions, additional benefits to ICT – energy cost benefits, general process innovations, even quality improvements – provide sufficient incentives to stimulate investment. To enable managerial selection of the innovations that produce significant emissions reductions, however, specific ICT-based energy management and emissions management systems are needed. The EC has identified the potential of ICT systems for reducing GHG emissions through energy-efficiency in COM (2009) 111 as a "quantifier" of and "enabler". In order words, ICT systems quantify how efficiently a production process is executed and enable management to make appropriate changes to these processes. These two major purposes of ICT are embodied by energy-management systems, as confirmed by our case studies and surveys, and apply to emissions-management systems as well. The spread of ICT emissions-management systems has been incentivised for marketing and reputational reasons, by personal management concern for climate impact, and by the opportunity to profit from providing related carbon management services to customers. The adoption of these systems has been historically weak and has only recently increased, indicating the need for some sort of policy support to encourage faster adoption of the ICT systems that truly work against climate change.

[121] See section 3.3 for a summary of these calculations.

With the EU ETS functioning efficiently in all EU countries, direct support for specific technologies for firm-level emissions reductions will not be needed. However, budding market incentives can be encouraged by **indirect policy support** measures specifically for **ICT-based energy and emissions management systems** without distorting the market. These measures can come in many forms, as listed in Table 28.

Table 27: Suggested indirect policy support for ICT systems

Policy Support	Foundation and Implications
Foster increased industry and cross-sectoral cooperation for development of energy and emissions-management ICT systems	Two heads are often better than one, especially when ICT-based energy and emissions management systems require a combination of technical and managerial knowledge. Fostering collaborative innovation among firms within a sector and even cross-sector (or with academic entities) specifically with regards to emissions-reducing ICT systems will accelerate the reduction of emissions per output in all energy-intensive sectors. Maersk's cooperation with a university for the development of influential ICT systems[122] exemplifies the benefits that cooperation can bring.
Documentation and publication of best practises regarding energy and emissions-management ICT systems	Along with providing greater support in the form of financing and incentives for the implementation of ICT-based optimisation and emissions-monitoring systems, policymakers can play an important role as centralisers of private sector knowledge and best practises. The case studies in this report discovered a wealth of interesting and useful ICT innovations that contribute directly to efficiency improvements and/or emissions reductions in European energy-intensive industries. However, these systems are often customised to the firm in question and/or require a great coordination effort for implementation. The more the firm-specific knowledge and experience can be gathered and shared across the industry, the faster industry-wide reductions in GHG emissions can be achieved.
Offer financing support for research and development of energy and emissions-management ICT systems	Not all firms have access to the research power that the large innovators in our case studies do, hindering ICT development from the get-go. Collection and distribution of best practices and lessons from the implementation of current ICT systems can speed up the adoption process, especially for smaller firms, leading to lower emissions per output for the aggregate sector. Support would be smartly targeted at research and development that furthers the cross-sectoral scope and implementation flexibility of current and new ICT-based energy and emissions management systems.
Increase awareness among end-users and manufacturers who form the market for energy-intensive industries	In general, increased public awareness and concern for emissions will also provide market-based pressure for emissions reduction when the public is the end-user. The greater the awareness, the greater the pressure on energy-intensive industries to implement energy and emissions management systems.

[122] See section 4.5.

The EC has made committements to policy progress in some of these areas in its most recent communications, as discussed in section 1.5. These include a recognition of the lack of easily accessible means by which potential energy-saving ICT innovations can be compared, and calls for support for sharing of data and best practices support for ICT innovations to combat climate change from Member States. However, the most specific plan for sharing of best-practices seems to be directed at regional and local authorities in the form of a web portal, as mentioned in COM (2009) 111. Other support for pilots and best practice is in the hands of member states to provide. The collection of best practices from industry for the use of other private companies may face obstacles due to concerns about losing one's competitive edge, and thus appropriate incentives may need to be provided.

