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The potential global CO_2 reductions from ICT use

Identifying and assessing the opportunities to reduce the first billion tonnes of CO_2

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designed and launched by WWF and HP

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Preface

We live in exciting times. With the rapid technological development new opportunities have emerged that allow us to provide better quality of life and at the same time reduce CO_2 emissions. As the world's population is getting richer and the cities are rapidly expanding such solutions are urgently needed.

This report written by Ecofys in collaboration with WWF is the world's first comprehensive global assessment of strategic opportunities for Information and Communication Technology (ICT or IT) solutions that can help accelerate the reduction of CO_2 emissions. It identifies one billion tonnes of strategic CO2 reductions based on a bottom up approach with concrete solutions. These reductions are equivalent to more than one quarter of EU's total CO_2 emissions.

The ten solutions areas that could deliver one billion tonnes of strategic CO_2 reductions are:

1. Smart city planning
2. Smart buildings
3. Smart appliances
4. Dematerialisation services
5. Smart industry
6. I-optimisation
7. Smart grid
8. Integrated renewable solutions
9. Smart work
10. Intelligent transport

These are solutions that require less investment in physical infrastructure and more re-thinking on how we approach different needs in society. All the solutions above already exist and are already implemented on a small scale. The only thing we need to do is to remove the barriers and create incentives for these kind of solutions in order to them to be used more widely.

The report is a result of an innovative private sector NGO partnership where WWF and HP have worked together. As part of this process HP will also create what probably will be the world's first customer catalogue of "low carbon IT solutions". This HP catalogue presents concrete solutions that are currently being provided by the company. This effort by the world's largest IT company will hopefully trigger a trend where the opportunity to use IT solutions to become a winner in a low carbon economy becomes more widely recognised in society.

WWF hope to increase the work in this area and focus on concrete projects, e.g. work with a limited number of cities that can implement innovative ICT solutions. We hope that this report can be used by companies along with individuals and governments in order to increase the use of innovative ICT solutions that contribute to the reduction of CO_2. The aim has been to consolidate existing studies to provide an overview and suggestions on how to take the discussion further and build on work that has already been done.

WWF have also produced a shorter report, "Outline for the first global IT strategy for CO_2 reductions: A billion tonnes of CO_2 reductions and beyond through transformative change ", which builds in the ten solutions identified in this report. The outline is meant to provide guidance to ensure that we create a framework for the key IT solutions so they provide "low-carbon feedback" when they are implemented, i.e. ensure that the solutions do not only reduce CO_2 directly when they are used, but also strengthen structures that support further emission reductions.

For a long time the focus has been on problems as soon as climate change is discussed. This report focus on the opportunities. It is now time to focus more on the opportunities and identify the winners in a low carbon economy. The challenges are huge but, as this report shows, the opportunities are even greater. Follow the work on www.panda.org/ict

Dennis Pamlin, Global Policy Advisor, WWF Sweden
May 2008

Executive Summary

This report focuses on the opportunities offered by ICT to reduce GHG emissions by:

- Analysing and comparing existing literature on the CO_2 emission reductions potentially enabled by ICT
- Proposing a methodological approach to leverage existing literature and further gain insight on the ICT impact on CO_2 emissions
- Providing a quantitative assessment of the emission reductions potential of individual ICT solutions (reference year 2030), highlighting opportunities for synergies and low carbon feedbacks
- Proposing a pragmatic approach for short term action, designed to achieve 1 billion tons of CO_2 emission reductions by 2030 (at the latest), while promoting virtual cycles for low carbon feedbacks and deeper CO_2 emission reductions

The **analysis of existing literature** highlighted that a general and shared approach to the analysis of the contribution of ICT to GHG emission reductions is still missing. Existing studies should be considered pioneering in nature and are best at raising awareness on opportunities and issues. They provide different insights on some of the impacts (typically the most direct ones) of different ICT application types or, through case studies, individual ICT applications. However, they are not able to fully capture the multiple influences that ICT applications can have on GHG emissions, especially if they unfold over a longer time period.

The fact that most papers are more suitable for awareness raising than for other purposes reflects the fact that in society at large, but also among experts of ICT and energy, the potential contribution of ICT to achieve GHG emission reductions is not yet well understood. The ability to analyze this phenomenon also suffers from lack of data needed for more rigorous analysis, as official statistics and data collection processes are not designed to gain insight on the interaction between ICT and GHG emission. Perhaps the most important drawback of existing literature is the broad variety of classifications and methodologies currently used, which hinders the ability to compare different analysis and to improve methodologies, data collection and calculations.

The **methodological approach** proposed to respond to this challenge:

- suggests a taxonomy, based on a tiered system, designed to classify the different ICT applications with beneficial impacts on GHG emissions, discuss the technologies that underlie the different ICT applications and analyse the multiple impacts of individual ICT applications (or groups of applications) on GHG emissions. Table 1 below illustrates the ICT applications proposed for tier 1 and tier 2. Lower level tiers can be added to identify specific types of ICT application (tier 3) or individual products (tier 4)[1]. The proposed classification is not intended as final. The hierarchical structure is in fact designed to accommodate integrations that can improve the granularity of the analysis or the accuracy of its parameters.
- proposes that the CO_2 emissions associated to each ICT application are consistently mapped utilizing a similar vector of GHG emission channels, thus producing tables such as table 2 below (which illustrates the ICT applications and channels for emission reductions in the building sector)

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[1] For example within smart appliances one can identify specific types of appliances (washing machines which match load with water and energy use, television sets that detect presence and switch off when the room is empty, etc.) or individual products (washing machine x, TV set y, etc.).

- **Smart Building**
  - *Planning and construction - Better design and simulation tools*
    - Urban planning tools
    - Building design and simulation tools
  - *Smart energy systems and components*
    - Smart appliances
    - Smart occupancy controls
    - Intelligent building controls
    - Smart meters/gateways
    - Remote management systems
- **Transport**
  - *Smarter work*
    - Telecommuting
    - Virtual Meetings
  - *Smarter transport infrastructure*
    - In vehicle electronics
    - GPS route and fleet management
    - Intelligent Transport Systems
    - Street light switching
- **Commerce & Services**
  - *Commerce*
    - E-commerce
    - Dematerialization of goods
  - *Services*
    - Electronic Invoicing
    - Electronic Payments
    - E-government
    - E-health
- **Production**
  - *Industrial production*
    - WiFi-stock & flow
    - Advanced sensors and controls
    - Process intensification & integration
    - Site-wide Energy Management Systems
    - Software assessment tools
  - *Other*
    - Precision agriculture
- **Energy production and delivery**
  - *Energy generation*
    - Prediction services for power in-feed renewables
    - Renewables generation management
  - *Electricity transmission*
    - Power line monitoring for increased transmission capacity
  - *Electricity distribution*
    - Smart electricity networks with increased consumer flexibility
    - Wide-area monitoring systems (WAMS)
- **Knowledge and behaviour**
  - *Consumers*
    - Electronic labelling
  - *Policy and corporate strategy*
    - Simulation and analysis tools
    - Benchmarking systems
    - Monitoring and evaluation tools

Table 1: Classification of ICT Applications with GHG impact (tier 1 and tier 2)

ICT applications	Impacts on GHG emissions (direct and emission emissions)						
	Buildings	**Industrial production**	**Waste**	**Transportation**	**Energy supply systems**	**Impacts on land**	**Other impacts**
Smart building							
Buildings construction - better design and simulation tools							
Improved urban planning	Fewer buildings and roads. Less energy use during operations.	Reduced production of materials	Less waste production, more recycling, less GHG per unit of waste	Reduced transportat of materials. Shorter trips and more efficient transport systems	More systematic and efficient use of renewable energy locally	More green spaces	Reduced energy expenditures increase disposible income and may lead to additional consumption (and emissions)
Better design and simulation tools	Reduced use of materials in individual buildings. Less energy use by individual buildings during operations.	Reduced production of materials	Less waste when buildings are decommissioned	Reduced transportation of materials	More systematic efficient use of renewable energy on-site	More green spaces	
Smart energy systems and components							
Smart appliances	Fewer hours of operation and more efficiency	emissions to manufacture additional components to make appliances smart					Reduced energy expenditures increase income and may lead to additional consumption (and emissions)
Smart occupancy control	Fewer hours of operation	emissions to manufacture controls					
Intelligent building control	Fewer hours of operation and more efficiency	emissions to manufacture controls					
Smart meters	Lower Carbon content in the energy used	emissions to manufacture meters			Higher market share to renewable energy		
Remote management (load control)	Lower Carbon content in the energy used	emissions to manufacture management system			Higher market share to renewable energy		

Table 2: Smart building – ICT applications and channels for GHG reduction

Executive Summary

Following the proposed classification, and leveraging the insight gained by existing literature, year 2030 projections from IPCC, WEO and WBCSD were utilized, and adapted, to estimate the emission reductions potential that could be enabled by ICT. This analysis constitutes the first attempt to systematically map the potential impact of a broad set of ICT solutions at a global scale, including developing countries.

The level of uncertainty associated to these estimates is high, reflecting the limited availability and high uncertainty associated with existing data, and the limitations of existing literature on this topic.

Despite these shortcomings the analysis suggests that significant opportunities to reduce GHG emission may be available if climate friendly solutions that leverage ICT systems are more systematically exploited (see examples in table below).

	Estimated Incremental Potential for GHG Emissions Reductions Enabled by ICT by 2030 $MtC0_2$		
	low	**medium**	**High**
Smart buildings – ICT in legacy buildings	121	545	969
Smart buildings – ICT for planning and operating new buildings	46	439	832
Transport mode switching enabled by smart urban planning	38	190	380
Telecommuting and virtual meetings (smart work)	68	159	404
In vehicle ICT and intelligent transport infrastructures (smart vehicles and intelligent transport)	581	1,486	2,646
E-commerce and dematerialization	198	927	1,822
ICT for energy efficiency in Industry (improving day by day operations: smart industry and plant and process design: I-optimization)	100	815	1,530
ICT in Energy supply systems (Removal of network constraints – 2020)	17	59	128
Estimated total potential for CO_2 emission reductions	**1,168**	**4,620**	**8,711**

Table 3: Estimated Potential for GHG Emission Reductions Enabled by ICT

ICT technologies do not offer one 'killer application', but a variety of ICT applications that, together, can provide a valuable contribution to the global effort to reduce GHG emissions. Opportunities exist in developed countries but also in developing countries, where it may be possible to leapfrog the GHG-heavy-ICT-poor solutions in use in developed countries and to implement innovative ICT technologies that reduce GHG emissions 'from the get go'. The quantitative estimates undertaken in the report focused on the emission reductions that can be achieved, with individual ICT solutions. However, several potential synergies exist between different ICT applications, which provide opportunities to create virtual cycles, or low carbon feedbacks, and achieve transformative, change. Although no quantitative estimates of this potential was possible at this stage, the qualitative analyses undertaken in the report indicate that the emission reduction opportunities are much greater than the ones provided by individual ICT applications implemented in isolation.

To harvest this potential we propose a pragmatic strategy for action**,** based on the identification of 10 ICT solutions, each able to deliver a GHG emission reduction wedge on average worth 100 $MtCO_2e$, thus achieving a first billion tons of GHG emission reductions. Taken together the selected ICT applications provide opportunities for synergies and for the activation of the virtual cycles that can lead to even greater transformations in energy systems and deeper GHG emission reductions, thus generating emission reductions that go beyond the arithmetical sum of the individual wedges (low carbon feedbacks – see picture below). Based on the trajectories for GHG emission reductions calculated for 2030, we believe that an appropriate target date for achieving the first billion tons of GHG emission reductions with these ICT solutions is year 2020 and that even faster results are possible with the implementation of public policies, and private sector strategies, that effectively complement the wedge-delivering-ICT solutions.

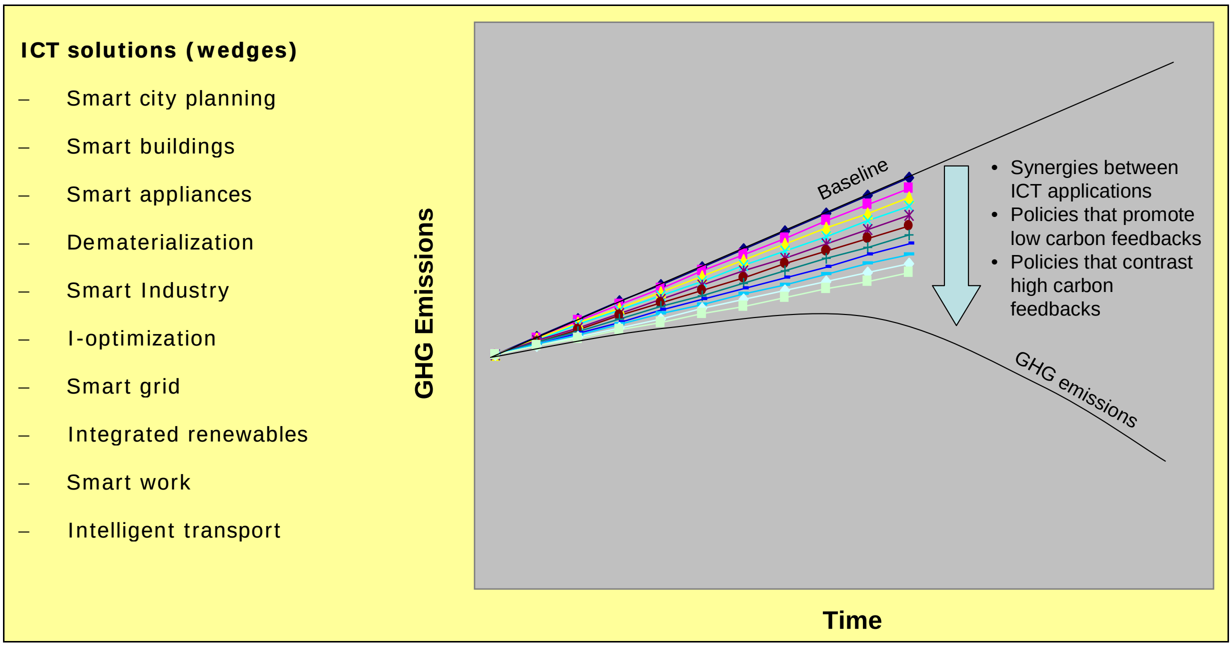

Figure 1: ICT solutions for the first billion ton of GHG emission reductions and to achieve systemic change

The opportunities offered by ICT will not be harvested automatically as, by improving efficiency and productivity, ICT also delivers more free time to workers, lower prices to consumers, higher profits to companies and higher disposable income. The use of these additional resources can lead to higher GHG emissions overcompensating initial gains or it can be used to accelerated further reductions. The size and direction of this rebound effect will depend on technological and economic development, and on the broader strategies and policies that societies and businesses will pursue. We can construct ICT technologies and use them in a way that reduces our environmental footprint, but we could also build ICT systems that contribute to environmental destruction.

Thus, additional work is needed to better understand the interactions between ICT and GHG emission but also, most importantly, to articulate policies and strategies that are able to nurture, disseminate and leverage ICT solutions that help reduce, at societal level and on a global scale, GHG emissions.

To gain insight on the interaction between ICT and GHG emissions the following activities are advisable:

- Agree upon a standard classification of ICT services with GHG impact, thus creating clear definitions of key concepts and a ‘shared language’ that is conducive to data collection, dialogue, comparison and learning and thus to a more rapid progress (in knowledge, business practices and policy) over time
- Agree on a common approach to allocate the contribution of the savings to ICT vs. other measures
- Set up appropriate data collection systems that are able to regularly gather the statistical data needed to assess and monitor progress in this field.
- Define a set of methodological guidelines that researchers and business people can deploy with more transparency and consistency when assessing individual ICT applications or families of applications – this may include a shared approach to the

analysis of direct, indirect and systemic impacts of ICT; explicit descriptions of calculation methods, guidelines for dealing with overlapping and double counting, recommendations for maintaining maximum transparency in data collection and assumptions, approaches to uncertainty analysis, etc.

- Make a concerned effort to collect relevant data and analyze potential impacts and opportunities in developing countries where the potential GHG benefit of ICT technology may be enormous

To nurture, disseminate and leverage ICT solutions and reduce GHG emissions through **policies and strategies:**

- Promote awareness building and education campaigns targeting business communities and the broader public
- Collect and disseminate information about best practices on ICT use for GHG emission minimization
- Facilitate the widespread adoption of uniform standards of communication and interoperability between different ICT devices with GHG benefits
- Fund technology development initiatives to improve critical ICT solutions or to tailor them to the needs of countries or sectors that are critical for the global GHG emission reduction effort (e.g. the creation tailored ICT tools for the design and planning of energy efficiency buildings in developing countries with high growth and booming construction sectors)
- Implement capacity building and technology transfer policies designed to benefit developing countries or sectors that are lacking in critical knowledge and expertise, but that are key to reduce GHG emissions (e.g. with designers within the building industry, to further increase the use of ICT to reduce the GHG footprint of new building)
- Remove regulatory barriers that hinder the offer of innovative ICT-based services with GHG benefits (e.g. in the energy sector: removing rigid dispatching or price regulations that do not allow real-time differentiation based on GHG emissions, in the administrative field: removing requirements for printed copies of legal documents)
- Leverage actively ICT to develop innovative climate change policies and tools (e.g. for traffic management, GHG emissions monitoring. Information dissemination, etc.)
- Use public procurement, and public services in general, to spur the adoption of ICT applications with positive GHG impacts
- Ensure that appropriate funding mechanisms for ICT investments with GHG benefits exist, especially for activities in developing countries (E.g. Within the Kyoto protocol framework, develop showcase CDM projects with appropriate methodologies)
- Introduce broad policies that, when resources (time or money) are liberated by efficiency-enabling ICT applications, automatically provide disincentives for the use such resources in ways that lead to additional GHG emission.

Overall the research illustrated in this paper shows a growing awareness on the opportunities offered by ICT to reduce GHG emissions. ICT may enable GHG emission reductions in a variety of sectors and through many different channels. A conscious deployment of ICT as an instrument to increase energy efficiency and reduce GHG emissions is just in its early days. This effort, however, can play a key role in our attempt to preserve the integrity of Earth’s climate. The success of this effort does not solely rely on ICT. It also dependents on our ability to orchestrate technological, economic and policy systems that channel ICT towards delivering lasting reduction in our GHG footprint.

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POTENTIAL GLOBAL CO_2 EMISSION REDUCTIONS FROM ICT USE: IDENTIFYING AND ASSESSING THE OPPORTUNITIES TO REDUCE THE FIRST BILLION TONNES OF CO_2 EMISSIONS

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1 Introduction

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Thus, the report is organised in the following sections:

Section 2 analyses the **existing literature** on ICT and climate change. Although the intersection between ICT and climate change represents a new topic, a number of researchers have started to investigate it. This section discusses such works, illustrating approaches and methodologies, comparing, analysis and discussing results.

On the basis of existing literature, section 3, proposes a **methodological approach** that we believe can help map the different ICT applications with GHG emission impact, and quantify their benefits. As a shared approach is currently lacking, researchers and practitioners cannot easily compare their results, refine their analyses and gain insight from other's work. A methodological approach proposed would facilitate these processes.

Section 4 focuses on the **quantification** of GHG benefits achievable through ICT, consolidating and discussing the conclusions reached by existing studies and discussing opportunities for synergies and transformative change. The analysis is the first attempt to map the potential impact of a broad set of ICT solutions at a global scale, including developing countries. It provides therefore a good basis to understand the scope of the opportunities available and to set priorities.

Building on the analysis of section 4, section 5 proposes a **pragmatic approach for action**. In particular section 5 identifies ten ICT applications that, by 2020, can deliver GHG emission reductions worth 100 Million tons of CO_2 ($MtCO_2$), thus delivering total GHG emission reductions worth 1 billion ton of CO_2 ($GtCO_2$). The section also discusses how implementing such ICT applications may generate synergies (low carbon feedbacks) that could profoundly impact energy systems and lead to structural, transformative change and dramatic GHG emission reductions. To successfully activate these synergies, it will be vital to also implement suitable **policies and strategies**, able to channel ICT towards uses and innovations that truly achieve a sustained reduction in GHG emission over time, while reducing negative rebound effects. Complementary policies and strategies are also discussed in section 5.

The document then concludes – in section 6 – with a **summary** of the main results reached, of their significance and of the implications for future activities.

A number of appendices are included with additional background information and analytical details.

2 Review of existing literature

Historically many researchers and practitioners have analysed the evolution of energy systems, including their technological and economic trajectories discussing the potential and possible implications for associated GHG emissions[1]. Likewise there is a significant literature on the impacts of ICT on economies and societies[2]. Rarely, however, have energy and ICT systems being analysed in conjunction.

The interaction between GHG emissions and ICT use, therefore, is not well understood. Such interaction is characterised by a number of complexities, for example:

- Individual ICT solutions are deployed as part of multiple and inter-linked processes
- ICT use has a broad and deep impact on the economy and society
- Long term or long range unforeseeable impacts (unintended consequences) are possible (if not common) with the implementation of ICT systems
- ICT deployment can have both a positive and negative impacts on GHG emissions

Few recent studies have investigated these dynamics and tried to assess the potential role that ICT technology, and specifically a strategic use of ICT applications and innovations, can have in reducing GHG emissions[3].

A number of studies were identified in preparation of this report and are listed in section 7: bibliographic references. For a subset of key studies individual evaluation cards were prepared assessing the following report characteristics:

- ✓ ICT applications investigated
- ✓ Geographic scope: which country or region does the study cover?
- ✓ Type of analysis performed: top down vs. bottom up; model based vs. ad-hoc estimate vs. case study vs. literature analysis
- ✓ Timeline: historical analysis vs. future projections. For GHG emission reduction estimated for the future is the timeline of such reductions provided?
- ✓ Baseline: Does the study clearly state a GHG emissions baseline against which GHG emission reductions are estimated
- ✓ Potential overlap and double counting: are the categories used in the analysis overlapping, and if so is the overlap accounted for in the emission reductions estimates?
- ✓ Transparency in assumptions and calculations: how well documented are the assumptions made in the study and the associated data collection processes
- ✓ Analysis of rebound effect: are possible indirect effects of ICT use accounted for? E.g. additional emissions caused by telecommuters at home, or by spending made possible by lower prices enabled by efficient production processes, etc.
- ✓ Communicability: are the arguments and analysis presented in the study easy to communicate to a wider public or are they complex (e.g. use complex definitions, models and algorithms) and for a public of experts?
- ✓ Discussion of uncertainty: do authors discuss the uncertainties associated with the analysis performed in their report (data collection, assumptions, calculation algorithms, etc.)
- ✓ Discussion of policy relationships and implications
- ✓ Savings in tonnes of CO_2

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[1] See for example IIASA http://www.iiasa.ac.at/Research/ECS/docs/technology.html or IEA World Energy Outlook http://www.worldenergyoutlook.org/

[2] For an overview with definition and references, see wikipedia http://en.wikipedia.org/wiki/Information_society

[3] A separate stream of literature focuses on the energy used and the GHG emissions directly caused by the production and use of ICT appliances, and on the potential savings achievable with energy efficiency gains in ICT devices and production processes. This report does not discuss these topics, as its explicit focus is on the broader GHG impacts deriving from ICT use outside the narrower ICT domain.

The tables and discussion below, summarize the main results of this analysis by virtue of contrasting and comparing a smaller number of representative studies, illustrating their approaches and characteristics, investigating the data, assumptions and calculations used. The studies analysed in the tables have been selected to illustrate the variety of approaches adopted by different authors.

The following studies are compared:

Sample studies on ICT and GHG emissions, for comparison

EPA/LBNL 2000 – John A. 'Skip' Laitner et alii *Re-estimating the Annual Energy outlook 2000 Forecast Using Updated Assumptions about the Internet Economy* available at http://enduse.lbl.gov/Info/46418-abstract.html

ENPA/IPTS – EMPA 2004 *The Future Impact of ICT on Environmental Sustainability* see also http://ftp.jrc.es/eur21384en.pdf

AeA 2007 – John A. 'Skip' Laitner, Karen Ehrhard-Martinez *Advanced Electronics and Information Technologies: The Innovation-Led Climate Change Solution*. Available at http://www.aeanet.org/aeacouncils/AeAEurope_Energy_Efficiency_Report_17Sep07.pdf

Telstra 2007 – Karl Mallon, et alii *Towards a high-bandwidth low-carbon future* available at http://www.telstra.com.au/abouttelstra/csr/docs/climate_full_report.pdf.pdf

WWF/ETNO - Dennis Pamlin, Katalin Szomolanyi *Saving the Planet at the speed of light* Available at http://assets.panda.org/downloads/road_map_speed_of_light_wwf_etno.pdf

ACI (2007) – Joseph Fuhr and Stephen Pociask, *Broadband services: economic and environmental benefits*, The American Consumer Institute, available at: http://www.internetinnovation.org/Portals/0/Documents/Final_Green_Benefits.pdf

Siikavirta et al, 2003. *Effects of E-Commerce on Greenhouse Gas Emissions: A Case Study of Grocery Home Delivery in Finland.* http://www.imrg.org/ItemDetail.aspx?clg=Events&cid=wp&pid=wp_Greenhouse_Gas_Emissions_Finland&language=en-GB

AT&T 2002 – Robert Atkyns et alii *Measurement of environmental impact of telework adoption amidst change in complex organizations: AT&T survey methodology and results* in Resources, conservation and Recycling 36 (2002) 267-285

Table 1: Studies selected for comparison

Table 2, below, illustrates the variety of ICT applications and definitions utilized by these studies. Table 3 shows differences in methodological approaches.

EPA / LBL	EMPA	AeA	Telstra	WWF / ETNO	ACI	Siikavirta	AT&T

• Changes in the industrial commodity production
• Changes in the transportation sector
• Changes in the commercial sector floor space
• Changes in the penetration of combined heat and power
• Changes driven by voluntary programs
• Changes in structural growth of the economy
• Impact of rebound effects
	• ICT industry
	• ICT use
	• E-business
	• Virtual mobility
	• Virtual goods
	• Waste management
	• Intelligent transport systems
	• Energy supply
	• Facility management
	• Production process management
		• Integrated energy management systems,
		• Advanced communications systems,
		• Advanced sensors, meters and controls,
		• Digitally addressable devices,
		• High energy efficiency end-use devices, and
		• Design and simulation tools.
		Examples
		• Street light switching,
		• Telecommuting for business travel and flexi workers,
		• Improved freight movements,
		• Smart grid,
		• Building optimization,
		• Manufacturing process control
			• Increased renewable energy
			• Personalised public transport
			• De-centralised business district
			• Presence-based power
			• Real-time freight management
			• 'on-live' high definition videoconferencing
			• Remote appliance power management
				• Travel replacement
				  • Video conference
				  • Audio conference
				  • Other areas
				• De materialization
				  • Virtual answering machine
				  • On-line phone billing
				  • Web taxation
				  • Other areas
				• Sustainable community/city planning
				  • Flexi work
				  • Other areas
					• E-commerce
					- Consumer and general business markets
					- Business supply chain
					• Telecommuting
					• E-materialisation
					– Saving plastic by downloading music and films
					- Savings from reduced US mail use
					- Savings from lower newspaper circulation
					- Savings from reduction in office and households printing
					• Telemedicine
					• Teleconferencing
					• Distance learning
						• Ecommerce	• Teleworking

Table 2 Overview of different ICT definitions and applications utilized and analyzed by selected studies

Key Characteristics	**EPA/LBL**	**EMPA**	**AeA**	**Telstra**	**WWF/ETNO**	**ACI**	**Siikavirta**	**AT&T**
Geographic scope	USA	Europe	Europe 27	Australia	Europe	USA	Finland	US
Type of analysis performed	Entire economy top down by sector. Model based. Key variable GHG emission per GDP produced	Model based analysis	Literature review and ad-hoc estimates based on existing literature	Ad hoc estimates with case studies.	Examples of individual ICT applications. Literature based.	Examples of individual ICT applications. Literature based.	Case studies and modelling.	Case study. Questionnaire used fro data collection.
Timeline	Future Potential Reference/target years are 2010 and 2020	Future Potential. Target year 2020	Future Potential. 2020 as potential target year for most important applications	Future Potential. Target year not explicit	Future Potential. Target year 2010.	Future Potential. Target year 2017.	Past 2005.	Past 1999 / 2000
Baseline clearly discussed	Yes	Yes	No	No	No	No	Yes	Yes
Potential overlap and double counting	No	Unclear	Limited	Limited	Limited	Moderate	Limited	Very low
Transparency	Low	Medium/high	Low - black box inputs	Medium/high	Low	Medium/Low	High	High
Analysis of rebound effect	Yes	Yes	No	No	Not explicitly discussed. Cases analysed included rebound effects	Limited	No	No
Communicability	Complex, model based analysis	Complex, model based analysis	Straightforward analysis, some reference to unpublished papers	Simple	Simple	Simple	Simple	Low
Discussion of uncertainty	No	Yes	No	No	No	No	Yes	Some
Policy discussion	No	Some	High level	Minimal	Yes	No	No	Some
Savings of CO_2	107 Million tons CO_2 in 2010	Broad range provided (between -15% and +2% of 2020 emissions)	589 Million tons CO_2	27.3 Million tons CO_2	50 Million tons CO_2	About 1 Billion tons of CO_2 over a 10 year period	0.19 to 0.95 Million tons of CO_2.	43,993 tons of CO_2

Table 3: Overview of the different methodological approaches used by selected studies

As highlighted above, there is no standard approach to the analysis. Through case studies, industry specific analysis and macroeconomic simulations these studies highlight a variety of GHG emission reduction opportunities associated with ICT use. Estimated reductions in GHG emissions vary greatly, also in reflection of the different analytical parameters used in the analysis, but are in the order of several million tons per annum.

Some 'usual suspects' applications and technologies (e.g. telecommuting and teleworking) are discussed in most reports. Otherwise the differences between reports are significant, as each report is typically based on different classification, methodology and calculation approach.

In many studies the level of transparency rigour and the complexity of calculation and analysis is kept relatively low, as:

- Categories are not fully elaborated and defined
- The impact of some applications may overlap with the impact of others, potentially generating double counting problems
- Calculation methods are not explicitly described
- Target years (when emission reductions are achieved) are not explicit
- Uncertainty in calculations is not explicitly discussed
- Calculations is based on assumptions upon which limited empirical evidence is provided
- Direct impacts of different applications are analyzed, but not their potential rebound effects
- The discussion of the interactions between the ICT and the policy domains is limited

All the key studies focus on developed countries (especially Europe and North America) but do not address potential impacts and savings in developing countries. This is a major deficiency of existing papers as:

- Developing countries already represent a significant share or world's GHG emissions, especially countries such as China and India, which already are the 1st and 5th worldwide emitters of GHGs
- Most growth in GHG emissions (from industrialization, new buildings, increased traffic and deforestation) is coming from developing countries – e.g. the reference scenario of EIA's world energy outlook projects that between 2005 and 2030 almost 50% of the increase in world primary energy demand will come from China and India alone
- Developing countries are investing in building their infrastructures, by and large starting from a green field. This provides great flexibility and the ability to implement strategies that are precluded to more advanced economies, where legacy infrastructures and technology lock-ins constrain available options. Developing countries have the opportunity to deploy technologies, infrastructures, organizations, processes, and policies that, as a system, are dramatically superior to the ones historically deployed in OECD countries. The dramatic changes occurring in developing countries offer therefore the opportunity to leapfrog the GHG-heavy-ICT-poor solutions in use in developed countries and to implement instead innovative ICT technologies that reduce GHG emissions 'from the get go'.

The potential GHG benefit of ICT in developing countries is therefore significant and should not be ignored. In developing countries, public policies or corporate strategies (both local governments/companies and foreign governments/companies that invest in, export to and import from these countries) that do not consider the opportunities, offered by modern ICT, to reduce GHG emissions, and pursue instead approaches based on the same GHG-intensive development patterns of western countries, may miss an momentous opportunity.

It can be argued that many of the papers that investigate the relationship between ICT uses and GHG emissions aim at increasing the awareness in the general public and within policy makers of western countries. Such studies provide insight of the opportunities that can be achieved but do not seek a level of completeness transparency, rigour or detail that would be required for a more accurate quantification or to implement policies and strategies that rely on accurate quantifications to be effective. Table 4 below shows how the drive to achieve different goals may influence the methodological approaches.

	Goals pursued by the Analysis				
Methodological requirements	*Awareness raising*	*Voluntary initiatives and demonstrations*	*Projects for voluntary markets*	*Policy articulation*	*Policy implementation (including Creation of mandatory markets)*
Geographic and sector scope	Any, depends on specific target audience and goals	At the level of the individual initiative, generally smaller geographical scale	At the level of the individual project, generally at plant or company level	Any, according to the responsibilities of the policy maker involved. Super national, national, regional or local. For GHG typically national or super national	For GHG typically national or super national
Timeline	Both past experiences and future potential	Past experiences	Past experiences	Future projections	Factual assessment of actual experiences on the ground
Communicability	Low degree of transparency acceptable	Low degree of transparency acceptable	High degree of transparency advisable	High degree of transparency required	High degree of transparency required
Need for simplicity	High	Medium	Medium/low	Medium/low	Low
Tolerance for uncertainty and error	High	High	Ideally low	Low/Medium	Ideally Low
Tolerance for overlap and double counting	High	High	Medium/Low	Low/Medium	Low
Need to discuss and understand rebound effects	Low	Medium	Medium	High	High
Need to cover policy components	Can be low. Dependent on the goals of the analysis	Can be low. Dependent on the goals of the analysis	Can be low. Dependent on the goals of the analysis	High	High
Goals of the studies selected for comparison	EPA/LBL, EMPA, AeA, Telstra, WWF/ETNO, ACI,	Siikavita, AT&T			

Table 4: Methodological requirements change in accordance to the goals of analysis

Definitions:

Geographic and sector scope	Identifies which country/ies, regions or sectors that are relevant in the study or for which the calculation are intended
timeline	Past = Analysis should focus on past historical experiences Future = Analysis should focus on future trajectories and projections
Communicability	High = requires that data, data sources, calculations, estimates are clearly and openly described Low = data, data sources, calculations, estimates may be documented with some approximation
Need for simplicity:	High = Assumes that the audience is not technical savvy and not fully familiar with the issues, e.g. general public or policy makers. It requires that definitions, calculations and analysis are kept at a level that is accessible and easy to grasp for such audience Low = Assumes that the audience is technically savvy and familiar with the issues analyzed. The level of complexity of calculation and communication can therefore be high if required to meet the goals of the analysis
Tolerance for uncertainty and error	High = Input data can be estimates that use uncertain inputs and result in outcomes that are probabilistic with high uncertainty ranges Low = data used must be most accurate (ideally measured), the calculation algorithms must be deterministic, the results must have a low uncertainty range.
Tolerance for overlap or double counting	High = the classification of sectors, ICT applications and associated hierarchies does not need to be clearly defined Low = Requires that each application analysed or calculation is uniquely identifiable and does not lead to overlap between different ICT innovations (no risk of double counting)
Need for policy component:	High = Requires a discussion of policy implications Low = Does not require a discussion of policy implications

The fact that most papers are more suitable for awareness-raising than for other purposes reflects the fact that in society at large, but also among experts of ICT and energy, the potential contribution of ICT to achieve GHG emission reductions is not yet well understood. The ability to analyze this phenomenon also suffers from the fact that the data needed for more rigorous analysis are often unavailable, as, for example, official statistical data, and associated data collection processes, are not designed to gain insight on the interaction between ICT and GHG emission.

The fact that different studies use different classifications and quantification approaches, however, represents an objective limitation of current approaches, as it makes comparison, constructive criticism and improvement more difficult. More uniform and shared classifications of ICT uses and cleared sector boundaries would help minimise confusion, overlap and double counting, while providing a 'shared language' that is conducive to more rapid progress (in knowledge, business practices and policy) over time.

The focus of existing studies on a limited set of developed countries represents, as highlighted above, an additional drawback of existing literature.

3 Methodological Framework

Existing literature, such as the analyses illustrated in section 2, discuss a variety of opportunities associated with the use of ICT to achieve reductions in GHG emission. The use of different classifications and methodologies, however, hinders the ability to compare different analysis and to improve methodologies, data collection and calculations.

Below we propose an approach, which we believe can be useful to:

- Classify the different ICT applications with beneficial impacts on GHG emissions, which can help provide a 'shared language' to interpret existing literature and organize future analyses.
- Discuss the technologies that underlie the different ICT applications
- Analyse the multiple impacts of individual ICT applications (or groups of applications) on GHG emissions

3.1 A classification of ICT applications with GHG impact

To consolidate and classify the different ICT applications with GHG benefits we suggest a tiered system that at the higher (tier 1) level differentiates between the following categories (based on the areas in which ICT is deployed):

- Smart Building
- Transportation/communication
- Commerce & Services
- Production
- Energy supply systems
- Knowledge and behaviour

These categories are based on the area in which ICT is deployed. Within each category lower level subcategories (tier 2 and 3) can be identified, as the ones listed in the figure below, which provide a more granular classification of ICT application.

- **Smart Building**
  - *Planning and construction - Better design and simulation tools*
    - Urban planning tools
    - Building design and simulation tools
  - *Smart energy systems and components*
    - Smart appliances
    - Smart occupancy controls
    - Intelligent building controls
    - Smart meters/gateways
    - Remote management systems
- **Transport**
  - *Smarter work*
    - Telecommuting
    - Virtual Meetings
  - *Smarter transport infrastructure*
    - In vehicle electronics
    - GPS route and fleet management
    - Intelligent Transport Systems
    - Street light switching
- **Commerce & Services**
  - *Commerce*
    - E-commerce
    - Dematerialization of goods
  - *Services*
    - Electronic Invoicing
    - Electronic Payments
    - E-government
    - E-health
- **Production**
  - *Industrial production*
    - WiFi-stock & flow
    - Advanced sensors and controls
    - Process intensification & integration
    - Site-wide Energy Management Systems
    - Software assessment tools
  - *Other*
    - Precision agriculture
- **Energy production and delivery**
  - *Energy generation*
    - Prediction services for power in-feed renewables
    - Renewables generation management
  - *Electricity transmission*
    - Power line monitoring for increased transmission capacity
  - *Electricity distribution*
    - Smart electricity networks with increased consumer flexibility
    - Wide-area monitoring systems (WAMS)
- **Knowledge and behaviour**
  - *Consumers*
    - Electronic labelling
  - *Policy and corporate strategy*
    - Simulation and analysis tools
    - Benchmarking systems
    - Monitoring and evaluation tools

Table 5: Classification of ICT Applications with GHG impact

Lower level tiers can be added to the classification proposed in table 5, to identify specific types of ICT application or individual products. For example within smart appliances one can identify specific types of appliances (washing machines which match load with water and energy use, television sets that detect presence and switch off when the room is empty, etc.) or individual products (washing machine x, TV set y, etc.).

This approach aims at providing a classification and hierarchy of the main ICT applications that impact GHG emission and that have been analysed by existing literature. ICT applications may include both ICT products, ICT components and ICT based services. This allows the analysis of structural changes that may take place in society, such as the transition from a products economy to a service economy. The approach provides a framework in which innovative private or public sector initiatives can be showcased and discussed in a manner that shows their fit with existing applications. Insights gained at lower lever tiers (e.g. with individual products and case studies) can provide inputs and references for higher level analysis. For example a car company may introduce a new in-vehicle device that helps drivers adopt driving styles that reduces CO_2 emissions and collects data on the behavioural changes and emission reductions achieved. The emission reductions generated by the new system can be included in category: 'transport\smarter transportation infrastructure\in vehicle electronics'. As other systems may also lead to changes in driving behaviour and GHG emission reductions – e.g. intelligent transport systems solutions that rely on a centralised traffic management system – the insight gained with the analysis of the impact of in-vehicle systems (e.g. in terms of emissions per km driven) may help define suitable parameters for the implementation and the assessment of these Intelligent Transport System solutions.

The proposed classification is not intended as final. The hierarchical structure is in fact designed to accommodate integrations that can improve the granularity of the analysis or the accuracy of its parameters.

3.2 ICT applications and underlying technologies

Different ICT applications, or application types, are typically built as an ensemble of different technological components.