In related initiatives, the EC has encouraged public-private partnerships for R&D to increase energy-efficiency gains from ICT. However, these efforts are focused on transport activities, such as through the 7th Framework Programme for Research and Technological Development. Procurement and PPP projects can increase the efficiency of public infrastructures, which is certainly necessary to reduce GHG emissions from the EU as a whole. For widespread carbon reductions from efficiency gains coming from the industrial private sector, collaborative innovation among private sector actors should also be encouraged. This collaboration can be facilitated through R&D financing support. Although not expressly studied in this report, financing options are provided under Cohesion Policy and are to be enhanced through the Recovery Plan proposed by the Commission in November 2008 (COM (2009) 111).

In general, these particular policies recommended by the EC are in line with the recommendations in this report. However, a wider scope of action and design of further creative incentives for emissions-reducing innovation is required, along with a strong effort to gain support both among all Member States and within industry.

Harmonised guidelines for recording and reporting emissions production in all sectors

In conjuction with a strengthened EU ETS and better incentives for the development and implementation of ICT-based energy- and emissions-management systems, completely standardised regulations regarding the monitoring and reporting of firm-level GHG emissions are needed. The EC has shown signs of supporting harmonisation of standards related to ICT for energy-management, such as recommending that Member States agree on EU-wide minimum specifications for smart meters (see section 1.5). However, standardisation must also focus directly on carbon emissions. Emissions costs can only be correctly allocated if all firms are reporting direct greenhouse has emissions according to the same procedures. Furthermore, life-cycle carbon-accounting systems, such as those implemented by Deutsche Post World Net,[123] need to be standardised. Comprehensive standardisation of carbon tracking procedures will have myriad benefits.

First, a standardised means of comparing the carbon footprint and direct emissions of European firms will increase companies' appeal to both investors and consumers. As more industries come under the direction of EU ETS, investors face "carbon risk": whether a firm will be subject to substantially increased costs when it must pay for its carbon emissions.[124] With an ability to credibly report their potential carbon costs,

[123] See section 4.2.

[124] The Carbon Disclosure Project examines this issue in detail: http://www.cdproject.net/

European firms will be more attractive on the international financial markets. In addition, these firms will be more attractive to increasingly climate change-conscious consumers.

Second, this report encountered substantial analytical problems due to a lack of comprehensive and comparable data, and better-harmonised emissions-accounting and reporting systems across the European Union will greatly increase the scope of meaningful analysis that can be done on the role of ICT and greenhouse gas emissions in industry. This analysis can be directed at smaller subsectors than the five sectors defined in this study, and/or at groups of countries that have been found to have significantly different structural conditions in most sectors, such as new Eastern European member states.

Focus policy support on new European Union member states

In all energy-intensive sectors analysed, we find significantly different relationships between ICT and GHG emissions when new Eastern European member states are excluded from the analyses. In some sectors, the emissions-reducing of ICT is simply of greater magnitude, but in other sectors the new member states seem to experience the opposite effect – increased ICT seems to have been historically associated with increased emissions. With the relatively recent economic transitions of these countries in mind, these results suggest that new Eastern European member states do not yet take advantage of the emissions-reducing ICT innovations as older member states do. These states likely require particular policy attention in order to guide marginal increases in ICT capital stock toward investments toward ICT-based energy- and emissions-management systems.

Furthermore, a special focus on wider implementation of ICT-based optimisation systems in the **transport sector in new European member states** is strongly advised. Where the EC has confirmed the importance of furthering ICT-based energy-efficiency gains for carbon emissions reductions in the transport sector in general (see section 1.5 and earlier sections of this chapter), these policies can be enhanced by a special focus on new member states. Case studies demonstrate that ICT-based systems significantly increase efficiency and reduce emissions in the transport sector, but the econometric analysis finds a historical emissions-reducing effect of ICT in the transport sector only for old, higher-income European member states. Furthermore, the transport sector comprises the greatest share of total economy emissions out of the eleven countries analysed, and new Eastern European member states produce the greatest emissions of the sector. Assistance for new, lower-income members in catching up in environmental efficiency in the transport sector will hit aggregate emissions where most desperately needed. All the policy support suggestions above apply, and even to a greater extent with regard to the transport sector. Extra policy support for the transport sector in new member countries can come in the form of grant financing for feasibility studies on the implementation of new ICT systems in current systems and incentives for national or large city governments to implement new efficient and integrated transport systems.