Typically ICT applications that achieve reductions in GHG emissions are built around the following information technologies components:

- Microprocessors and Application Specific Integrates Circuits (ASICs), digital electronic components that incorporate the functions of a central processing unit (CPU) on a single integrated circuit (IC), typically embedded in a multitude of devices e.g. components that switch off an iron after x minutes of non use
- Sensors and controls, of various characteristics and applicability, critical component of many energy efficiency solutions e.g. devices that sense presence and switch off lights or heating systems when not needed
- Special purpose IT enabled devices, integrating different IT components to perform special purpose function e.g. advanced meters
- General purpose IT equipment, such as computers and peripherals of general use in many business and non business environments

- Software systems and applications, the software component of ICT, which could be designed to support a broad variety of applications and solutions
- Advanced communication and Internet, wireline and wireless communication solutions that enable person to person, person to machine and machine to machine communication[4]

Within each of these technological components a variety of actual products can be found (different ASICs, sensor types, meters, software applications, communication technologies, etc.). The combination and integration of different components can lead to a large variety of energy saving, GHG emission reducing applications. Over time the rapid technological progress in these components offer opportunities to develop and deploy new solutions to reduce GHG emissions. The table below illustrates the role played by different technological components with the various ICT applications identified by Table 5:

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[4] Classification based on High Road Strategies the Potential of Information Technology Applications to Enable Economy-Wide Energy Efficiency Gains report to the ACEEE for the ACEEE-AeA Europe Project August 17, 2007

	Underlying technologies					
	Microporcessors & ASICs	Sensors and controls	IT enabled devices	IT equipment and systems	Software systems and applications	Advanced Communication and Internet
Smart Buildging						
Planning and construction - Better design and simulation tools						
Urban planning tools				√√	√√√	
Building design and simulation tools				√√	√√√	
Smart energy systems and components						
Smart appliances	√√√	√√√	√			
Smart occupancy controls	√	√√√	√			
Intelligent building controls	√√	√√	√√√		√√	√√
Smart meters/gateways		√√	√√√			√
Remote management systems	√√	√√√	√√√	√√	√√√	√√
Transport						
Smart work						
Telecommuting					√√	√√√
Virtual Meetings					√√	√√√
Transportation infrastructure						
In Vehicle electronics	√√√	√√√	√			
GPS route and fleet management			√√√			√√√
Intelligent Transport Systems	√√	√√	√√	√√	√√√	√√√
Street light switching	√√	√√√	√			
Commerce & Services						
Commerce						
E-commerce				√√	√√	√√√
Dematerialization of goods				√√	√√√	√√√
Services						
Electronic Invoicing and payments				√√	√√	√√√
E-government				√√	√√√	√√√
E-health				√√	√√√	√√√
Production						
Industrial production						
WiFi-stock & flow		√√	√√√			√√√
Advanced sensors and controls	√	√√√	√√√			√
Process intensification & integration		√√	√		√√√	√
Site-wide EMS	√	√√√	√√	√	√√√	√√
Software assessment tools					√√√	√√
Other						
Precision agriculture		√√	√√√	√	√√√	√√√
Energy production and delivery						
Energy generation						
Prediction services		√		√√	√√√	√√
Renewables generation management		√√√	√√	√	√√	√√
Electricity transmission						
Power line monitoring	√	√√√	√	√	√	√√√
Electricity distribution						
Smart electricity networks	√	√√√	√√	√	√√√	√√√
Smart grid and remote load control	√	√√√	√√√	√	√√√	√√√
Knowledge & behavior						
Consumers						
Electronic labelling	√	√	√	√√	√√	√√√
Policy and corporate strategy						
Symulation and analysis tools				√√	√√√	√
Benchmarking systems				√√	√√√	√
Monitoring and evaluation tools	√√	√√	√√	√√	√√√	√

Table 6: ICT applications and underlying technological components
Key: √√√ Technological is core component in the application, √√ Technological is an important component of the application but it is not its core, √ Technological is present but has marginal role in the application
Source: own elaboration integrated with elaborations of High Road Strategies for ACEEE[5]

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[5] High Road Strategies the Potential of Information Technology Applications to Enable Economy-Wide Energy Efficiency Gains report to the ACEEE for the ACEEE-AeA Europe Project August 17, 2007

With the combination of different technological components large number of individual application and solutions can be identified or developed (e.g. different types of simulation tools, in-building controls, e-commerce configurations, GPS based solutions for transport improvement, etc.) and can be tailored and applied to specific problems and target markets (e.g. residential buildings in tropical, temperate or Arctic countries, commercial buildings in cold mountain regions or hot arid areas, etc.). It has been argued that there may be a million potential advanced technology configurations that could be applied to reduce energy consumption while maintaining economic well-being and quality of life[6].

Mapping and understanding the technologies underlying different ICT applications provides the following advantages:

- Industrial representatives and policy makers that define their activities in terms of underlying technologies can better identify the possible links between their activities and GHG emissions.
- When ICT applications with great potential for GHG emissions reductions are identified, understanding their technological make up can help highlight areas where capacity building, R&D or technological dissemination activities may be required to overcome technological bottlenecks.
- To policy makers willing to implement industrial policies to support the development of ICT applications to reduce GHG emissions, an understanding of the key technological components provides insight on the different policy elements that may need consideration.
- When new applications are defined in concept, the technical components and steps needed for proof of concept demonstration and implementation can be identified more easily

3.3 ICT applications and their impacts on GHG emissions

Different ICT applications impact GHG emissions through different channels and affecting different variables. For example an ICT application that improves building techniques may reduce the volume of materials utilised by the building industry, or their composition, whereas the deployment of smart occupancy controls within buildings may reduce the hours of operation of some equipment and the associated emissions. Smart meters may enable the sale of surplus renewable energy produced on-site (e.g. by small scale PV or urban turbine systems) to the grid and better energy pricing. Other applications, such as an increasing adoption of e-government or e-payments may reduce the use of specific materials (e.g. paper) and the number of kilometres travelled by customers and citizens, it can also lead to a reduction in buildings' use, which, over time, could even result in a lower number of buildings. Singularly and combined, the various changes enabled by ICT may lead to deeper changes in behaviour and in the broad organization of social and economic systems, with further impacts on GHG emissions.

With ICT as an enabler, future energy (and economic) systems will be characterised by a highly complex interplay between different technologies and socio-economic activities (See the picture below for an illustrative example).

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[6] See Joel Yudken (2007) Assessing the potential of Information Technology Applications to Enable Economy Wile Energy Efficiency Gains a report to the American Council for an Energy Efficient Economy Washington DC

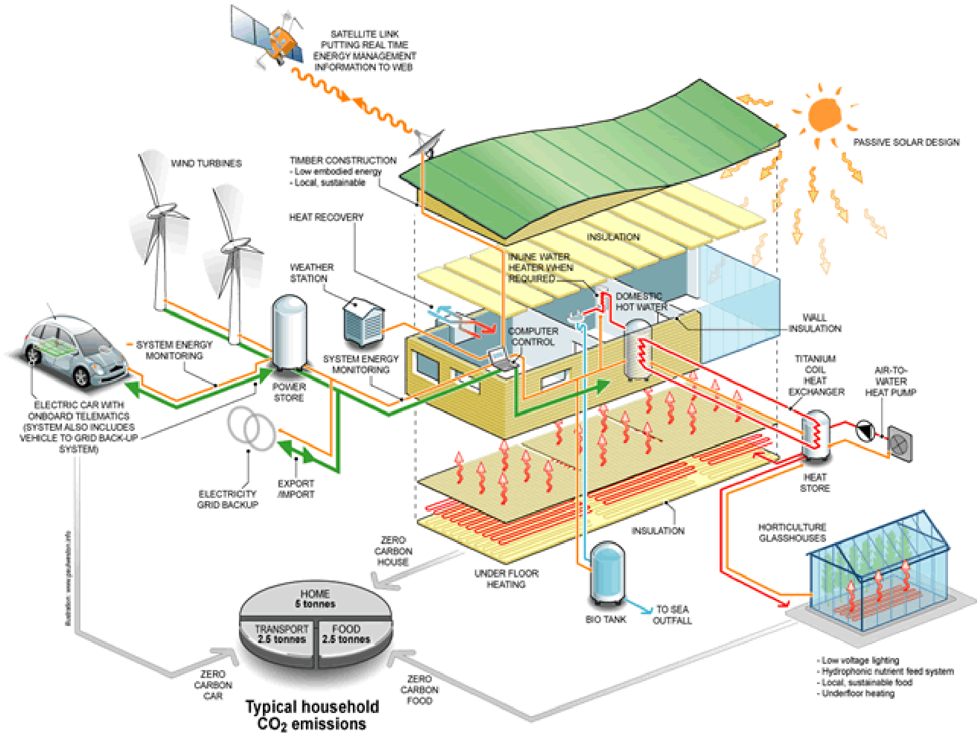

Figure 1: ICT and energy systems

When assessing the impacts of ICT applications on GHG emissions, and when analysing past literature on this topic the multiple interactions between different technologies and human activities should be considered.

The possibility of feedback loops and the presence of overlapping impacts should also be taken into account. E.g. ecommerce may change the demand for transportation services, while ICT-enabled changes in transportation systems may improve the efficiency of transportation system, reducing the GHG intensity associated with transportation services. More efficient transportation system may in turn lead to a growth in e-commerce. Compared to a hypothetical baseline all impacts of the ICT applications, and their interaction, should be considered. If interactions are not included the result will most certainly be wrong. The estimate of the impact will either be too low as synergies are lost (e.g. ecommerce leading to more efficient transportation system and more efficient transportation systems leading to more ecommerce), or too high as double counting takes place e.g. if the quantification of the emissions reductions associated with e-commerce (thanks to less kilometres travelled) does not take into account the reduced GHG emission per km travelled deriving from ICT use in transportation systems.

As past studies have often focused on individual sectors or technologies, utilizing different classifications, any use of such studies to produce an aggregate estimate of GHG emission reduction should consider the classifications and assumptions utilized by each study. Likewise if original estimates are undertaken, such estimates should take into consideration interactions such as the ones illustrated above (and discussed in more detail for each ICT solution in section 4).

Table 7 and Table 8, below, aim at providing a tool to facilitate these activities. Table 7 illustrates the various channels through which ICT applications can influence GHG emissions, indicating the variables that can be affected.

Channels for GHG reductions	**Variables affected**
Buildings	• Smaller number or smaller sized buildings (fewer m2) • Reduced period of operations for GHG producing equipment (fewer hours or operation) • Reduced energy use per hour of operation of equipment (higher energy efficiency) • Reduced carbon content in energy used (e.g. because of a larger use of renewable energy) o Larger production of RE by independent power producers o Buildings as producers of energy, delivered to the grid
Industrial production	• Lower production of individual products or components (dematerialization) • Lower energy or GHG emissions per unit of production (more efficiency)
Waste	• Less waste production • More recycling • Less GHG emissions per unit of waste produced
Energy supply systems	• More renewable energy deployment (higher market share for renewable energy) • Less GHG emissions per unit of energy produced with fossil fuels • Less transmission and distribution losses
Transportation	• Fewer trips • Shorter trips to perform similar functions • Higher use of more efficient (public) forms of transportation • Increased efficiency in vehicles (less energy use per km travelled) • Energy mix delivered to the grid (e.g. vehicles as generators of energy that is delivered to the grid)
Impacts on land	• Larger areas of green space • More carbon storage per area of green space • Less CH_4 and N_2O emissions per area of farmed land
Other impacts (including rebound risks)	• More free time leading to additional travel • More disposable income leading to increasing consumption and associated GHG emissions • Lower prices leading to increasing consumption and associated GHG emissions • More profits leading to increased investment in GHG emitting or reducing activities • New values in relation to nature • New low-impact consumption preferences • More demand for policies that reduce GHG emissions

Table 7: Channel for GHG emissions reduction and variables affected

Table 8 combines data on ICT applications and GHG emission channels. This enables a mapping of the impact of different ICT applications (from Table 5:) on different GHG emissions channels (from Table 7).

	Channels and impacts on GHG emissions						
ICT applications	Buildings	Industrial production	Waste	Transportation	Energy supply systems	Impacts on land	Other impacts
ICT application category layer 1 (e.g. Smart building) • ICT application type layer 2 (e.g. Better design and simulation tools) o ICT application group layer 3 (e.g. improved urban planning) ▪ Individual ICT application layer 4 (e.g. case study city x) • Etc.							
ICT application category layer 1 • ICT application type layer 2 o ICT application group layer 3 ▪ Individual ICT application layer 4 • Etc.							
Etc.							

Table 8: ICT applications and Channels through which they affect GHG emissions

The format of Table 8 can be used as a conceptual tool to identify and discuss the various GHG impacts of different ICT applications. This can guide the selection of quantification approaches for individual impacts, and the aggregation of all the impacts of individual applications, applications types, or categories.

Estimates of GHG emission reductions can take place at a higher or lower hierarchical level. The choice of the level at which the analysis takes place may depend on data availability and on the goals of the analysis. Often the scarcity of relevant data inhibits the quantification of emission reductions at a granular level for individual ICT applications. By and large existing studies focus on different application types or categories or GHG emission reduction channels.

In the section below the structure provided by Table 8 will be used to analyze existing literature.

4 Calculation GHG opportunities for individual ICT solutions

This section discusses the GHG emission reduction opportunities associated with different ICT uses, following the approach laid out in section 3.3, and illustrates how existing studies have quantified potential emission reductions. The significance of such results is analysed and discussed and, when appropriate, year 2030 projections from IPCC, WEO and WBCSD are used and adapted to analyse the GHG emission reductions scenarios that could be achieved with ICT. The section provides a quantitative estimate of the opportunities associated with individual ICT solutions, while also illustrating the synergies possible between different ICT solutions, which can lead to transformative change and deeper GHG emission reductions. The uncertainty associated with these estimates is high, also reflecting current data (un)availability. Uncertainty is explicitly discussed in the text. This analysis performed in this section is the first attempt to map the potential impact of a broad set of ICT solutions at a global scale, including developing countries. The analysis illustrates the scale of the benefits that could be achieved with individual ICT solutions, highlighting opportunities for synergies, thus providing insight for prioritization and action.

4.1 Smart building

In most countries, buildings are the largest driver for both energy use and CO_2 emissions. The 160 million buildings of the EU, for example, are estimated to use over 40% of Europe's energy and to drive over 40% of its carbon dioxide emissions[7]. According to the US Energy Information Administration (EIA) the share of energy and green house emissions associated with buildings is even larger in the US, with 48% of the total[8].

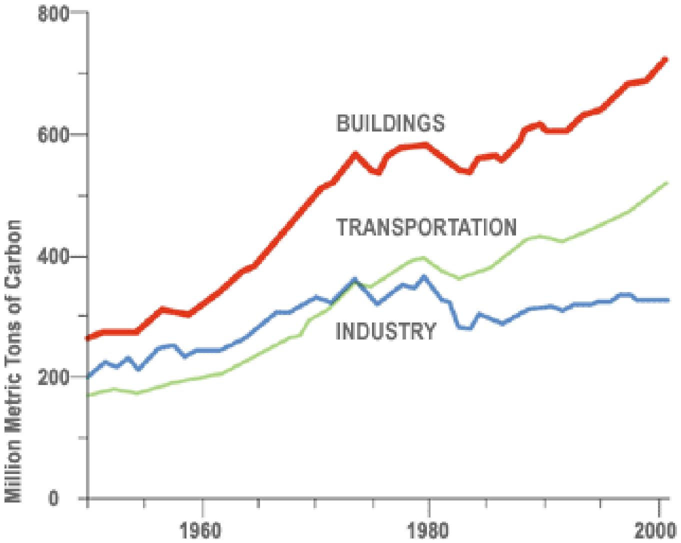

Figure 2: CO2 Emissions from Buildings, Transportation and Industry, USA.

In several developed countries emissions from buildings, and their proportion on total emissions, have been steadily increasing over the last fifty years (see US data on the graph). Larger size buildings and an increasing number of energy-using appliances within buildings have been the main drivers for such growth.

In developing countries, on the other hand, the share of buildings on total energy use and emissions is much lower (e.g. in the order of 10% of the total in China).

With rapid industrialization and urbanization taking place, however, energy use and GHG emissions associated with buildings are increasing rapidly also in developing countries where dramatic economic growth is associated

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[7] http://www.euroace.org/reports/CIBSE_EUBD.pdf

[8] These estimates include both direct emissions generated through fossil fuel use (e.g. for heating) and indirect emissions generated through electricity use

with a booming construction sector. A significant number of new buildings are therefore added every year in many developing countries. In the 2000-2005 period, for example, China added about 6.5 billion square meters of new residential buildings[9].

Business as usual projections for GHG emissions associated to buildings estimate that worldwide GHG emissions will reach about 15 billion CO_2 by 2030, with Asian countries contributing to about 1/3 of such emissions (See below)

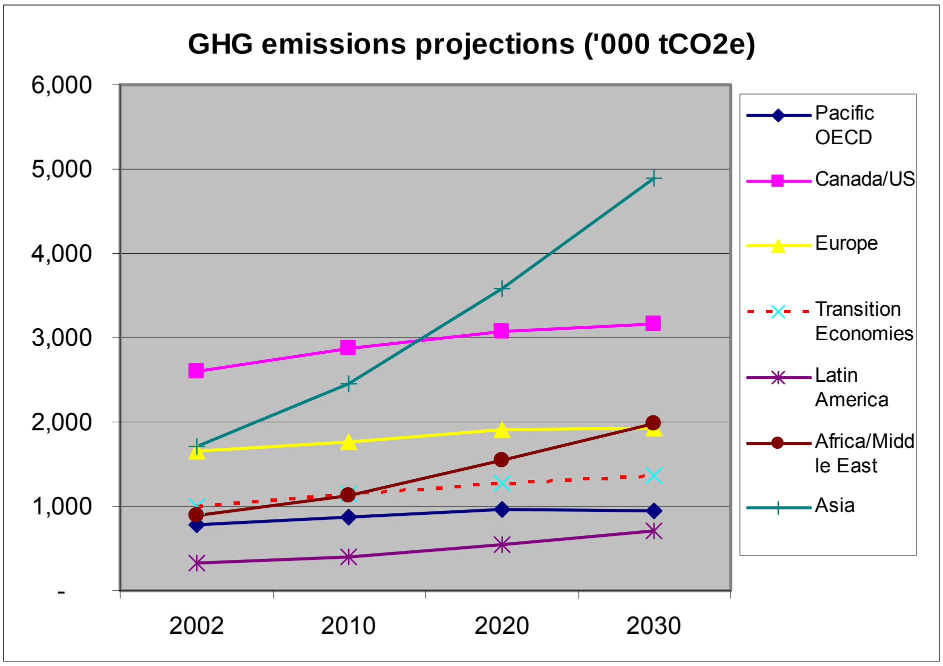

Figure 3: Projected GHG emissions from the building sector 2002 – 2030. Source World Energy Outlook 2004

Reducing the energy and GHG footprint in both existing and new buildings represents therefore a key challenge to tackle global warming.

Moreover, the construction process is in itself a highly energy and GHG intensive process as the materials used in construction (e.g. steel and concrete) have a high degree of embodied energy. Higher efficiency in construction activities can therefore harvest significant benefits in terms of GHG emission reductions, particularly in fast growing counties in the developing world.

ICT applications can contribute to the reduction of the carbon footprint in the built environment, both during construction and during operations.

Through design and simulation tools architects and engineers can create buildings and cities of superior environmental performance. Within buildings, IT enabled, smart appliances can optimize the use of energy (and other resources) needed to perform a specific service. IT controls, coupled with smart meters and remote energy management systems can provide a higher level of intelligence to the buildings. Together these applications may enable buildings to become suppliers of renewable energy produced locally and to orchestrate energy demand in response to changes in renewable energy supply.

The table below illustrates the GHG benefits that are associated with the use of different ICT applications within buildings.

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[9] China Statistical yearbook 2007, http://www.stats.gov.cn/tjsj/ndsj/2007/indexeh.htm

ICT applications	Impacts on GHG emissions (direct and emission emissions)						
	Buildings	Industrial production	Waste	Transportation	Energy supply systems	Impacts on land	Other impacts
Smart building							
Buildings construction - better design and simulation tools							
Improved urban planning	Fewer buildings and roads. Less energy use during operations.	Reduced production of materials	Less waste production, more recycling, less GHG per unit of waste	Reduced transportat of materials. Shorter trips and more efficient transport systems	More systematic and efficient use of renewable energy locally	More green spaces	Reduced energy expenditures increase disposible income and may lead to additional consumption (and emissions)
Better design and simulation tools	Reduced use of materials in individual buildings. Less energy use by individual buildings during operations.	Reduced production of materials	Less waste when buildings are decommissioned	Reduced transportation of materials	More systematic efficient use of renewable energy on-site	More green spaces	
Smart energy systems and components							
Smart appliances	Fewer hours of operation and more efficiency	emissions to manufacture additional components to make appliances smart					Reduced energy expenditures increase income and may lead to additional consumption (and emissions)
Smart occupancy control	Fewer hours of operation	emissions to manufacture controls					
Intelligent building control	Fewer hours of operation and more efficiency	emissions to manufacture controls					
Smart meters	Lower Carbon content in the energy used	emissions to manufacture meters			Higher market share to renewable energy		
Remote management (load control)	Lower Carbon content in the energy used	emissions to manufacture management system			Higher market share to renewable energy		

Table 9: Smart building – ICT applications and channels for GHG reduction

4.1.1 ICT as an enabler of GHG emission reductions in existing buildings

Solutions such as smart appliances or smart occupancy control appear to be more suitable for the retrofit of existing buildings, as they lead to improvements in individual sub-systems within buildings. In several circumstances, however, also more complex ICT solutions (i.e. building management systems that allow a complete and remote building control) can be successfully implemented. The table below provides some examples of ICT solutions that have been successfully deployed to reduce energy use and GHG emissions in the existing buildings.

	**Controls – Bye Bye Standy** Bye bye Standy provides wireless connectivity to sockets, it enables users to assign sockets to different groups and to remotely switch on and off remotely all appliances associated to a group. The devices works up to 30m distance. The producer claim that, in the UK, users can save GBP 38 per annum on average, equivalent to about 162 kwh and 84 kg of CO2 emissions per annum[10]
	**HVB Immobilien - intelligent elevators** By revamping their elevator systems and deploying modern, intelligent elevator controls, HVB Immobilien was able to substantial increase load capacity while simultaneously achieving a 30% energy saving. Intelligent elevator control systems include optimising the movement of a group of elevators with respect to time, energy, load, etc[11].to add source
	**InterfaceFLOR – Energy Mirror** InterfaceFLOR's facility at Scherpenzee installed an Energy Mirror® that tracks energy consumption at the office building 24-hours a day. Real-time and historical data collected by the energy mirror enables the tracking of ongoing efforts to reduce overall energy consumption. The Energy Mirror has become a motivator to employees, encouraging them to become more aware of their own energy consumption and empowering them to improve consumption patterns. Employees identified and harvested a number of energy efficiency improvement opportunities that may have otherwise gone unnoticed, such as excess ventilation being provided during unoccupied periods.
coop	**Coop**, Switzerland's second-largest retailer, set up an Energy Management System that combines data collection from its 1500 stores with a comprehensive building management system. The system is designed to meet target values for temperature and consumption of fuel and water. It also oversees the recovery of energy from the cooling systems, and has enabled a 60% reduction in heat energy demand[12].

Table 10: Examples of ICT use in the built environment

To date many of the studies that looked at the potential impact of ICT in the built environment focused primarily on the use of ICT technologies in energy appliances and systems, which are utilized during the

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[10] See http://www.byebyestandby.co.uk/

[11] Copyright image Khoi Vinh

[12] Case study discussed by ebusiness-watch www.ebusiness-watch.org/events/documents/WS080207_Energy_Press-Release.doc

period of occupancy of the buildings. Most analysis have focused on developed economies, where the building infrastructure is by and large already in place and new buildings represent a small portion of the overall built environment.

An institution that specifically analysed ICT uses in the built environment is the AeA. In particular the AeA report *Advanced Electronics and Information Technologies: The Innovation-Led Climate Change Solution* looked at opportunities in the European Union and estimated that the potential energy savings achievable by 2020 in European buildings thanks to ICT is as high as 20%. Using current CO_2 emissions from the building sector as a baseline, the authors of the report estimate that in Europe such improvement can add up to 260 million tonnes of CO_2 avoided per annum.

The AeA study indicates that the timeframe for the envisioned gains is consistent with the EU targets for 2020, but does not provide a granular breakdown of the impact of different ICT applications, with indication of their specific dissemination time. The study does not discuss in detail the conditions under which emissions reduction may or may not be achieved e.g. what rebound effects may take place and what technological and policy scenarios would enable or hinder the achievement of the anticipated emission reductions within the building. Thus the AeA study appears to provide an indication of the potential that is achievable in ideal conditions.

A significant potential also emerges from a number of smaller scale studies reviewed by IPCC AR4. Such studies highlight that for more complex application, such as Building Energy Management Systems (BEMS)[13] estimates of energy savings vary between 5% and 40%[14]

Thus existing literature indicates that a systematic deployment of ICT solutions within energy systems of existing buildings can deliver significant increases in energy efficiency.

Utilizing baseline emission data from the World Energy Outlook the table below utilizes such insights and provides an illustration of the GHG emission reductions that can be achieved by 2030 under different scenarios of ICT deployment and effectiveness within buildings. The analysis focuses on opportunities in **'legacy buildings'**, defined as buildings in operations in 2010 for which baseline GHG emissions are assumed to remain constant in the 2010 – 2030 period. By 2030 adoption of ICT solutions is assumed to reach 30% in developed countries and 20% in developing countries (i.e. approximately 1.5% per annum in developed countries and 1% per annum in developing countries).

	Baseline 2030 GHG emissions from 2010 legacy buildings Mt CO2e	Energy Efficiency gains enabled by ICT %	Potential GHG emission reductions enabled by ICT Mt CO2e	Adoption of ICT to achieve energy efficiency	GHG emission reductions Mt CO2e
Pacific OECD	872	5 – 40%	44 – 349	30%	13 – 105
Canada/US	2,880	5 – 40%	144 – 1,152	30%	43 – 346
Europe	1,768	5 – 40%	88 – 707	30%	27 – 212
Transition Economies	1,139	5 – 40%	57 – 456	20%	9 – 68
Latin America	404	5 – 40%	20 – 162	20%	3 – 24
Africa/Middle East	1,120	5 – 40%	56 – 448	20%	8 – 67
Asia	2,451	5 – 40%	123 – 981	20%	18 - 147
World	10,634		532 – 4,254		121 – 969

Table 11: Smart buildings estimated GHG emission reduction in existing buildings deriving from improvements in energy efficiency enabled by ICT – source Ecofys elaboration using WEO data

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[13] BEMSs are defined as control systems for individual buildings or groups of buildings that use computers and distributed microprocessors for monitoring, data storage and communication (Levermore, 2000).

[14] IPCC AR4 chapter 6 page 400 also citing: Birtles and John, 1984, Hyvarinen, 1991; Brandemuehl and Bradford, 1999; Brandemuehl and Braun, 1999; Levermore, 2000;Roth *et al.*, 2005.

4.1.2 ICT as an enabler of GHG emission reductions in new buildings and urban developments

When **new buildings** are built additional opportunities become available. Designers can apply ICT tools to plan buildings that minimize energy consumption – e.g. simulating and optimizing envelope measures and passive solar heating techniques – achieving significant improvements in building's energy performance. Moreover, advanced ICT solutions can be deployed within the buildings to optimize energy use and the overall performance of the building (see some examples in the box below).

	**Schiphol Real Estate – office building simulation** Schiphol Real Estate is using DesignBuilder in conjunction with EnergyPlus to simulate the energy performance of office building projects. DesignBuilder enables the creations of variants of the buildings (by changing for example the orientation of the building, the glazing percentage, the insulation thickness) in order to identify the optimal solutions for reducing building energy demand (heating, cooling and electricity) while maintaining the internal required comfort level. The system is estimated to enable a 90% reduction in the consumption of natural gas and a 40% reduction in the consumption of electricity. EnergyPlus enables an assessment of the opportunities to utilize renewable energy technologies on site.
	**NICE** With the support of Dutch companies Econcern and Essent, Next door Internet Communication and Energy service Café (NICE) Gambia Ltd. is developing multi-utility internet cafes that are energy independent and offer internet services, IT training, television service as well as banking and micro-finance services to rural communities in Gambia. Wireless broadband connection and the energy supply are complementary components of the NICE Café. In designing the energy systems for the cafes NICE leverages software tools to simulate and size the PV components, and Design Builder to simulate natural ventilation and minimize the use of mechanical ventilation[15]
	**Smart homes** Advanced ICT solutions are often showcased within individual smart homes. Historically, showcased smart homes focused on demonstrating and pushing the frontier on ICT use while energy efficiency was not directly targeted. More recently, state of the art technology, energy efficiency and GHG emission reduction have become interwoven in several examples of smart buildings. such as: • The Wired house[16] • The Loblolly house by Kieran Timberlake consultants[17] • The San Francisco Federal building[18] • The Chicago Spire [19]

Table 12: Design and simulation tools to improve efficiency and reduce GHG emissions in new buildings

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[15] Source, telephone conversation with Econcern representatives

[16] See http://www.wired.com/promo/wiredlivinghome/

[17] See http://www.kierantimberlake.com/pl_sustainability/loblolly_1.html

[18] See http://www.morphosis.net/

[19] See http://www.newcityskyline.com/CSSalesCenter.html and http://www.thechicagospire.com/

We have identified no study that analyses specifically the potential aggregate impact of design and simulation tools on GHG emissions during construction and the life-time of the building. However, individual case studies, such as the ones described above, indicate that design and simulation tools can enable significant improvements in energy efficiency and reductions in GHG emissions. A systematic deployment of advanced ICT solutions within new buildings further increases this potential.

Studies undertaken in Europe highlighted that applying ICT tools to plan buildings that minimize energy consumption – e.g. simulating and optimizing envelope measures and passive solar heating techniques - designers can achieve significant improvements in building's energy performance.

In moderately cold climates, such as the ones of Central Europe, for example, heating needs can be reduced from over 200 kWh/m^2/year[20] to less than 15 kWh/ m^2/year (i.e. by over 90%[21]. Significant improvements were also shown for a variety of different energy uses (see example on graph). Recent analyses also show that, with an integrated approach, which can be enabled by ICT tools. Economies of scale can be achieved where energy saving costs decrease as the amount of energy saved increases. Therefore highly energy-efficient buildings can cost less than buildings built according to standard practices[22].

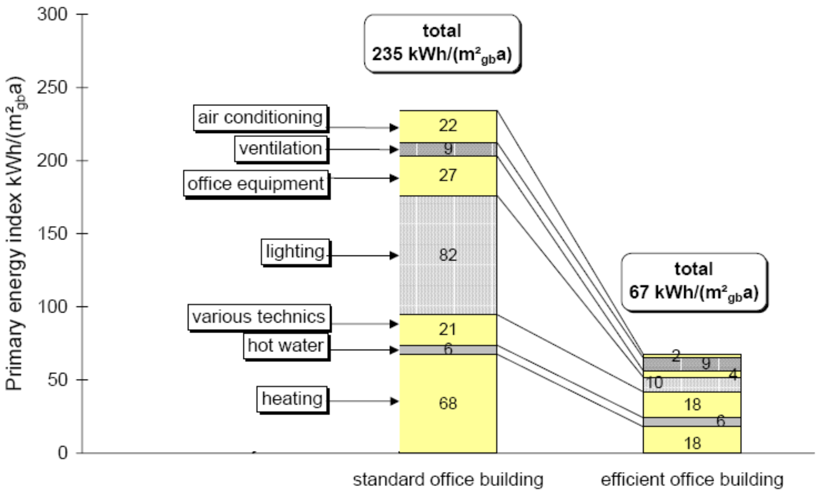

Figure 2: Primary energy index for the "standard" and the "efficient office building"

Figure 4: Primary energy index for 'standard' and 'efficient office building' (example from Germany)

In addition to the opportunities that derive from efficiency gains, such as the ones described above, additional GHG emissions reductions can be obtained if new buildings are designed to also utilize, as much as possible, renewable energy sources available locally (e.g. with PV systems, solar heater systems, urban turbines or geothermal systems) or to utilize the grid when more renewable energy is being delivered to the grid.

Overall there is a significant potential to achieve efficiency gains and GHG emission reductions with new buildings, where:

1. ICT tools can be deployed to design and plan buildings that fit with the environments in which they are built
2. During their use-phase advanced ICT solutions adapt the buildings' behaviour and performance to changes in the external environment and to the needs of their users.

With new buildings the opportunities are significant especially in developing countries where strong growth, demographic pressures and urbanization processes are driving the construction industry and where a dramatically increase in building stocks is likely in the years to come (see box).

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[20] The average for existing buildings is 220 kWh/m2/yr in Germany and 250–400 kWh/m2/yr Central/Eastern Europe

[21] IPCC AR4 Chapter 6, also referencing Krapmeier and Drössler, 2001; Gauzin-Müller, 2002; Kostengünstige Passivhäuser als europäische Standards, 2005

[22] Harvey, 2006; Chapter 13, cited by IPCC AR4 chapter 6

Urbanization processes

	Urban population 2005 (thousands)	Urban population 2030 (thousands)	Urban population 2050 (thousands)	Change between 2005 and 2030 (thousands)	Change between 2005 and 2050 (thousands)
More developed regions	899,848	1,015,630	1,071,393	115,782	171,545
Least developed countries	206,996	539,448	966,884	332,452	759,888
Less developed regions, excluding least developed countries	2,057,791	3,410,002	4,360,014	1,352,211	2,302,223
Europe	525,831	550,287	556,724	24,456	30,893
North America	268,209	351,430	401,478	83,221	133,269
Latin America and the Caribbean	432,554	603,385	682,551	170,831	249,997
Africa	349,392	759,402	1,233,971	410,010	884,579
Asia	1,565,109	2,669,175	3,486,320	1,104,066	1,921,211
China	530,659	879,892	1,027,294	349,233	496,635
India	325,563	611,407	914,888	285,844	589,325
Japan	84,363	86,304	82,086	1,941	- 2,277
Oceania	23,540	31,401	37,247	7,861	13,707
World	3,164,635	4,965,081	6,398,291	1,800,446	3,233,656

Accommodating over 3 bn. people in urban environments represents a major challenge for societies and for the environment. E.g. if each person joining the cities between 2005 and 2050 was to require 30 square meters for housing, if each square meter was to consume 100 kWh per annum and if each kWh was to generate 0.6 kg of CO2 emissions, then the additional emissions generated by urbanization environments would sum up to about 5,800 MtCO2.

Table 13: Urban population in selected countries and regions – source Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2006 Revision and World Urbanization Prospects: The 2007 Revision

The analysis above shows that focusing ICT towards designing and operating buildings, and associated appliances, that dramatically reduce energy use, produce renewable energy locally, when possible, and utilize grid energy when renewable energy is available, can provide substantial benefits in terms of avoided GHG emissions.

Such benefits could be even higher when design tools and ICT technologies are applied not at a building scale, but at a larger scale to improve city planning or to design new communities.

Thanks to improved processing power, data availability and software capabilities, ICT applications can be used to simulate and analyse holistically complex urban systems and seek solutions that increase quality of life while reducing overall energy use and generating a minimum amount (or even a negative amount) of GHG emissions. In such urban environments, ICT can also be deployed as a key infrastructure component, providing additional flexibility and intelligence to the day to day operations of a city. ICT applications solutions could, for example:

- simulate potential traffic patterns to plan an urban layout and include urban infrastructures that enable citizen to maximize walking, biking or public transportation and reduce the use of private transportations.

- model the flows of material uses to build systems that minimize waste production while maximizing reuse and recycling
- forecast energy use and the availability of renewable energy resources to integrate local renewable energy production in the city energy system
- simulate, understand and address problems associated with urban heat-islands
- provide context-dependent information to citizen to optimize their energy use and minimize GHG emissions

Some examples of ICT use at urban scale are provided below:

	**Building an Eco-city - Dongtan** Design and engineering company, Arup is using advanced design tools to help the Shanghai Industrial Investment Corporate (SIIC) develop Dongtan, an eco-city that aims at being as close to carbon neutral as possible. Dongtan's infrastructure will be rich in technology and will include advanced management systems for both energy and transportation. The city is designed to produce its own energy from wind, solar, bio-fuels and recycled city waste. A network of cycle and footpaths will help the city reduce traffic and congestion and achieve close to zero vehicle emissions. Clean technologies such as hydrogen fuel cells will power public transport. Farmland within the city will use organic farming methods to grow food[23].
 *Figure VR planning map of ShenZhen's Center in 2004*[24]	**Building a digital city – Shenzhen** Early in 2002, the city government of Shenzhen began its digital development and management trial project. ICT technologies were utilized from the planning phase leveraging satellite imaging to create an urban simulation module. An overall digital city management system was created and made available to city planners. A variety of communication technologies (GPS, GPRS, WAP, integrated electric monitor system, remote sensing, satellite imaging) are integrated in the portfolio of technologies utilized by the city planners. The use of ICT in Shenzhen aims at reducing the resources needed for construction and at creating economic development modules that better utilize natural resources while providing comfortable living environments[25].

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[23] See http://www.arup.com/eastasia/project.cfm?pageid=7047

[24] Source: computer simulation technology implement in Shenzhen urban planning and design,(Chinese) http://www.86vr.com/case/cityplanning/200411/4524.html

[25] Source: computer simulation technology implement in Shenzhen urban planning and design,(Chinese) http://www.86vr.com/case/cityplanning/200411/4524.html

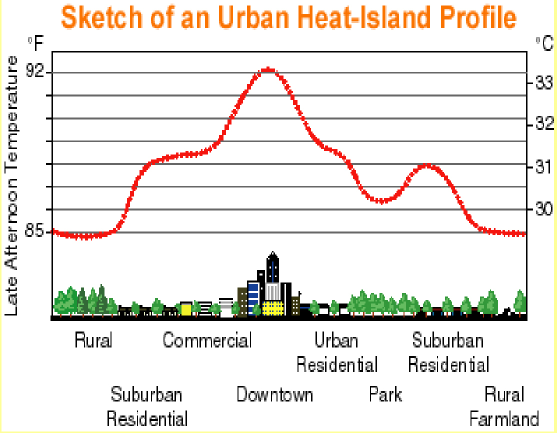

Figure 5: Sketch of an urban heat-island profile – source http://eetd.lbl.gov/HeatIsland/HighTemps

EPA's Urban heat-islands Mitigation Impact Screening Tool (MIST)

Urban heat-islands refer to situations in which urban and suburban temperatures are 1 to 6°C (2 to 10°F) hotter than nearby rural areas (see picture below)[26].

Typically higher temperatures increase peak energy demand, air conditioning costs, air pollution levels, and are a cause of heat-related illness and mortality.

The US Environmental Protection Agency has developed an ICT tool that helps planners assess the impact of urban heat-islands and simulates the impact of various mitigation strategies. The tool, together with additional tools available on EPA's Heat Island web site, helps planners articulate comprehensive master plants or implement and monitor individual mitigation strategies e.g. to educate citizens, increase urban albedo, extend urban vegetative cover or reduce waste heat generated by energy usage – all strategies that, by reducing urban temperatures, reduce air conditioning usage and, consequently GHG emissions[27].

Table 14: Design and simulation tools to improve efficiency and reduce GHG emissions at city scale

The analysis of existing literature and anecdotal evidence from case studies highlight that a systematic use of ICT during the planning stage of new buildings and the integration of ICT within the building infrastructure, can help achieve significant GHG emission reductions, if ICT is directed towards achieving energy efficiency and increasing the use of renewable energy. Such benefits can be further enhanced if ICT is strategically leveraged during urbanization processes when broader city-scale improvements can also be achieved.

When new buildings are built, or new cities (or parts thereof) are created the gains enabled by ICT can vary dramatically depending on how well builders and city planners harvest the potential of ICT. At one extreme only marginal improvements may be realized, similar to the ones achievable in legacy buildings, if ICT is not focused on achieving GHG emission reductions. At the opposite extreme, dramatic improvements could be obtained if ICT is deployed strategically from early planning to day to day operations, to minimize energy use and GHG emissions.

Utilizing emission data from the World Energy Outlook the tables below provide an illustration of the GHG emission reductions that can be achieved by 2030 under different scenarios of ICT deployment in buildings that will be built in the 2010-2030 period and in city planning activities taking place in the same period.

	Building GHG emissions from new buildings build between 2010 and 2030 Mt CO2e	**Energy Efficiency gains enabled by ICT %**	**Potential GHG emission reductions enabled by ICT Mt CO2e**	**Adoption of ICT to achieve energy efficiency**	**GHG emission reductions Mt CO2e**
Pacific OECD	81	5 – 90%	4 – 73	30%	1 – 22
Canada/US	282	5 – 90%	14 – 254	30%	4 – 76
Europe	159	5 – 90%	8 – 143	30%	2 – 43
Transition Economies	232	5 – 90%	12 – 209	20%	2 – 42
Latin America	307	5 – 90%	15 – 276	20%	3 – 55
Africa/Middle East	855	5 – 90%	43 – 769	20%	9 – 154
Asia	2,445	5 – 90%	122 – 2,201	20%	24 – 440
World	4,360		218 – 3,924		46 – 832

Table 15: Smart buildings estimated GHG emission reduction in new buildings deriving from improvements in energy efficiency enabled by ICT – source Ecofys elaboration using WEO data

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[26] For further information on Urban Heat-Island effects see http://www.epa.gov/heatisland/index.html

[27] See http://www.heatislandmitigationtool.com/

As highlighted above, when ICT is used at urban scale to plan cities that promote walking, biking and public transportation, additional GHG emission reduction can also be achieved from the transportation sector. The table below illustrates the GHG emission reduction opportunities that are achievable with urban design and planning tools that enable a reduction on private car travel by 1%, 5% and 10% respectively[28].