Enhance relevant data collection measures and scope of available data to support more comprehensive analysis

As discussed throughout this report, various gaps or undesirable characteristics of the data available for analysis limit the conclusions that can be drawn from our econometric methods. With a truncated production data set from EU-KLEMS, the effects of important developments in the ICT sphere and from the implementation of the EU Emissions

Trading System starting in 2005 are not incorporated into the econometric estimations. In order ensure that future structural evolutions can be analysed, we recommend that EU KLEMS continue to collect and publish the range of production data used in this report in future years.

The limitations to analysis do not just stem from the length of the data set, however. In order to reduce bias in the estimated effect of increases in ICT capital on GHG emissions (and on other important measures such as productivity), we recommend that a wider range of metrics regarding ICT be collected. These metrics should attempt to capture both the composition of ICT capital stock through disaggregated measures and the cost of implementing such ICT systems. Ideally, a measure of quantifying “embedded” ICT – the ICT systems hidden in other capital stock, such as vehicles, that are not classified as ICT stock per se – will also be developed. More detailed measures of ICT will allow for more precise cost-benefit analyses of how particular ICT innovations contribute directly to climate change and other phenomena of policy concern.

We also recommend the collection and provision of a firm-level data set in order to reduce the bias introduced in econometric analyses due to the use of aggregated production data. Countries that ratified the Kyoto Protocol are urged to collect detailed information on GHG emission levels, but this information is not provided in the form of a publically-useful data set. In the EU countries, emissions are measured and monitored for all production facilities (e.g. firm-level) that belong to a sector covered under the EU-ETS. However, these emissions data are not directly linked to other crucial production data such as gross output, factor composition and levels, etc. Certain private sector sources of firm-level information databases exist, which could be combined with emissions data as a first step toward creating a firm-level data set for more detailed policy analysis.

One central impediment to the collection of firm-level data is the desire of firms to maintain confidentiality. Confidentiality can easily be preserved by creating a data set with anonymous tags instead of firm names. Alternatively, data can be released only for specified research purposes instead of for general public use. The other major drawback to the collection of more data is, of course, its cost. This concern for cost will need to be weighed by the EC and other interested bodies against a desire to investigate and address the actual dynamics of European industry. It is clear that the effectiveness of sophisticated analyses of ICT capital, in particular, will remain extremely limited until such data is collected.

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IPCC: Intergovernmental Panel on Climate Change, www.ipcc.ch

OECD (2009): Organisation on Economic Co-operation and Development, www.oecd.org

UNFCC (2009): United Nations Framework Convention on Climate Change, unfccc.int

Abbreviations

DEA	Data Envelopment Analysis
DMU	Decision Making Unit
EU	European Union
EU ETS	European Union Emissions Trading Scheme
GCC	Glass, ceramic and cement
GHG	Greenhouse gases
ICT	Information and Communication Technology
IPCC	Intergovernmental Panel on Climate Change
OECD	Organisation on Economic Co-operation and Development
UNCED	United Nations Conference on Environment and Development
UNFCCC	United Nations Framework Convention on Climate Change

Appendix I: Extended methodology explanation

Estimation methods

This appendix describes the methods of estimating the regression equations that are implemented in this study, the assumptions made during the process, and the implications for the results.

The linear, log-linear and non-linear regression models from section 3.1.1 are estimated using the following three estimators: the ordinary least-squares estimator (OLS), the within-group fixed effects estimator, the generalised least squares estimator (GLS). In the following paragraphs, we discuss the properties of each of these estimators and the implications for our analysis.