	2005 emissions LDV MtCO2e	2030 emissions LDV MtCO2e	% reduction in LDV traffic			Net Emission reductions from mode switching MtC02		
			low	Medium	high	low	medium	High
OECD North America	1,282	1,623	1%	5%	10%	16.2	81	162
OECD Europe	516	535	1%	5%	10%	5.3	26	53
OECD Pacific	219	219	1%	5%	10%	2.2	11	22
FSU	100	229	1%	5%	10%	2.2	11	22
Eastern Europe	53	82	1%	5%	10%	0.8	4	8
China	64	303	1%	5%	10%	3.0	15	30
Other Asia	64	174	1%	5%	10%	1.7	9	17
India	29	103	1%	5%	10%	1.0	5	10
Middle East	29	67	1%	5%	10%	0.7	3	7
Latin America	133	294	1%	5%	10%	2.9	15	29
Africa	63	167	1%	5%	10%	1.7	8	17
Total	2,551	3,797				38.0	190	380

Table 16: Emission reductions from travel mode switching enabled by smart urban planning

It can be argued that in fast growing cities in developing countries there is a higher flexibility and higher potential for GHG emission reductions through city planning. On the other hand advanced planning tools may find a faster penetration in developed countries, where a deeper technological and knowledge infrastructure may already be available. Table 15 assumes that these two effects balance each other and that similar potential for GHG emission reductions are present in both developed and developing countries.

The relatively low turnaround time of urban infrastructure (and transportation infrastructure in general), will likely limit the impact that city planning may have on transportation patterns and GHG emissions by 2030. There is however little data available for a rigorous assessment of these opportunities, thus the level of uncertainty in the estimates provided above is very high.

4.1.3 Uncertainty analysis

Overall, the uncertainty over the energy efficiency gains and GHG emission reductions achievable with ICT use in the built environment and in urban environments is high as a broad mix of solutions and technologies, both ICT and 'traditional', could be deployed to achieve the same result. For example energy savings in climate control could be achieved with smarter sensor that tailor the use of HVAC systems to users' needs (e.g. optimizing room temperature and considering users' presence or absence in a room) but also with better building envelopes. The relative cost-effectiveness of difference solutions

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[28] The GHG emission reductions that may be achieved by leveraging ICT tools to moderate heat islands effects are not explicitly quantified here due to the insufficient data on the relevant phenomena.

may vary greatly, especially with existing buildings where structural improvements become more expensive and lock-in effects are in existence. ICT, however, can also play a critical role in analyzing these trade-offs and identifying the solutions, both ICT-related and 'traditional', that can deliver the maximum environmental benefits.

Even higher uncertainties exist when assessing the potential to achieve improvements at the level of whole cities, when GHG emission reductions may derive from transportation, waste management, or, indirectly in production sectors.

The analyses performed above highlight that even if advanced, efficiency gaining, ICT technologies may have a higher penetration in developed countries they have a greater impact when deployed in new buildings and urban infrastructures. As a result the overall opportunities for GHG emission reductions are likely higher in developing countries, where urbanization processes and the construction of new buildings will drive a greater proportion of CO_2 emissions growth.

Giving this high developmental pace, an effort to accelerate the deployment of ICT solutions to reduce energy use in developing countries would likely deliver substantial GHG benefits.

Currently, the data available for developing countries are scarce and only allow for aggregate top-down analysis of higher uncertainty. Given the scale of the potential opportunities in developing countries it is therefore advisable that more complete and better data collection processes are activated.

4.1.4 Conclusions

Despite the high level of uncertainties, overall the data indicate that significant benefits are possible when using ICT to build and operate smarter buildings. ICT can therefore play a key enabling role in achieving 'zero emission' buildings and cities in which GHG emission reductions from the built environment are dramatic reduced or totally eliminated.

ICT applications can play a key role in delivering solutions that achieve emission reductions in the short term while can also activating virtual cycles, or low GHG emissions feedbacks, that leverage network economies and lead to processes of progressive GHG emission reductions over time (see example below).

Low GHG emissions feedback

As the number of smart appliances and controls within buildings increase, the implementation a complete building management system, to centrally orchestrate such devices, becomes more convenient. With advanced building management system in place, the incentive to also deploy smart meters grows, as smart meters, in combination with building management systems, enable building managers to minimize energy use when fossil fuel energy is available and maximize it when cheap renewable energy becomes available. In a competitive energy market this leads energy providers to offer a greater variety of price and product offers, also increasing the flexibility and intelligence of their networks, In turns this provides an incentive to deploy intelligent systems and renewable energy components within buildings.

Processes such as the one described above are vital for achieving a vision of buildings and cities with 'zero emissions', and in which:

- the focus is truly on delivering 'good living services' to their occupants
- the building structures are tailored to fit within the natural environments in which they are built and to minimize the use of natural resources

- the energy needed to deliver the services required by building occupants is delivered without waste
- (whenever appropriate) buildings produce their own energy – and sell to the grid the excess energy produced
- energy use within the buildings is managed so that energy is imported from the grid when energy produced with renewable energy sources is available
- urban and regional structures enable the minimization of emission associated with transportation and waste production

Thus ICT can be a key enabler to dramatically reduced, or totally eliminate, in some circumstances, GHG emission from the built environment.

There is no evidence, however, that suitable ICT applications, and resulting GHG benefits, will roll out rapidly and automatically, as several cognitive, cultural, technology, regulatory, and financial barriers exist.

Forward looking public policies and corporate strategies can play a critical role in removing barriers to adoption and in stimulating the take up of ICT solutions that reduce GHG emissions. Policies and strategies may for example include:

- The creation of better and more tailored (for geography, or specific market segments) ICT tools for the design and planning of energy efficiency buildings or communities
- Capacity building strategies targeting the building industry (including architects, engineers, builders, planning officials) to further increase knowledge and use of ICT in both planning and implementation phases
- Awareness building and education campaigns targeting the broader public
- The provision of appropriate incentives to planners linked with the reduction of energy use and GHG emission
- The removal or regulatory barriers that hinder the offer of more sophisticated energy systems (e.g. removing regulated tariffs that do not allow price differentiation between time of day or differentiations based on GHG emission)
- The deployment of standard methodologies to uniformly asses the GHG impacts of ICT applications and make the associated information available to potential buyers and renters in a transparent manner
- Facilitating the widespread adoption of uniform standards of communication between different ICT devices used in the built environment
- Within the Kyoto protocol framework, develop showcase CDM projects with appropriate methodologies

4.2 Transportation

Greenhouse gas emissions from transportation have been steadily increasing in both developed and developing countries, driven by

- an increasing demand for mobility (average km travelled per person),
- a growing market share of private transportation vs. public transportation, and
- a trend towards larger and heavier vehicles as well as vehicles with more functionalities (e.g. air conditioning).

Combined these trends have more then compensated the efficiency gains achieved by vehicle manufacturers.

These trends are present in both developed and developing countries alike. In developed countries the major drivers for growth are larger vehicle size and increased km travelled, while in developing countries the major driver for growth is the dramatic increase in the number of vehicles in circulation[29].

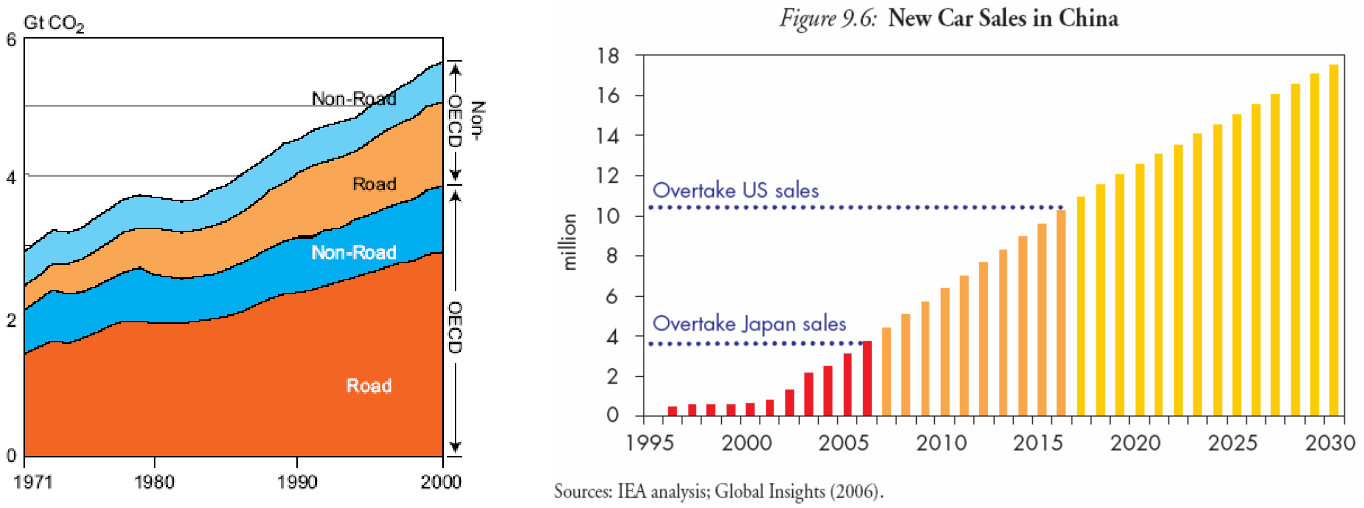

Figure 9.6: New Car Sales in China

Sources: IEA analysis; Global Insights (2006).

Figure 6: Historical GHG emissions from the transport sector and projection for new car sales in China – source IEA 2006 and WBCSD

Current projections of future growth forecast a dramatic increase in the number of private vehicles in circulation and in the total GHG emissions (including freight, air travel and public transportation) generated by the transportation sector (see below).

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[29] See IPCC AR4 Chapter 5 page 329

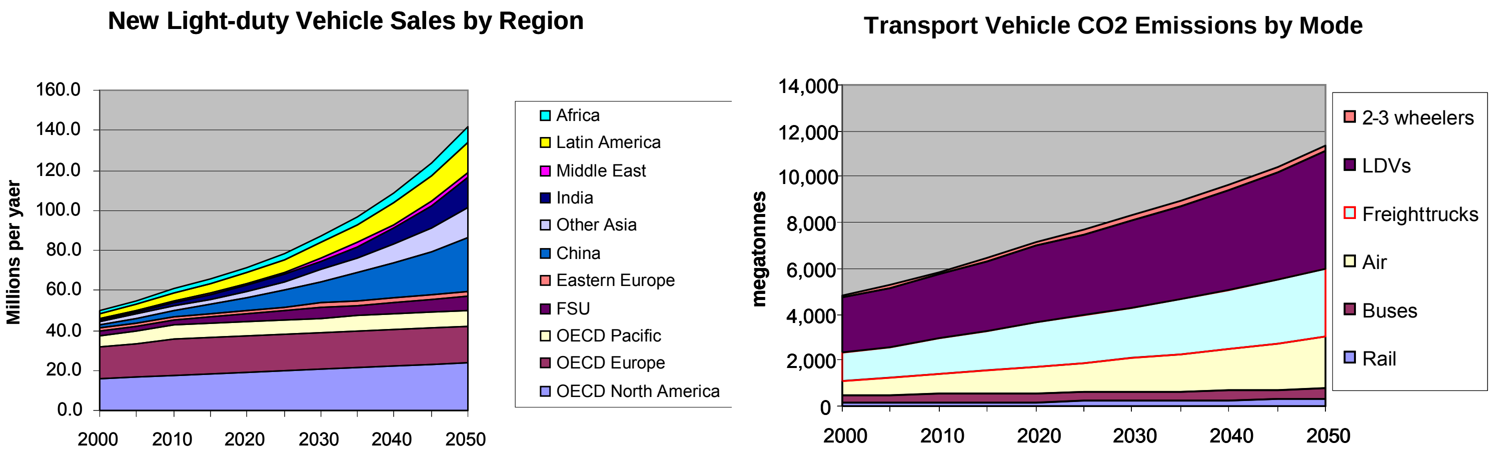

Figure 7: Future growth of light duty vehicles and GHG emissions from the transport sector – source WBCSD

Information and communication technologies can play a major role in reducing GHG emission from the transportation sector if used to:

- Substitute digital information exchange to physical travel in work related settings
- Make public transportation more efficient, e.g. by enabling new forms of public transportation, such as 'personalized public transport'
- Enable the charging of full costs (including environmental costs) to private transportation, reducing the incentives for this mode of transportation
- Decrease the average km travelled by each vehicle by optimizing travel patterns (e.g. selecting faster route or minimizing time spent looking for parking)
- Improve driving styles to reduce emissions per km travelled e.g. through sensors for keeping safety distance between vehicles and minimize changes in speed
- Improve the efficiency of individual vehicles
- Optimize the energy use in rail and road networks
- Integrate and optimize logistics

The table below summarizes the GHG impacts that ICT applications can have in transport.

ICT applications	Impacts on GHG emissions (direct and emission emissions)						
	Buildings	Industrial production	Waste	Transportation	Energy supply systems	Impacts on land	Other impacts
Transport							
Smarter work							
Telecommuting	Reduced lighting, heating, floorspace in commercial buildings. Increased lighting, heating, floor space in residential buildings			Fewer km travelled by commuters. Decreased traffic congestion.			More free time and disposable income may result in increased traveling and spending. Risk of increased urban sprawl.
Teleconferencing				Fewer km of business travel			Potential broadening of companies' areas of operations
Smarter traffic infrastructure							
In vehicle electronics				Less fuel used per km travelled			More efficient travelling may result in more travel
GPS route and fleet management				Fewer km traveled by private vehicles and trucks			
Intelligent Transport Systems		Less production of private transport vehicles and trucks, more production of public transport vehicles		Fewer km traveled. Less fuel used per km travelled		less need to build roads	
Street light switching				Less electricity use			More funds available for public authorities

Table 17: Transport – ICT applications and channels to GHG emission reduction

4.2.5 Telecommuting

Telecommuting is perhaps the most investigated ICT application in terms of ITC impact on energy use and GHG emissions.

Most research on this application has taken place in the US and has focused at the impact of telecommuting on transportation emission patterns.

Utilizing a detailed questionnaire with its employees, AT&T assessed the take up of telecommuting practices within its company, highlighting an increase in productivity and job satisfaction in telecommuters, and estimating that AT&T's telecommuters saved about 5.1 million gallons of gasoline, equivalent to about 44,000 metric tons of avoided emissions (this study did not consider potential impact on energy use and emissions in buildings).

Focusing on the US market as a whole the Consumer Electronics Association estimated that about 3.9 million Americans current telecommute and that telecommuters save between 17-23 kg of CO_2 emissions a day. Thus the CEA estimates that currently US telecommuters avoid emitting between 10 and 14 Million tons of CO2 per annum.

Looking at existing and potential take up of telecommuting the American Consumers Institute envisions that an additional 10% of US workforce could take up telecommuting over a 10 year period. Considering only benefits deriving from the reduction of car commuting, the ACI estimates that such change would allow the US economy to save each year about $96.5 bn, reducing gasoline use by 16.6 bn liters and CO_2 emissions by 38.5 million tons[30].

Similar results emerged from research done in Europe.

In the UK a pilot survey undertaken by BT indicated that, on average, home-workers saved 3,149 miles (about 5,000 km) of home to office travel, most of which would have been by car rather than by public transport. Respondents were also asked if they had increased leisure journeys: only 7 out of the 43 home-workers interviewed said they had, and the increased mileage was low in relation to the savings from home-office travel[31].

In simulating impacts on congestions NERA 'conservative assumption' on car commuting is that compared to a business as usual scenario home workers will enable a 10% reduction in traffic in 2005 and 15 per cent in 2010, with a noticeable impact on traffic congestion[32].

Discussing potential aggregate savings at European level, and citing a study by the European Telecommunications Network Operators Association (ETNO) and the World Wildlife Fund, the AeA notes that if just 10 percent of the EU employees became flexi-workers 22 million tonnes of CO_2 might be saved annually[33].

Thus both US and European studies point out that telecommuting can potentially enable millions of tons in GHG emission reductions.

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[30] Joseph Fuhr and Stephen Pociask: Broadband services: economic and environmental benefits The American Consumer Institute October, 2007 http://www.internetinnovation.org/Portals/0/Documents/Final_Green_Benefits.pdf

[31] Reported in MOTORS AND MODEMS REVISITED The Role of Technology in Reducing Travel Demands and Traffic Congestion by John Dodgson Jonathan Pacey Michael Begg NERA, London, May 2000

[32] John Dodgson, Jonathan Pacey and Michael Begg "Motors and Modems Revisited: the role of technology in reducing travel demands and congestion" NERA

[33] AeA 2007 – John A. 'Skip' Laitner, Karen Ehrhard-Martinez Advanced Electronics and Information Technologies: The Innovation-Led Climate Change Solution. Available at http://www.aeanet.org/aeacouncils/AeAEurope_Energy_Efficiency_Report_17Sep07.pdf

Several authors, however, pointed at a number of indirect, rebound effects that may reduce the positive impacts of telecommuting on traffic levels and GHG emissions. In particular potential traffic (and GHG emissions) increases have been associated with:

- Latent demand from people who decide to travel as congestion, thanks to telecommuting, decreases
- Leisure travel from telecommuters that take advantage of the commuting time saved thanks to telecommuting
- Increased urban sprawl, facilitated by the diminished need to live in proximity to offices

Despite the recognition of these dynamics, the prevalent consensus in the literature is that overall telecommuting reduces the km travelled and the GHG emissions deriving from transportation. The debate on the size of rebound impacts is however open. It is clear, however, that the size of possible rebound effects depends on the cultural, economic and policy framework in which telecommuting is deployed e.g. an environment in which lack of urban does not encourage mix used living, telecommuting may lead to increasing sprawl and in additional leisure and chores related travel. Flanking policies and measures can therefore maximise the impact of telecommuting and minimize the rebound effect. The dynamics, drivers, and sizes of potential indirect impacts need more rigorous analysis and field research, as data are currently lacking and as the conditions that lead to larger or smaller direct and indirect impacts of telecommuting are not fully understood.

The table below utilizes WBCSD projections[34] of 2030 GHG emissions from light duty vehicles to provide an estimate of the emission reductions that could be achieved with a more systematic adoption of telecommuting. The analysis assumes that, on average, telecommuters would avoid 75% of their commuting emissions and projects three different scenarios in which telecommuting is adopted by 5%, 10% and 30% of commuters. The resulting global reductions in GHG emission are 43, 85 and 256 MtCO2e. Potential GHG emissions reductions in the public transportation sector are not considered, under the conservative assumption that the number and mileage of public transport vehicles would not be reduced in response to the higher number of telecommuters.

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[34] WBCSD Mobility 2030: meeting the challenges of sustainability

	2005 emissions LDV MtCO2e	2030 baseline emissions LDV MtCO2e	% emissions from commuting	% of commuting emissions saved by individual telecommuters	Telecommuting take up			Emission reductions from telecommuting MtC02		
					low	medium	high	low	medium	High
OECD North America	1,282	1,623	30%	75%	5%	10%	30%	18	37	110
OECD Europe	516	535	30%	75%	5%	10%	30%	6	12	36
OECD Pacific	219	219	30%	75%	5%	10%	30%	2.5	5	15
		-								
FSU	100	229	30%	75%	5%	10%	30%	2.5	5	15
Eastern Europe	53	82	30%	75%	5%	10%	30%	1	2	6
China	64	303	30%	75%	5%	10%	30%	3.5	7	20
Other Asia	64	174	30%	75%	5%	10%	30%	2	4	12
India	29	103	30%	75%	5%	10%	30%	1	2	7
Middle East	29	67	30%	75%	5%	10%	30%	1	2	5
Latin America	133	294	30%	75%	5%	10%	30%	3.5	7	20
Africa	63	167	30%	75%	5%	10%	30%	2	4	11
Total	2,551	3,797						43	85	256

Table 18: Emission reductions enabled by telecommuting (only direct emissions considered[35])– Ecofys analysis based on WBCSD baseline projections

With an increasing adoption of telecommuting and the resulting change in transportation needs, vehicle ownership may also be affected as individual telecommuters may decide they do not need to own a private vehicle. This would generate a positive spill-over (in terms of increased GHG emission reductions) as telecommuters would further decrease their travel related emissions by walking, biking and using more public transportation also for chores and recreational travel. In itself, the decrease in the total stock of light duty vehicles would lead to a reduction in GHG emissions associated with vehicle production (perhaps partially compensated by an increase in GHG emissions associated with the production on public transportation vehicles or bikes). These additional positive impacts on GHG emissions have not been assessed here.

In addition to impacting emissions from transportation, telecommuting also changes usage patterns (and GHG emissions) from buildings, as telecommuters may increase energy use and emissions from their homes while enabling their companies to use less energy in existing building or build/rent less building spaces. It is apparent that if residential buildings were to use more energy and less efficiently than office buildings, then telecommuters increasing use of energy in their homes (E.g. to heat rooms that would otherwise be left at ambient temperature), would compensate part of the benefits deriving from reduced travelling. Rigorous analyses are lacking and very few studies have explicitly estimated these impacts.

One of the first researchers to discuss these topics was Romm, who estimated a net electricity savings per telecommuter of 3,000 to 4,400 kWh per year in the US[36]. The uncertainties about this estimate

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[35] ‘Well to tank’ emissions associated to the use of fossil fuels are not considered in this analysis. Such emissions have been estimated in 10-15% of direct emissions. Other potential emission reductions, e.g. associated to a lower car ownership leading to lower emissions from car manufacturers are also excluded from this analysis.

[36] Romm 1999 estimated an incremental electricity consumption of 500 kWh for home office and 1000 kWh for shared-office, to be compared to 270 square feet (25 sq m) of office space saved, requiring 5,400 kWh per year

and about their applicability outside the US are high. For this reason the potential impact of telecommuting on emissions associated with residential and office buildings has not been included in the estimates provided above.

It is clear, however, that policy makers and companies seeking to leverage telecommuting to reduce GHG emissions should better understand and quantify the emission patterns at their employees' houses, to ensure that this mitigation strategy achieves the emissions reductions sought.

4.2.6 Virtual meetings

Virtual meetings are here defined as gatherings of two or more people (co-workers) that are mediated by an advanced telecommunication devices and do not involve the physical contiguity between participants. Virtual meetings can take place through audioconferencing, videoconferencing and more modern forms of telepresence (see example below).

"…A typical Halo studio uses 2.43 kilowatts of electricity per hour over a 24-hour period (assuming 8 hours of use and 16 hours in standby mode). Total consumption is 58 kilowatt-hours per day of electricity. One round trip flight for three passengers from London to Tokyo generates the same level of CO2 emissions as a Halo Studio located in Europe for an entire year….." Halo brochure

Telepresence example - HP HALO
Product value proposition: Enable meaningful distance collaboration for product development, manufacturing and marketing.
Technical components of collaboration studio:
Dedicated high bandwidth network connection
(3) Broadcast-quality cameras and lenses
(4) Plasma screen monitors,
Dedicated collaboration channel, including a VGA connection for sharing content via laptop
(1) High-definition overhead object camera
(1) Front curved wall
(3) Speakers
(1) HCS equipment rack: audio mixer, a frame grabber, CODEC, a scan converter, a server, collaboration client software, third-party device driver software and an HCS connection user interface.
(1) Network router
(7) ELP ceiling light fixtures, including lamps
(1) Graphic eye lighting control system
Custom designed, HP proprietary software and GUI

With the use of virtual meetings (including audio-conferencing, videoconferencing and more modern forms of telepresence) GHG benefits derive from the avoidance of business related travel, particularly when air travel is avoided.

Systematic monitoring of these activities does not occur and rigorous data on the impact of teleconferencing on business travel are not readily available. Anecdotal evidence, however, suggests that virtual meetings can have a noticeable impact on business travel, as highlighted by the examples below.

Source	**Finding**
BT trial 1983-86 (Bennison 1998)	87% of respondents felt that teleconferencing reduced the amount of travel they were making
BT (BT c. 2001 and Hopkinson et al 2003)	• 71% of respondents said their last conference call had replaced a meeting (with 52% or respondents stating that this was 'definitively the case'), whilst 5% stated that it had generated a meeting • 0.5 million car/van trips and 51-59 million miles of travel saved for 108,000 people (approximately 5 trips and 450-550 miles per person per year) • 46% avoided trips would have taken place during peak periods • 10 – 11% reduction in business mileage
Epson Telecentre (SustainIT undated, Bibby 2000)	Telecentre with 8 desks estimated to save 30,000 vehicle miles per annum (3,750 miles per desk)
Tetrapak (Arnfalk 2002)	Business travel reduced by 10% due to videoconferencing
Telia (Arnfalk 2002)	Between 1997-2000 business travel by air reduced by over a third, partly due to more virtual meetings (particularly audioconferencing)
Survey with 4 Swedish companies (Arnfalk 2002)	• 45-61% respondents said videoconferencing had reduced their own travel • 15-25% said it had reduced other people's travel • 17-20% said it had only had a minor effect • 1-3% said it had increased their travel
Mason Williams (2004)	Video meeting equipment meant that travel costs have dropped by a third
SCAG meeting (Mokhtarian 1988)	• Total vehicle miles increased by 29% by replacing a regional meeting for a teleconference, as shorter distances to teleconference facilities were outweighed by increased attendance • Travel in peak-hour, congested conditions was replaced by travel in off-peak, less congested conditions • 1.8% of all business travel may currently be substituted by teleconferencing
Canadian employees (Redekop 1994)	25% respondents made less business trips due to communication technologies in 1992, and 28% in 1994
Canadian business travellers (Roy and Filistrault 1998)	• 24.2% said they were travelling less oftern as a result of company policy to increase utilisation of teleconferencing • Of those participating in at least one videoconference in the previous yearm users stated that videoconferencing had been a substitute for an air trip in 45% of cases • 1.8% of all business travel may currently be substituted by teleconferencing
HP 2008	Case study of Halo telepresence solution applied to a HP team responsible for transferring manufacturing responsibility for an HP product from Oregon to Singapore: • cut an estimated 44 international employee trips from the project. • prevented about 145 metric tons of carbon emissions from being released into the environment

Table 19: Future scale and impact of teleconferencing. Source Cairns S, Sloman L, Newson C, Anable J, Kirkbride A & Goodwin P (2004) 'Smarter Choices – Changing the Way We Travel'

The analyses discussed above typically illustrate case studies of individual companies. The literature review did not identify rigorous analyses that consolidated and aggregated these results, providing projection at regional or country level.

The replacement of in person meetings that would require air travel is probably the most effective way to achieve economic savings and GHG emission reductions utilizing virtual meetings. The table below provides a calculation of the potential GHG benefits that may derive, globally, by the use of virtual meetings to substitute air travel. Utilizing WBCSD projections[37] for GHG emissions deriving from air-travel, and estimating that in OECD countries 30% of air travel is for business purposes, while in non OECD countries the proportion is 40%, the table shows that with a 5%, 15% and 30% substitution of

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[37] WBCSD Mobility 2030: meeting the challenges of sustainability

business travel by virtual meetings the potential GHG emission reductions would reach about 25, 74 and 148 MtCO2e respectively.

	2005 emissions total air travel MtCO2e	2030 baseline emissions total air travel MtCO2e	Assumed baseline emissions from business travel 2030 (%)	Emission from business travel 2030 MtCO2e	% baseline travel avoided thanks to virtual meetings			Emission reductions from virtual meetings MtC02		
					low	medium	high	low	medium	high
OECD North America	274.	458	30%	137	5%	15%	30%	6.9	20.6	41.2
OECD Europe	189	335	30%	100	5%	15%	30%	5.0	15.1	30.1
OECD Pacific	68	108	30%	32	5%	15%	30%	1.6	4.8	9.7
FSU	14	32	40%	13	5%	15%	30%	0.6	1.9	3.9
Eastern Europe	12	30	40%	12	5%	15%	30%	0.6	1.8	3.6
China	36	108	40%	43	5%	15%	30%	2.2	6.5	12.9
Other Asia	45	113	40%	45	5%	15%	30%	2.3	6.8	13.5
India	12	38	40%	15	5%	15%	30%	0.8	2.3	4.5
Middle East	22	45	40%	18	5%	15%	30%	0.9	2.7	5.4
Latin America	49	144	40%	58	5%	15%	30%	2.9	8.6	17.3
Africa	18	49	40%	20	5%	15%	30%	1.0	2.9	5.9
Total	738	1459		493				24.7	74.0	148.0

Table 20: Emission reductions enabled by virtual meetings – Ecofys analysis based on WBCSD baseline projections (only direct emissions from aircraft considered[38])

As good baseline data and projections on business travel are lacking, especially for developing countries, the uncertainty associated to the analysis is high. Even scenarios of low take up of virtual meetings, however indicate a significant potential for GHG emission reductions.

4.2.7 ICT use within transportation infrastructures and vehicles

The analysis of potential benefits arising from a broader use of ICT within **transportation infrastructures** highlight a variety of areas with opportunities to improve efficiency and reduce GHG emissions. For example **within vehicles** ICT can be deployed to[39]:

- Improve efficiency of vehicle engines (e.g. direct injection enabled by improvements in valve control may increase efficiency by 18%)
- Monitor operating conditions of car components with aerodynamic impact (e.g. using sensor technologies to maintaining tires in optimal conditions can reduce emissions by 3%)
- Enable driving conditions that minimize energy use (eco-driving), which are estimated to improve efficiency by 5% to 20%
- Provide drivers with real time information about their fuel use, which has been shown to lead to changes in driving styles and on a reduction in fuel used
- Better run and monitor air conditioning systems (e.g. to signal possible risks of leaks of gasses with high global warming potential)

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[38] GHG impacts not considered here include ‘well to tank’ emissions and other GHG impacts caused by air travel (e.g. primarily NOx emissions and enhancement of cirrus cloud coverage

[39] Various sources were used for the estimates reported here, including IPCC AR4 WG3 chapter 5, ENI 30% initiative (http://www.30percento.it/default.htm) and the ‘Economist’ magazine.

- Facilitate the design of vehicles that use lighter materials or benefit from improved aerodynamics (weight and aerodynamics are, with engine efficiency, the largest drivers for vehicle emissions)
- Enable new transportation solutions (see example below)

Skysails offers a wind propulsion system based on large towing kites. The company claims that depending on prevailing wind conditions the towing system can save a ship 10 to 35% of annual fuel costs, whereas under optimal wind conditions fuel consumption can temporarily be cut by 50%.

The operation of the kite system at sea rely on a sophisticated control system, highly dependent on ICT technologies.

We could not identify any specific study that assessed the GHG emissions reductions achievable with an increased use of ICT in transportation infrastructures and within vehicles. It is however clear that electronics are playing a growing role in vehicles design and in transportation infrastructure, improving the performance and efficiency of transportation systems, thus reducing their GHG emissions.

As with other ICT applications a critical problem when trying to estimate the potential impact of ICT within vehicles is the difficulty of disentangling the role of ICT from the impact of other more 'traditional' energy efficiency measures that utilize some ICT components or that could be implemented without modern ICT e.g. if CAD tools are used to design a lighter and more aerodynamic vehicle should the associated emission reductions be 'credited' to ICT? Lack of relevant and detailed data impeded a detailed bottom up analysis of these dynamics in this report. The anecdotal evidence provided above, however, and expert input, indicate that a concerned effort to leverage ICT to increase average vehicles efficiencies, could generate a significant impact. The table below provides some conservative estimates assuming that ICT use in vehicles (LDV, trucks, busses, two wheel vehicles and trains) could generate savings of 5 to 15% as compared to the 2030 baseline (i.e. 0.15% to 0.5% per annum). In such scenarios global GHG emission reductions would be between 449 and 1,347 $MtCO_2$.

			Vehicle efficiency improvement			Emission reductions from vehicle efficiency improvements MtC02		
	2005 emissions all vehicles MtCO2e	2030 baseline emissions all vehicles MtCO2e	Low	medium	high	low	medium	high
OECD North America	2,120	2,815	5%	10%	15%	141	281	438
OECD Europe	1,224	1,511	5%	10%	15%	76	151	229
OECD Pacific	499	589	5%	10%	15%	29	59	91
FSU	204	401	5%	10%	15%	20	40	67
Eastern Europe	93	155	5%	10%	15%	8	15	26
China	315	827	5%	10%	15%	41	83	145
Other Asia	412	806	5%	10%	15%	40	81	137
India	164	395	5%	10%	15%	20	40	69
Middle East	237	387	5%	10%	15%	19	39	63
Latin America	398	792	5%	10%	15%	40	79	134
Africa	181	378	5%	10%	15%	19	38	63
Total	5,846	9,055				453	906	1,460

Table 21: Emission reductions deriving by efficiency gains enabled by ICT deployment in vehicles (only direct emissions considered)– Ecofys analysis using WBCSD baseline data

The potential for efficiency and GHG emission reduction associated with **GPS fleet management and intelligent transport systems** have been mostly analyzed through individual case studies or research projects. With these ICT solutions, more than with any other transportation solution discussed in this section, analysts debate the risks of traffic (and GHG emissions) increase, due to latent demand from people who decide to travel as congestion decreases and travelling becomes easier and more enjoyable[40].

A critical factors is likely to be how successful these solutions are at enabling a migration from more polluting to less polluting forms of transportation (e.g. from private transportation to public transportation). For these technologies more than others, therefore, the policy conditions under which ICT is deployed will play a critical role in the achievement of possible GHG emissions benefits. This can for example be achieved with a combination of technologies that increase the convenience of public transportation while ensuring that private vehicles pay the full cost (including the environmental costs) associated at their use (see examples below)

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[40] The ITS study: The future impact if ICTs on environmental sustainability, for example, estimates that Intelligent Transport Systems may lead to a net increase in GHG emissions

 iris NextBus - Find out bus arrival time at your bus stop Bus Stop No (5 digits. eg 52069) 52069 Not sure, click here Service No 153 submit Home Service No: 153 NextBus: 9 mins Subsequent bus: 18 mins Bus Stop No: 52069 ComfortDelgro, Braddell Rd Brought to you by SBS Transit Next Query Disclaimer 	A number of bus operators are introducing systems to provide real time information on bus routes, availability and waiting times. Typically such systems include • on-bus computer with GPS receiver bus • a central computer system to manage analyse and distribute incoming data • a communication system to send data from the buses to the central computer system. • gateways to the various telecommunication networks where traffic information is displayed (e.g. web or sms) • electronic display units at designated stops Examples include: King County, WA, USA[41], Melbourne, Australia[42] Singapore[43], Dublin, Ireland[44]
txt2go	Go North East, UK enables customers to purchase tickets by sms anytime anyplace. To buy a ticket customers can simply text "Bus Day" or "Bus Single" to 60060 from their mobile phone. The txt2go ticket is sent to the customers' mobile phones within a few minutes by sms. Once they have received their ticket on their mobile phones customers simply need to show their ticket (sms message) to the driver. The driver check, date, time and security code.
PRONTOBUS	TEP, the transport company of the municipality of Parma, Italy, offers a bus on demand service during low peak periods. Customers can book a bus by calling a toll free number of via the internet. TEP's booking and fleet management systems provide the key back office functions of this services[45]
	A number of cities have introduced or are considering systems to charge drivers for the pollution or congestion they generate. The congestion charge system of London is probably the highest profile and best known example[46] Such system is run on a generally automatic basis using CCTV and Automatic Number Plate Recognition. On line Communication and payment systems are also key components of the system. After four years of operation the system in London was reported to generate a 16% reduction in private vehicle traffic[47]

Table 22: Examples of ICT solutions that encourage the use of public transportation and discourage the unnecessary use of private vehicles

Solutions such as the ones described above, which can shift traffic from private vehicles to public transportation (or other non/low polluting forms of transportation), can have a significant impact. Typically travelling by public transportation is 40-80% more GHG-efficient than travelling by private vehicles, especially when those vehicles are private cars (see table).

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[41] See http://mybus.org/ accessed February 2008

[42] See http://www.metlinkmelbourne.com.au/ accessed February 2008

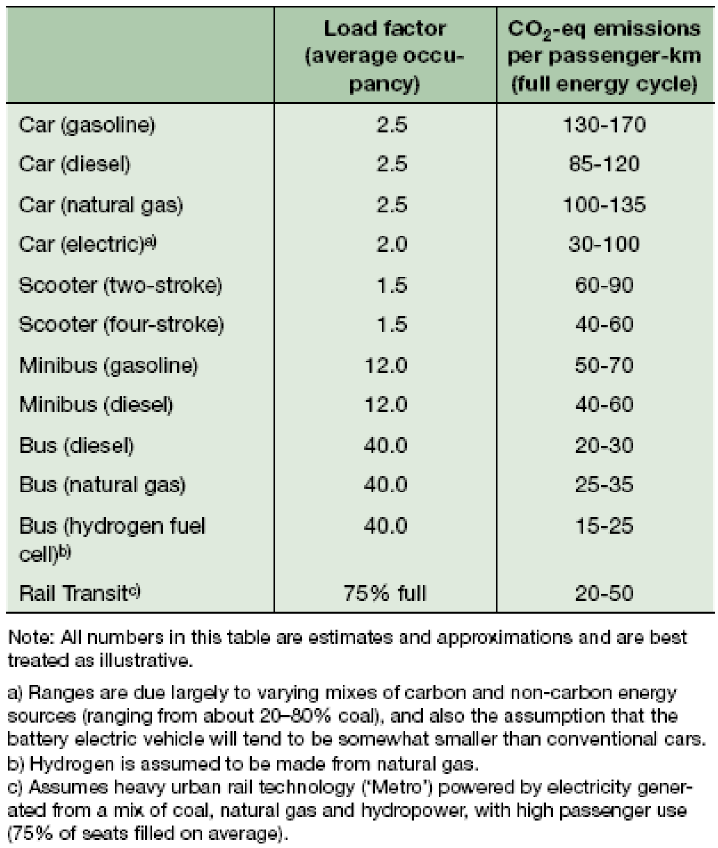
[43] See http://www.slashphone.com/113/7328.html accessed February 2008

[44] See http://www.dublinbus.ie/projects/real_time_passenger_information_system.asp accessed February 2008

[45] See http://www.tep.pr.it/page.asp?IDCategoria=947&IDSezione=5606 accessed May 2008

[46] For an overview of the system see http://en.wikipedia.org/wiki/London_congestion_charge or http://www.tfl.gov.uk/roadusers/congestioncharging/6744.aspx accessed February 2008

[47] Transport for London Central London Congestion Charging Impacts Monitoring available at http://www.tfl.gov.uk/assets/downloads/fifth-annual-impacts-monitoring-report-2007-07-07.pdf



	Load factor (average occupancy)	CO_2-eq emissions per passenger-km (full energy cycle)
Car (gasoline)	2.5	130-170
Car (diesel)	2.5	85-120
Car (natural gas)	2.5	100-135
Car (electric)[a]	2.0	30-100
Scooter (two-stroke)	1.5	60-90
Scooter (four-stroke)	1.5	40-60
Minibus (gasoline)	12.0	50-70
Minibus (diesel)	12.0	40-60
Bus (diesel)	40.0	20-30
Bus (natural gas)	40.0	25-35
Bus (hydrogen fuel cell)[b]	40.0	15-25
Rail Transit[c]	75% full	20-50

Note: All numbers in this table are estimates and approximations and are best treated as illustrative.

a) Ranges are due largely to varying mixes of carbon and non-carbon energy sources (ranging from about 20–80% coal), and also the assumption that the battery electric vehicle will tend to be somewhat smaller than conventional cars.
b) Hydrogen is assumed to be made from natural gas.
c) Assumes heavy urban rail technology ('Metro') powered by electricity generated from a mix of coal, natural gas and hydropower, with high passenger use (75% of seats filled on average).

Table 23: GHG emissions per passenger km comparison of different modes of transportation – source IPCC AR4 based on Sperling and Salon 2002

In extrapolating the projections described in table below, a conservative assumption was made, assuming that, on average, public transport would enable a 50% decrease in GHG emissions as compared to private transportation.

Using WBCSD 2030 projections for light duty vehicles three scenarios are analysed assuming that ICT could enable a 3%, 20% and 40% switch to public transportation by 2030. Under these assumptions possible benefits in terms of GHG emission reductions would sum to 57, 380 and 760 MtCO2e respectively (See table below).