The basic Ordinary Least Squares (OLS) estimator is applied only to the linear model. It treats all data as pooled, not allowing us to take advantage of the panel characteristics of our data (e.g. recognising the fact that our data is drawn over a certain period of time from a certain group of countries). This restriction has certain drawbacks for the purposes of this study. Most importantly, when an OLS estimator is applied to panel data and individual-specific unobserved effects are present, the estimation results can be inconsistent (Nerlove 2005). In this study, "individual-specific effects" is the technical term for the myriad structural differences among countries (our observed "individuals" within each sector). These differences could be caused by investment incentives, corporate tax policy, management culture, level of education of the labor force, or geographical constraints, for example. When working with panel data, it is important to control for these individual effects. Especially when macroeconomic data is used, individual-specific effects are extremely common and often significant. For example, Judson et al. (1999) find that country (individual) effects explain much more of the variance in energy consumption than do time effects. In this study, the existence of significant individual-specific effects would imply that the base level, or intercept, of the GHG emission intensity curve for each country in each sector is significantly different.

In response to the issue of controlling for individual-specific (structural) effects, a few estimation options are available. One option is to include dummy variables in the regression that represent each of the countries from our data set, in which case the OLS estimator can be applied and those individual-specific effects will be controlled for. However, the preferred estimation method is usually the within-group fixed effects estimator, because it allows one to easily control for all unobserved individual-specific effects without the addition of dummy variables. Precisely, the within-group fixed effects estimator controls for all unobserved individual-specific effects *that do not vary over the time period* through the use of a differences-from-means transformation of the data and the application of the least squares estimator.

The GLS random effects estimator is also commonly used to control for time-invariant individual-specific effects, but under different assumptions than the within-group fixed effects estimator. The within-group fixed effects estimator allows for the correlation of the explanatory variables in the regression equation with the unobserved time-invariant individual-specific effects. This allowance is particularly important to explore in this study. For example, it is possible that the ICT capital intensity of the metal sector in Germany is strongly associated with the particular corporate tax policies instituted in Germany (and so on for each country). In this case, the within-group estimator would be most appropriate. The random effects estimator, in contrast, makes the assumption that the explanatory variables are not correlated with the unobserved time-invariant individual-specific effects (Wooldridge 2002). Precisely, the random effects estimator treats the time-invariant individual-specific effects as a component of the regression error. In this case, returning to the previous example, there still could be a significant difference between the German metal sector's base-level GHG emission intensity and the metal sector's base-level GHG emission intensity in other sample countries. However, the ICT capital intensity of the German metal sector is treated as a phenomenon that is not related to the particular policy or geographical structure of Germany specifically.

During the course of the estimation process, the linear, log-linear, and non-linear models are estimated using both the fixed and random effects estimators. Both estimators are implemented with the use of cluster-robust standard errors. As highlighted in Stock and Watson (2008), not controlling for clustering in panel data can lead to a bias in standard error estimations. The use of cluster-robust standard errors relaxes the standard assumption of independence among all observations, instead assuming independence only across clusters of observations. This controls for heteroskedasticity and serial correlation of arbitrary form (Rogers, 1993), improving the robustness of this study's evaluation.

The estimated four regression equations are included below, without terms for structural effects:

Linear Model: (1)

$$\frac{GHG}{GO}_{it} = \beta_0 + \beta_1 NRG\_P_t + \beta_2 \frac{KICT}{GO}_{it} + \beta_3 \frac{KNICT}{GO}_{it} + \beta_4 time_t$$

Log-Linear Model: (2)

$$Log(\frac{GHG}{GO}_{it}) = \beta_0 + \beta_1 Log(NRG\_P_t) + \beta_2 Log(\frac{KICT}{GO}_{it}) + \beta_3 Log(\frac{KNICT}{GO}_{it}) + \beta_4 time_t$$

Non-Linear Model: (3)

$$\frac{GHG}{GO}_{it} = \beta_0 + \beta_1 NRG\_P_t + \beta_2 \frac{KICT}{GO}_{it} + \beta_3 (\frac{KICT}{GO}_{it})^2 + \beta_4 \frac{KNICT}{GO}_{it} + \beta_5 time_t$$

Non-Linear Model, Version 2: (4)

$$\frac{GHG}{GO}_{it} = \beta_0 + \beta_1 NRG\_P_t + \beta_2 \frac{KICT}{GO}_{it} + \beta_3 (\frac{KICT}{GO}_{it})^2 + \beta_4 \frac{KNICT}{GO}_{it} + \beta_5 (\frac{KNICT}{GO}_{it})^2 + \beta_6 time_t$$

In the above equations, $\frac{GHG}{GO}_{it}$ denotes emissions per output for a given country in a given sector, NRG_P_t is the annual producer energy price (Euro, 1995 prices), $\frac{KICT}{GO}_{it}$ is the ICT capital intensity of a given country in a given sector, $\frac{KNICT}{GO}_{it}$ is the non-ICT capital intensity of a given country in a given sector, and $time_t$ is the time trend included in the model (years). Country effects are not included in the models here for simplicity, but they are estimated during the estimation process.

The choice between a fixed-effects and random effects estimator is a technical one, which is made when the application of both estimators produces significant results.

Particular statistical tests are available that allow us to determine whether the assumption of no-correlation required by the random effects estimator is valid for the model and data in this study. When the assumption is valid, the random effects estimator is more efficient, and thus allows us to better estimate the significance of the effect of ICT capital intensity on GHG emission intensity. The random-effects estimator also allows inference for the underlying population (e.g. European countries for each sector), while the fixed-effects estimator only allows inference for the sample set (Baum, 2006). In this case, the results of this study would be only applicable for the eleven countries selected for analysis.

A few assumptions made with both the within-group fixed effects and GLS random effects estimators are important to note. First, although both estimators control for all unobserved effects that do not vary over time, unobserved *time-variant* individual-specific effects are also often of concern when working with macroeconomic panel data. For example, the within-group fixed effects estimator applied to our dataset would control for the effect of investment policies that have remained the same for the past twenty years, but it would not control for a distinct change in management efficiency since 2000. While in general concern about time-varying individual-specific effects is well-founded, this study's ability to control for these effects is limited by access to data and the desire to perform separate regressions for each sector. A common method for controlling for time-variant specific unobserved effects is to include dummy variables for each country, each time period, and for each combination of country and time period. However, this study's sectoral approach to the econometric analysis reduces the number of observations to just over 100 for each of the analysed sectors. If so many dummy variables were included, the loss of degrees of freedom would make the regression estimation results irrelevant. Ackerberg, Caves, and Frazer (2005, preliminary) offer a more sophisticated means of treating the issue of identifying a production function with unobserved, time-variant effects that could be correlated with the explanatory variables in the presence of scarce data. However, their approach is untested in other literature. Instead, the assumption is made that within a given sector, the unobserved effects do not vary over time. It is similarly assumed that within a sector, the time trend included in the model does not vary across countries. Lastly, within each sector, the effect of ICT capital intensity, non-ICT capital intensity, and energy price on emission is not allowed to vary across countries.

Model selection process

This appendix describes the process by which the most appropriate econometric model for each of the five analysed sectors is identified, including detailed descriptions of the statistical tests implemented.

In order to find the appropriate model for each sector, the linear, log-linear and non-linear models are estimated. All models are estimated with both fixed-effects and random-effects, and the linear model is additionally estimated without structural effects.

The first choice made is whether to model structural effects. For the within-group fixed effects estimator, the significance of the model is determined by a whole-model F-test, and the significance of the specific effects is determined by an F-test on those effects as a group. The whole-model ANOVA F-test tests the null hypothesis that the coefficients of the explanatory variables are simultaneously equal to zero (for each sector). Subsequently, a fixed-effects F-test tests the null hypothesis that the constant terms are simultaneously equal across countries within a sector (Baum 2006). Unless otherwise noted, this study rejects the null at a 5% level. For the random effects estimator, the significance of the model is determined by a Wald test. The Wald test applied for the random effects model similarly tests the null that the explanatory variable coefficients are simultaneously equal to zero. Unless otherwise noted, this study rejects the null at a 5% level.