	2005 emissions LDV MtCO2e	2030 baseline emissions LDV MtCO2e	% emissions reductions of public transportation as compared to LDV	% LDV traffic ‘lost to public transportation			Net Emission reductions from mode switching MtC02		
				low	Medium	high	Low	medium	high
OECD North America	1,282	1,623	50%	3%	20%	40%	24.3	162.3	324.6
OECD Europe	516	535	50%	3%	20%	40%	8.0	53.5	107
OECD Pacific	219	219	50%	3%	20%	40%	3.3	21.9	43.8
		-							
FSU	100	229	50%	3%	20%	40%	3.4	22.9	45.8
Eastern Europe	53	82	50%	3%	20%	40%	1.2	8.2	16.4
China	64	303	50%	3%	20%	40%	4.5	30.3	60.6
Other Asia	64	174	50%	3%	20%	40%	2.6	17.4	34.8
India	29	103	50%	3%	20%	40%	1.5	10.3	20.6
Middle East	29	67	50%	3%	20%	40%	1.0	6.7	13.4
Latin America	133	294	50%	3%	20%	40%	4.4	29.4	58.8
Africa	63	167	50%	3%	20%	40%	2.5	16.7	33.4
Total	2,551	3,797					57	380	760

Table 24: Emission reductions from travel mode switching (only direct emissions considered) - Ecofys analysis using WBCSD baseline data

Whereas the solutions described in Table 22 are already viable and impact traffic and GHG emissions in real life situations, they still are relatively simplistic in their set up. Most public transportation solutions mentioned above, for example, are based on a rigid service delivery and a communication model that is centralized: i.e. a public transportation company operates fixed routes and broadcasts to customers information about bus availability on those routes. A fuller exploitation of the ICT potential could enable a significant increase in flexibility and quality of service in public transportation. For example ICT could be used to establish low-cost real-time two-way communication channels between public transport companies and their customers, so that real time information is collected and the public transport operator can adjust bus routes in response to real time customers’ needs. A further step of this process would be to consider any vehicle as a public transportation vehicle, where demand and supply are continuously matched by ICT. In this scenario any vehicle owner (not just companies that specialize in public transportation) would operate as a public transportation supplier.

Likewise existing systems for congestion and pollution charging are relatively crude in that charges are typically levied at fixed (virtual) gates in the city, do not take into consideration actual km travelled or emissions generated in the congested area, do not fully differentiate by vehicle type or driving behaviour, etc. all factors that influence congestion and pollution. Also here ICT can dramatically increase the sophistication and flexibility of the systems and their ability to reduce GHG (and other) emissions.

Obviously building systems that collect and use a large set of data about public transportation users or drivers’ behaviour would require addressing important issues of privacy, social acceptability, and education. Addressing these issues and creating more sophisticated systems, however, would be important, as a shift to less polluting modes of transportation would provide a significant contribution of GHG emission reduction efforts.

Fleet management systems are also important for **freight transportation** and associated emissions. For example past research has highlighted that in developed countries at any given time 20 to 30% of all trucks on the road are circulating empty, while load factors may be in the order of 50%. The situation may be even more extreme in some developing countries[48].

Inefficient route planning may also add additional unnecessary kilometres to each delivery and the consequent GHG emissions.

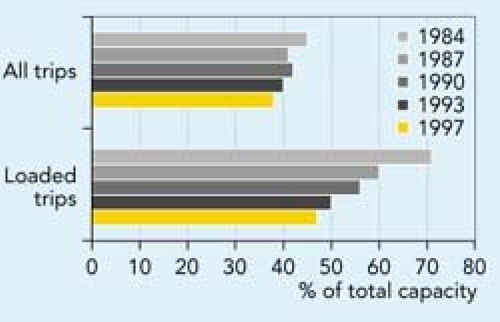


Figure 8: Load factor for trucks over 6 tonnes, source Statistics Denmark, Denmark 2005

In both these areas lack of timely, context-relevant information is a key cause of inefficiency. In both these areas advanced information and communication technologies can provide viable efficiency improving solutions.

The analysis below highlights the potential for GHG emissions reductions from truck transportation, assuming ICT-enabled improvements in load factors. Efficiency improvements of 5%, 15% and 30% (to reach total load factors of 52.5%, 57.5% and 65% assuming a baseline load factor or 50%) would generate GHG emission reductions for 71, 213 and 426 MtCo2e respectively.

	2005 emissions light and heavy duty trucks MtCO2e	2030 baseline emissions light and heavy duty trucks MtCO2e	% improvement in total load factor			Net Emission reductions from total load factor improvement MtC02		
			low	Medium	high	Low	medium	high
OECD North America	370	504	5%	15%	30%	20	59	118
OECD Europe	282	374	5%	15%	30%	14	43	86
OECD Pacific	87	120	5%	15%	30%	2	7	14
FSU	46	79	5%	15%	30%	2	6	13
Eastern Europe	12	22	5%	15%	30%	1	2	5
China	59	153	5%	15%	30%	4	11	22
Other Asia	130	274	5%	15%	30%	9	27	54
India	56	145	5%	15%	30%	5	14	28
Middle East	130	204	5%	15%	30%	4	13	26
Latin America	154	272	5%	15%	30%	8	24	47
Africa	39	80	5%	15%	30%	2	6	13
Total	1366	2,226				71	213	426

Table 25: Emission reductions from improvements in freight management (only direct emissions considered) – Ecofys analysis using WBCSD baseline

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[48] See http://answers.google.com/answers/threadview?id=164154 for references to a number of recent articles on the topic, see also EEA 'Are we moving in the right direction?' available at http://reports.eea.europa.eu/ENVISSUENo12/en/page029.html

4.2.8 Double counting and low carbon feedbacks

The scenarios discussed above for telecommuting, virtual meetings, in-vehicle and infrastructural efficiency improvements, have been analyzed independently from each other. I.e. the baselines of each strategy were not adjusted to consider the possible impacts of other strategies (e.g. the reduction in traffic generated by telecommuting was not included in baseline for the calculation of GHG emission reductions possible thanks to public transportation or increased vehicle efficiency). Pursuing different strategies jointly would obviously harvest higher benefits than pursuing only one strategy. The overall impact, however, would not simply be the sum of individual impacts (see table below).

			2030 emissions after…				
	2005 emissions all vehicles MtCO2e	**2030 baseline emissions all vehicles MtCO2e**	**10% of commuters become telecommuters**	**15% business air travel is avoided by virtual meetings**	**20% of LDV traffic migrates to public transport**	**15% improvement in freight trucks load**	**10% vehicle efficiency improvement**
OECD North America	2,120	2,815	2,778	2,710	2,392	2,317	2,085
OECD Europe	1,224	1,511	1,499	1,449	1,344	1,288	1,159
OECD Pacific	499	589	584	568	525	507	456
FSU	204	401	396	391	346	335	301
Eastern Europe	93	155	153	148	132	129	116
China	315	827	820	804	745	722	649
Other Asia	412	806	802	785	751	710	639
India	164	395	393	387	367	345	311
Middle East	237	387	385	379	366	335	301
Latin America	398	792	785	764	706	665	599
Africa	181	378	374	367	334	322	290
Total	5,846	9,055	8,970	8,751	8,009	7,675	6,908

Table 26: Transportation emission following different ICT applications(only direct emissions considered) – Ecofys analysis using WBCSD baseline data

The table above simply considers the arithmetical relationship between the baselines of different ICT applications. In reality an emission reduction approach that seeks to leverage multiple strategies of GHG emission reductions in the transportation sector will also generate behavioural and systemic impacts that are not captured by the mere arithmetic. Virtual cycles may for example be established such as the one described in the box below.

Virtual meetings and virtual cycles (low carbon feedbacks)

An increased use of virtual meetings at work familiarizes more employees with the use of ICT to perform work remotely. This leads more employees and employers to consider telecommuting as an acceptable mode of work, and causes an increase in the number of telecommuters. With a growing number of telecommuters, and an increased portion of working hours at home, car ownership decreases, while the demand for public transportation, shared ownership vehicles, smart energy-efficient buildings and urban environments that better meet needs locally increases. This leads to a larger number of mixed-use developments that enable less energy intensive lifestyles. As the number of mixed-use developments grows, awareness on their benefits increase, as does the awareness about the opportunities offered by virtual meetings and telecommuting, thus restarting the cycle.

Existing literature and data do not allow a good analysis of the dynamics described above and therefore a quantitative estimate of these dynamics is not attempted here. Moreover the positive dynamics described above are by no means automatic, as perverse cycles, in which rebound effects dominate (e.g. telecommuting, leading to sprawl, leading to less public transportation and bigger cars) are also possible.

4.2.9 Conclusions

Overall the deployment of ICT technologies in transportation provides significant opportunities to reduce GHG emissions. However risks of rebound effect are also present and need to be considered, to remove barriers to virtual cycles and establish disincentives to perverse behaviours. Several policies and strategies can be implemented to promote the deployment of ICT applications in the transportation sector that generate beneficial GHG emission impact. Such policies may include:

- Remove regulatory barriers that may hinder the adoption of telecommuting (e.g. in some EU countries rigid labour law don’t fit well with working relationship in which telecommuting is broadly adopted)
- Increase awareness about the opportunities offered by telecommuting and virtual meetings to remove cultural barriers and facilitate take-up
- Supporting the development and deployment of intelligent managements systems for public transportation
- Leverage ICT to introduce more sophisticated systems (such as congestion charges) that discourage the use of polluting vehicles
- Favour the development of standard approaches to calculate the GHG benefits deriving by ICT adoption in the transportation field
- Ensure that funding for research in intelligent transportation system and other ICT technologies for the transportation sector is addressed towards applications that reduce GHG emissions

4.3 Commerce and Services

This section focuses on ICT solutions that are applied in the service sector and that can lead to GHG emission reductions. In particular the section will discuss opportunities associated with **e-commerce**, the process of performing commercial trades electronically, **dematerialization**, the process of substituting digital products to physical ones, and **electronic service delivery**, the migration of services that were delivered in a person to person manner to a delivery method that is mediated by the internet or by other ICT supports.

Several activities and examples are present in these categories (see examples below)

.

Category	**Examples**
E-Commerce	• The US 5 largest Internet retailers: o Amazon: books, music and a growing number of other products o Staples and Office Depot: office supplies o Dell, and Hewlett Packard: computers and other consumer electronics • Ebay: person to person auctioning and trade • Various travel sites such as Travelocity, Expedia, Ebookers • EDI for Business to business applications
Dematerialization	• Substitution of printed material with digital information, e.g. for newspapers, magazines, catalogues, brochures, directories, information based books, office papers, forms) • Electronic delivery of software, music, games, and movies
Services	• Electronic invoicing and payments • E-government: government's use of information technology to exchange information and services with citizens, businesses, and other arms of government. • E-learning • E-health: Electronic Medical Records, Telemedicine, Evidence Based Medicine, Consumer Health Informatics, Health knowledge management, Virtual healthcare teams, eHealth Grids for Medical research

Table 27: Examples of ICT use with commerce and services

E-commerce, the use of ICT to perfect trades and deliver products and services is rapidly growing worldwide. According to the US census bureau, the value of all e-commerce accounted for around 3.5% US retail sales in 2005 with an increase of 22% from 2004[49]. Some industries such as books, travel, and computer hardware and software have online sales exceeding 10% of total retail revenue in their respective industry[50]. For the US actual e-commerce sales, including travel, are likely to exceed $259 billion in 2007[51].

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[49] "E-Stats," U.S Census Bureau, May 25, 2007 http://www.census.gov/eos/www/2005/2005reportfinal.pdf

[50] "State of Retailing Online 2007" report from the National Retail Federation (NRF) and Shop.org. For previous analysis of the same topic see also K. Cassar (2003) Jupiter market forecast report: Retail through 2007. Darien C: Jupiter Direct

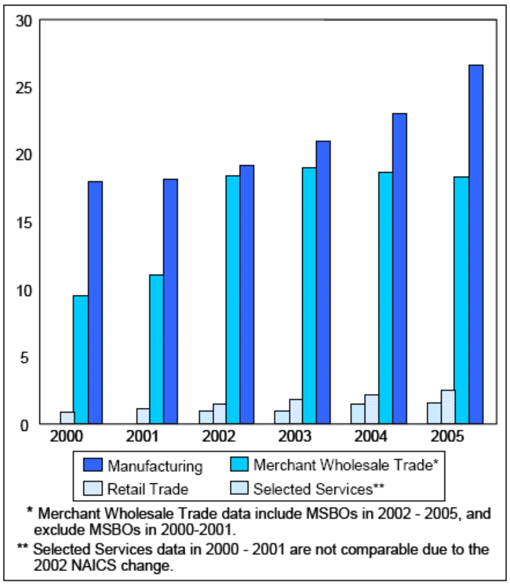
[51] CNN Money: Online sales spike 19 percent http://money.cnn.com/2007/05/14/news/economy/online_retailing/

It has been estimated that, including business to business commerce (B2B), the e-commerce market could reach 25-30% of total sales in the US by 2012[52].

E-commerce is showing a similar growth pattern in the EU, thanks to a combination of better internet connection and an increased familiarity with on-line shopping. Around 30% of the EU-25 population regularly shops online and the B2C (business to consumers) segment is growing rapidly.

In 2006, European B2C e-commerce sales of goods and services (including online travel, event tickets and digital downloads) totalled $182 billion. With a projected annual growth rate of 34% over the 2006 – 2010 period, the market is projected to triple, reaching $578 billion by 2010.

Both in US and Europe the vast majority of sales is in the B2B (business to business) segment which accounts for around 87% of the total online sales in Europe (see picture below) and for about $2.2 trillion of turnover in the US[53][54].



* Merchant Wholesale Trade data include MSBOs in 2002 - 2005, and exclude MSBOs in 2000-2001.
** Selected Services data in 2000 - 2001 are not comparable due to the 2002 NAICS change.

Figure 9 E-commerce as % of total value, 2000-2005, USA.

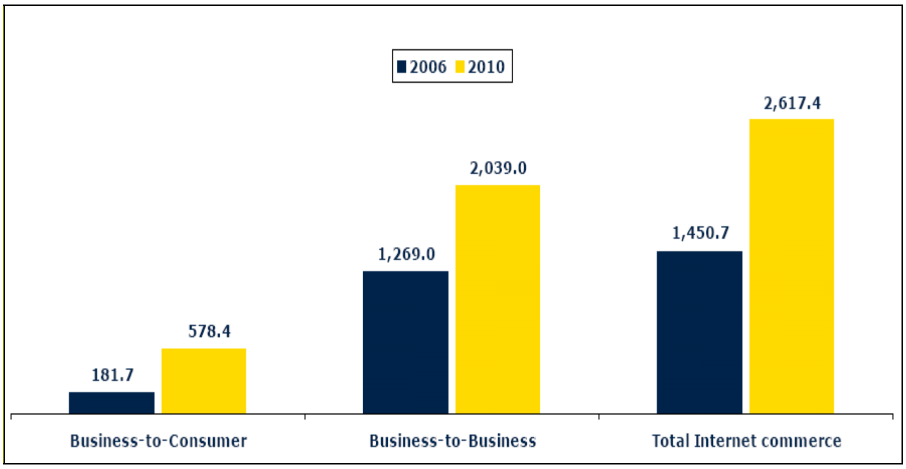


Figure 10 Internet commerce in Western Europe*, 2006 and 2010, in billion Euro
****Includes EU15 plus Norway and Switzerland, source: EITO 2007***

To date in many developing countries, including China, the growth of ecommerce (and of the other activities discussed in this section) is somewhat slowed by a lower penetration of the internet and by the

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[52] See http://www.internetadsales.com/modules/news/article.php?storyid=7225

[53] "E-S Alex Evans and David Steven: Climate change: the state of the debate , 2007, Centre on International Cooperation, The London Accord CO2, available at: http://www.london-accord.co.uk/final_report/reports/pdf/b1.pdf

[54] The data discussed in these figures focus broadly on commercial transaction. They therefore include products that are 'dematerialized' (such as the sale of MP3 music files) and sold on-line but do not fully account for all dematerialization processes (e.g. when dematerialization occurs with products that are not sold online) or for the electronic delivery of services that do not result in a commercial transaction (e.g. e-government). Overall, however, they provide an indication of the rapid growth of these activities and of the impact they may have on the broad economy, and thus on its environmental footprint.

deficiency in key areas such as internet security or electronic payments. These barriers, however, will likely be removed over time.

The success of e-commerce relies on the ease of use provided to buyers and on improvements in the efficiency associated with the logistics of the trade. E-commerce therefore can help reduce GHG emissions by:

- reducing the amount of physical spaces needed in sales structures (e.g. retail stores),
- reducing inventories,
- enabling the adoption of more efficient delivery systems (reducing emissions from transportation), and
- affecting product reuse.

Dematerialization processes deliver similar benefits with additional GHG reductions that stem from the reduction in physical materials used and the associated reduction in storage and transportation needs. With electronic service delivery the main benefits are associated with the reduction in transportation requirements (for chores) and with the reduction in material use (especially paper and printing materials). The following table summarizes the channels by which GHG emission reduction take place in these areas:

	Impacts on GHG emissions (direct and emission emissions)						
ICT applications	Buildings	Industrial production	Waste	Transportation	Energy supply systems	Impacts on land	Other impacts
Commerce and services							
Commerce							
E-commerce	Reduced floor space in commercial and industrial buildings (heat and electricity)	Optimal stock management	More waste for packaging.	Reduced km travelled by shoppers. Increased km travelled by shipping companies.			More efficient person to person commerce may lead to more product reuse and less waste creation, but potentially more packaging and transportation emissions. Expectations of rapid delivery may promote high-GHG-shipping.
Dematerialization	Reduced floor space (heat and electricity)	Reduced material and energy use	Less waste for packaging and products	No transport needs for dematerialized goods and services			Network effects may lead to further dematerialization over time
Services							
Electronic Invoicing		No paper, ink, printers production	Less paper, ink cartridges and printing equipment waste	Elimination of invoice shipping			As customers become accustomed to services delivered electronically, network effects may lead to additional services and efficiency opportunities
Payments		No paper, ink, printers production	Less paper, ink cartridges and printing equipment waste				
Electronic access to public administration	Reduced floor space in office buildings (heat and electricity). Reduced printing	No paper, ink, printers production	Less paper, ink cartridges and printing equipment waste	Reduced km travelled for chores			
E-health		Less paper, ink, printers production for medical records	Less paper, ink cartridges and printing equipment waste	Reduced km travelled for medical visits			

Table 28: Commerce and services – ICT applications and channels for GHG reduction

4.3.10 E-Commerce

A number of studies have evaluated the potential impact of the phenomena discussed in this section. Typically studies on e-commerce have focused on individual cases or sectors (e.g. the impact of electronic commerce on the trade of books or CDs), comparing supply chains of e-commerce businesses with 'brick and mortar' ones and estimating the GHG emissions of the two cases. Individual case studies are used to infer broader (economy-wide) estimates. Typically energy uses and GHG emissions analyzed are the ones associated with floor space utilization (retail stores and warehouses) and transportation. For dematerialization processes, manufacturing activities and raw materials used are also included in the estimates.

Author	**Finding**
Romm, 2002	Citing analysis by Sawhney and Contrerat (1999) and the EIA (1998) pointed out that '*Amazon.com has 20 times the inventory turnover and eight times the sales per square foot of traditional superstores… Warehouses consume about half the energy per square foot of retail stores. So a plausible estimate for the ratio of commercial building energy consumption per book sold for traditional stores versus online stores is 16-1*'[55]
Scott Matthews et al., 2002	Focused on retail bookstores comparing potential impacts in the US and Japan[56]. The results of the study reveal that for book stores there is limited environmental gain by using e-commerce as opposed to traditional shops, the reduction in energy use ranges from -2% to 12% (assuming a 35% returns under the traditional shopping scenario), depending on the delivery method adopted. Net increases in emissions are associated with airfreight while emission reductions are achieved with truck delivery.
Ralph Gay et al., 2005	Analysed online sales of personal computers[57]. The study highlights that reduction in GHG emissions are possible but vary greatly, depending on the means of transport adopted for delivery. In particular, they estimate that emission reductions may be around 29%, when air travel accounts for 10% of deliveries, but are as low as 1.8%, when air travel accounts for 75% of deliveries.

Thus opportunities to decrease GHG emission reductions with e-commerce vary greatly depending on the means of transportation chosen for delivery. This is at least the case with goods that are shipped long distance.

The results are markedly different, however, when comparing traditional and e-shopping of groceries, as analyses of this sector typically show that e-commerce unequivocally reduces transport-related emissions and energy consumption.

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[55] Romm Joseph (2002) The internet and the new energy economy Resources, Conservation and Recycling 36 (2002) 197-210

[56] Scott Matthews et al, Energy implications of online book retailing in the US and Japan, Environmental Impact Assessment Review (2002) 493-507.