Country effects are significant in all estimations, and so are included in the model, and the estimation results for the OLS estimation without country effects are not included in the reported results. The subsequent choice made is whether to model structural (individual-specific) effects as fixed effects or random effects. The Hausman test is a statistical test that helps make this decision. The Hausman test utilizes the regression estimates from a fixed and random effect estimation of the same equation and compares the estimated coefficients. The fixed effects estimator is consistent whether or not the assumption of no correlation between the explanatory variables and the unobserved individual-specific time-invariant effects is true. However, it is inefficient compared to the random effects estimator when the assumption is true. In contrast, the random effects estimator is consistent and more efficient only when the assumption is true. The Hausman test thus evaluates the null that the coefficients of the explanatory variables estimated with fixed and the random effects estimators are the same (Baum 2006). The null is rejected at a 5% level, with a rejection of the null implying that the fixed effects estimator should be used.

Aside from the decision on fixed v. random effects, a decision can also be made as to which of the three models most appropriately fits the data. This process is explained in the body of the report in section 3.1.1. The choice to move from the linear model to the non-linear one is made based upon the significance of the quadratic term, with a check to make sure that the adjusted R-squared has also improved in the non-linear model. The choice between the non-linear and the log-linear model is more difficult, however, because the R-squares are not directly comparable. Since the effect of ICT on emission is the central interest in this study, rather than finding a model that completely explains the variation in emission intensity in each sector, the significance of the ICT variable is also used as a model-choice metric. For example, if the ICT effect is much more significant in the non-linear model, that model is preferred over the log-linear one. However, the choice of one particular model is not truly necessary in the context of this report, so often the results from both the log-linear and non-linear model are reported and compared without making a decisive conclusion as to which model is best. In any case, this study recommends more research into the specification of the functional form of the relationship between ICT capital and GHG emissions in each of the energy-intensive sectors analysed.

As a final note, the second version of the non-linear model, in which the quadratic term for non-ICT capital is also considered, is only once formally included as part of the discussion of the best model for ICT capital intensity and emission intensity in this study. In other sections, the results from the non-linear model with quadratic non-ICT trends are used to confirm the validity of the estimated effect of ICT capital intensity in the other three models, but the quadratic term related to non-ICT capital is itself not significant.

Appendix II: Additional regression results

The second version of the non-linear model, in which a quadratic term for non-ICT and ICt capital is included, proves to be a relevant model in the transport and storage sector. The results for the regression are mentioned in the text of section 3.2.5 and included here in Table 28, with the results from other considered models also included for easy reference.

Table 28: Further results of the parametric analysis for the transport services sector (excluding the Czech Republic, Slovenia, and Portugal)

	Log-Linear Model	**Non-Linear Model, version 1**	**Non-Linear Model, version 2**
Dependent variable: GHG emissions per output			
Independent variables:			
- Energy prices	-0.0477	-0.00043	-0.00017
- ICT capital intensity	-0.0406	-0.00240**	-0.00301***
- ICT capital intensity, squared		+0.00836**	+0.00961***
- Non-ICT capital intensity	+0.1277	+9.63e-06	+0.00084***
- Non-ICT capital intensity, squared			-0.00020***
- Time	-0.0135***	-9.65e-06**	-0.00001***
Model statistics:			
Significance of Whole Model	***	***	***
Hausman Test: Are there significant structural effects?	Yes *** (Random Effects)	Yes *** (Random Effects)	Yes *** (Random Effects)
R squared (within)	0.5515	0.5582	0.6582
Significance levels: * = 90%, ** = 95%, *** = 99%			

Source: DIW econ, 2009.