[57] Ralph Gay et al, Modelling Paradigm for the environmental impacts of the digital economy, Journal of organizational and electronic commerce (2005) 61-82.

Author	**Finding**
Heiskanen, et al, 2001	Modelled the Finnish economy and showed that CO_2 emissions associated to grocery shopping could be reduced between 7% and 90% depending on the assumptions (e.g. the vehicle used for the shopping trip)[58]
Siikavirta et al, 2003	Highlighted that e-grocery could lead to a 18% to 87% reduction in the CO_2 emissions that cars emit for groceries shopping (which would correspond to 2% to 9% of total transport emissions in Finland) [59]
Persson 2000	Studied the city of Stockholm in Sweden and extrapolated that, in Sweden potential emissions reductions ranged from 7% to 8% of total transport emissions if 10% of all purchases of daily household goods take place via the net, whereas an increase of online shopping to 50% of daily household goods, could reduce emissions by 34%[60]

In addition to impacting emission from transportation, e-commerce can impact emissions from commercial buildings, by decreasing energy use and emission in both retail stores and warehouses.

Author	**Finding**
Romm (2002)	Estimated that, in the US market, digital distribution channels and more efficient inventory management could lead to a decline in the use of retail buildings by 1.5 billion square feet (140 Mln m^2) and to a reduction in warehouse space by 1 billion square feet (94 Mln m^2). Combined the total CO2 emissions avoided per annum would be around 20 $MtCO_2$.
The American Consumer Institute[33],	Built on Romm's conclusions and revised other studies on e-commerce. Projecting a doubling in ecommerce over a ten year period, estimated a total reduction in greenhouse gases emissions of 206.3 Mln. tons (187 Mln metric tons) per decade[61].

When looking at impacts on transportation, the advantage of E-commerce derives from the fact that delivery of (physical) goods directly via warehouses is more effective than having people using their cars for their shopping at retail stores. The size of this advantage largely depends on the type of delivery medium chosen (e.g. when deliveries are done by airplane the e-commerce advantage reduces dramatically), on the means of transportation of customers travelling to the retail stores and by their distance travelled. Thus such factors would depend on the urban setting and (public transportation) infrastructures available to the customer. Despite some offsetting due to air mail and air travel of some goods the literature indicates that the overall impact is likely to be positive and that well-planned on-line shopping can deliver significant benefits in terms of GHG emission reduction. The analysis below provides an estimate of the reduction in transport-related GHG emission, under various e-commerce scenarios.

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[58] Heiskanen, et al, 2001. Dematerialisation: the potential for ICT and services. The Finnish Environment 533. The Finnish Ministry of Environment (in Finnish)

[59] Siikavirta et al, 2003. Effects of E-Commerce on Greenhouse Gas Emissions: A Case Study of Grocery Home Delivery in Finland

[60] Persson et al (2000) Future CO2 savings from on-line shopping jeopardised by bad planning, available at: http://www.scanamerica.net/www/ftp/E-EffLogisticsSweden.pdf

[61] Joseph P. Fuhr Jr. Stephen B. Pociask Broadband Services: Economic and Environmental Benefits, October 31, 2007 http://www.internetinnovation.org/Portals/0/Documents/Final_Green_Benefits.pdf

E-commerce adoption (% of daily household goods)	Impact on transport emissions
50%	34%
20%	14%
10%	7%
5%	3.5%
3%	2.1%
2%	1.4%
1%	0.7%

Table 29: E-commerce adoption and impact on transport emissions, Assumption based on Person analysis of Swedish market

				E-commerce adoption (% of daily household goods)			Net Emission reductions from e-commerce MtC02		
	2030 baseline emissions LDV MtCO2e	2030 baseline emissions trucks MtCO2e	2030 baseline emissions total MtCO2e	low	Medium	high	low	medium	high
OECD North America	1,623	504	2,127	2%	10%	20%	29.8	148.9	297.7
OECD Europe	535	374	909	2%	10%	20%	12.7	63.6	127.3
OECD Pacific	219	120	339	2%	10%	20%	4.7	23.7	47.4
	-	0							
FSU	229	79	308	1%	5%	10%	2.2	10.8	21.6
Eastern Europe	82	22	104	1%	5%	10%	0.7	3.6	7.3
China	303	153	456	1%	5%	10%	3.2	16.0	31.9
Other Asia	174	274	448	1%	5%	10%	3.1	15.7	31.3
India	103	145	248	1%	5%	10%	1.7	8.7	17.4
Middle East	67	204	271	1%	5%	10%	1.9	9.5	19.0
Latin America	294	272	566	1%	5%	10%	4.0	19.8	39.6
Africa	167	80	247	1%	5%	10%	1.7	8.6	17.3
Total	3,797	2,226	6,023				65.8	328.9	657.7

Table 30: Emission reductions from light duty vehicles and trucks deriving by e-commerce adoption

As highlighted above, existing case studies and research on the impacts of e-commerce on GHG emissions provide estimates that vary in scope and magnitude with significant differences between sectors and countries. The level of uncertainty in the estimates is therefore high.

4.3.11 Dematerialization

To assess the impact of dematerialization processes and electronic service delivery a number of studies have identified and analyzed cases of individual products or services that migrated or could migrate to a digital delivery method. Typically in these analyses, baseline life cycle emissions have been estimated for the product or services under investigation, assessing how the consumption of the materials and energy responded to product dematerialization or the electronic service deliver process.

In particular these analyses indicate that plastics and paper used for communication and entertainment appear to be primary target for dematerialization.

The ACI study considered the potential reduction in use of these two materials, and the consequent GHG emissions reductions, associated to the increasing sales of virtual goods in the US. Using analysis of Romm[62] and the Boston Consulting Group, the authors of the ACI report estimate that in the US e-newsprint could reduce emissions by 1- 1.65 million tonnes per year, the report also shows that if each average office worker avoided printing only 5 pages per year, this could reduce emissions by about 2.63 MtCO2 per year. Saving one page per day in households, instead, would reduce emission by 0.64 MtCO2[63]. Additional savings were identified in terms of reduced printing of catalogues, directories, manuals and information books (encyclopaedias)[64]. The report indicates that 300,000 tonnes of paper could be avoided from an estimated 25% reduction of directories printing due to the switch to the internet (using 2003 data as a baseline). This corresponds approximately to a reduction in emissions of 0.9 MtCO2eq. Similarly the switch to the online version of information books such as encyclopaedias displaced 300,000 tonnes of U.S. paper, corresponding to around 1MtCO2e. The ACI study also reports that downloading music could reduce CO_2 emissions by 0.42MtCO2 per year from avoided CD manufacturing and shipping. In summary, dematerialising paper could save up to 4.3 $MtCO_2$ whereas paper and plastic dematerialisation could achieve 4.7 $MtCO_2e$ per year although the potential can be higher.

Studies such as Romm's, the ACI's, and other studies that have analyzed various other products, provide estimates on the GHG emissions reductions that can be achieved with dematerialization of a variety of products and services. Some examples are provided below.

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[62] Joseph Romm, 1999, The internet economy and global warming.

[63] All results are for the USA.

[64] Boston Consulting Group, Paper and the Electronic Media, September 1999. Romm, 2001, The Internet Economy and Global Warming: A Scenario of the Impact of E-commerce on Energy and the Environment

Dematerialization processes	CO2 emissions reduction per unit	Notes/assumptions
Digital sale of music and video replacing CD and DVD cases	554 g CO2 per CD	91 g plastic per unit sold, 2.3 litres of oil per kg of plastic, 2.6 kg of CO2 per litre of oil – based on ACI study
Virtual answering machines substituting physical devices	~30 kg approx per user	WWF/ETNO[65] estimates based on European data
On-line invoicing substituting paper based invoicing	0.783 kg/ person/y	WWF/ETNO[66] estimates based on European data for one bill..
Web taxation substituting paper based forms	~1 kg/ person /y	WWF/ETNO[67] estimates based on European data
A 140 g daily newspaper	350 – 462 g	Romm 1999[68] referencing Boston Consulting Group and http://www.printgreener.com/earthday.html
A 160 g weekly magazine	608 g	Romm 1999[69] referencing Boston Consulting Group and http://www.printgreener.com/earthday.html
A 500 g paper catalogue	1.25 – 1.65 kg	Romm 1999[70] referencing Boston Consulting Group and http://www.printgreener.com/earthday.html
Office paper	3.8 tCO_2 / t office paper	Romm 1999 referencing Boston Consulting Group

Table 31: Dematerialization and GHG emission reductions

Product dematerialization and electronic service deliver can drive GHG emission reductions both in developed and developing countries, with impacts that can very significantly depending on the level of dematerialization and electronic service delivery that will actually be achieved. The calculations below provide an indication of some of the potential impacts

	Estimated worldwide market (number)	Estimated baseline emissions MtCO2	% dematerialization			Emission reductions from dematerialization MtC02		
			low	Medium	high	low	medium	high
CDs and DVDs	6,210	3.4	20%	60%	100%	0.69	2.06	3.44
Answering machines	10	0.3	20%	60%	100%	0.06	0.18	0.30
Utility invoices	12,023	0.6	20%	60%	100%	0.12	0.36	0.60
Banking invoices	13,540	0.7	20%	60%	100%	0.14	0.41	0.68
Tax returns	2,257	2.5	20%	60%	100%	0.50	1.49	2.48
Daily papers	201,828	40.4	20%	60%	100%	8.07	24.22	40.37
Weekly magazines	28,912	19.7	20%	60%	100%	3.93	11.80	19.66
Catalogues	3,761	2.6	20%	60%	100%	0.51	1.53	2.56
Brochures advertising	135,396	6.8	20%	60%	100%	1.35	4.06	6.77
Books	2,257	10.7	20%	60%	100%	2.14	6.43	10.72
Medical records	36,069	0.9	20%	60%	100%	0.18	0.54	0.90
Total						32	95	158

Table 32: Emission reductions from dematerialization in the field of paper and media

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[65] ETNO/WWF, Saving the climate @ the speed of light, based on a Wuppertal Institute research, more on: http://www.wupperinst.org/FactorFour/best-practices/answering-machine.html

[66] ETNO/WWF, Referring to a Oko Institut study for Dutch Telecom where 1million customers switching to online billing save 206 tonnes of paper per year.

[67] ETNO/WWF, results based on a LCA analysis for Magyar Telecom (Hungary) where existing web-based taxation and paper-based posted taxations are compared.

[68] Romm (1999) The Internet Economy and Global Warming: A Scenario of the Impact of E-commerce on Energy and the Environment, The Center for Energy and Climate Solutions a division of The Global Environment and Technology Foundation. Available at: http://www.p2pays.com/ref/04/03784.htm

[69] Romm (1999)

[70] Romm (1999)

The analysis highlights a good potential to limit material consumption by switching to digital communication and entertainment. With several activities and services, however, there are some limits in terms to the GHG emissions savings that can be obtained via dematerialisation. As shown in the picture below for Germany, the material intensity per capita per year is high in several areas where the products used cannot be fully digitised, such is the case, for example, with housing, food and clothing[71].

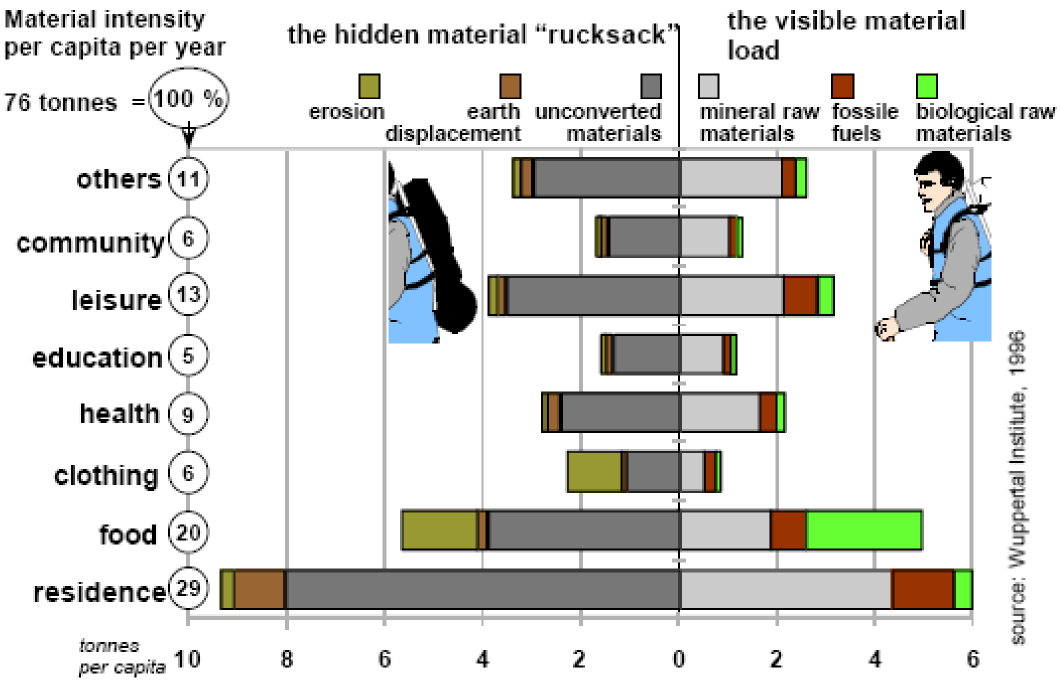

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Figure 11: Tonnes of material per capita and year in Germany

Whereas Figure 11 indicates that the potential for full dematerialisation is effectively limited to only a part of the materials typically used in day to day activities, partial dematerialization is possible with several products, where a *relative* reduction in the quantity of materials required to perform an economic functions is achieved. According to Hekkert et al[72], Approximately 40% of the global primary energy use and emission of CO_2 is related to the production of materials. Better materials or improved management of materials could therefore lead to substantial reductions in CO_2 emissions.

Advanced supercomputers are playing a pivotal role in materials science enabling the simulation and analysis of new material's properties. Thanks to ICT, for any given task, new materials can be studied and identified faster and with better results. If or when this is directed towards the production of lighter and better materials, which require less energy for their production, then GHG emission reductions are achieved. ICT (e.g. CAD/CAM software in industry) also enables the use of existing materials more effectively by enabling innovative product designs that use less materials or substitute energy intensive

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[71] Wuppertal Institute: http://www.digital-eu.org/uploadstore/theme_reports/dematerial_report.pdf

[72] Reduction of CO2 emissions by improved management of material and product use: the case of primary packaging, Marko P. Hekkert , Louis A.J. Joosten , Ernst Worrell, Wim C. Turkenburg, Resources, Conservation and Recycling 29 (2000) 33–64

materials with materials of lighter GHG footprints. Thanks to these processes of partial dematerialization GHG emission reductions can be achieved in industrial production activities. As highlighted below, even with a relatively small degree of dematerialization, emission reductions achieved may be relevant.

			Relative dematerialization			Emission reductions from partial dematerialization MtC02		
	2002 emissions MtCO2e	2030 baseline emissions MtCO2e	low	medium	high	Low	medium	High
North America	1,552	1,887	1%	5%	10%	19	94	188
Western Europe	1,348	1,451	1%	5%	10%	15	73	146
Pacific OECD	811	905	1%	5%	10%	9	45	90
Transition economies	1,058	1,540	1%	5%	10%	15	77	154
East Asia	503	1,071	1%	5%	10%	11	54	108
South Asia	540	1,022	1%	5%	10%	10	51	102
China	2,044	3,424	1%	5%	10%	34	171	342
Latin America	481	932	1%	5%	10%	9	47	94
Africa	317	525	1%	5%	10%	5	26	52
Middle East	360	644	1%	5%	10%	6	32	64
Total	9,013	10,062				101	503	1,006

Table 33: Emission reductions deriving by partial dematerialization in production processes – Ecofys analysis using data

4.3.12 Uncertainty analysis

Overall the uncertainties about the estimates of GHG emission reductions from ecommerce, dematerialization and electronic service delivery are high. As highlighted above existing data provide some insight of these phenomena but the understanding is still relatively limited, especially for the evaluation of potential global impacts.

The potential take up of e-commerce and e-services and the level of dematerialization achieved could vary dramatically, likewise the GHG impact of individual processes throughout the value chain can also follow different paths, depending on global dynamics in economies and society e.g. the presence of a more or less efficient transportation systems, the customers' demand for fast delivery of goods and services, the presence of cultural or legal norms that lead to printing most documentation, etc.

Risks of negative rebounds effects are also very relevant with e-commerce and dematerialization processes as the ease of access to products and services, and their reduced costs (also in terms of time required to acquire a product) free up resources that can be utilized to increase consumptions and associated GHG emissions.

4.3.13 Opportunities to establish low carbon feedbacks

Currently e-commerce and e-services applications, and the empirical research that has analysed them, still represent pioneering applications that take place in economic and social structures that are, overall, typical of industrial societies. Whereas a transformation process towards an information society is taking place, a prevalence of physical infrastructures, social norms, production processes, legal frameworks, etc. are still typical of a previous development paradigm. Dramatic effects may take place over time if commerce and services deliver structures change radically and if electronic forms of transaction, production and service-delivery become generalized. If accompanied with forward looking policies and strategies that channel these changes towards lower GHG emission paths (e.g. to eliminate risks of rebound effects, exploit synergies with other innovations that reduce GHG emissions, etc.), these processes could play a critical role in feeding virtual cycles that could achieve significant reductions in GHG emissions over time

E-shopping virtual cycle – an example

The growth of e-shopping leads to a growth in demand for transportation services that deliver goods from factories to customers' homes. The demand leads to economies of scale and increased efficiency (also enabled by the use of modern ICT in freight management systems), which, in turn, facilitate the growth of e-commerce. This leads to a larger number of customers to perform a larger proportion of chores on line. Retail shops are under pressure and decrease in number, leading to a further increase of customers that use e-shopping. Companies that sell or deliver goods and services electronically adopt organizations and work practices that leverage ICT to implement virtual offices, virtual meetings, telecommuting, etc. With a larger proportion of shopping on-line, a growing number of services delivered electronically, a reduced need to commute to work and travel for work, car ownership decreases. Public transportation services and car sharing services gain popularity and market share, reaching critical mass and improving efficiency (also thanks to the deployment of ICT technology). More investment is directed towards public transportation infrastructures while the costs of infrastructures for private transportation are spread over a smaller number of private vehicles and become more expensive for the single car owner, further decreasing the convenience to utilize private vehicles. Public transportation services and freight transportation adopt price structures that take into full account all transportation costs, including emissions costs (also in response to public policies that enforce the *polluter pays* principle). This provides an incentive to live in more compact urban environments, which are well served by public transportation infrastructures, which in, turn, increases the demand, utilization and efficiency of public transportation services (for both people an goods). As less people live a life style that is car-dependent, demand for e-shopping increases.

The scenario described above is just one of the scenarios that could unfold. Many other scenarios are also possible and both corporate leaders and policy makers can play a critical role in influencing final outcomes.

4.3.14 Conclusions and Policy implications

As highlighted above the overall impact of e-commerce, dematerialization and electronic service delivery on GHG emission is highly uncertain and strongly dependent on the socio-economic environment in which these applications are deployed. Private and public sectors strategies can therefore make a difference by channelling these applications towards configurations that lower GHG emissions. In particular policy makers can accelerate the digitalization in the commercial and services sectors, while reducing the risks of rebound effects, thus driving GHG emissions down. Policies that can help achieve this goal include:

- Increase the penetration of broadband internet access in all households
- Educate the broader public on the use of electronic equipment (focusing on practices that are beneficial for the environment)
- Remove Legal requirements that force companies and private citizens to retain printed copies of documents for many years
- Enable secure and simple solutions for electronic payments/invoicing
- Facilitate the creation and adoption of communication standards for dematerialized products and services
- Help develop calculation standards to evaluate and document the GHG impact of individual transactions (both digital and brick and mortar)

- Research and innovation support to identify the most CO_2 emitting activities and focus on reducing GHG emissions in these areas.
- Recognize the GHG benefits achievable through ecommerce and dematerialization (and conversely introduce disincentives for transactions that have a larger GHG footprint)
- Actively adopt forms of electronic delivery in the public sector
    - e-Government and public administration services (e.g. certificates, official documents, etc.)
    - In education (facilitating remote learning)
    - In health (in countries that have public health systems)

4.4 *Industrial production*

Globally, industry emits directly and indirectly about 37% of total GHG emissions. In individual countries the contribution of industry to total GHG emissions can vary from around 30% (this is the case in advanced economies where the service sectors represent the largest proportion of the economy) to over 80% (as in the case of rapidly industrializing countries such as China). This also reflects a large shift in the relative size of industry-related GHG emissions during the last part of the 20th century (see picture below).

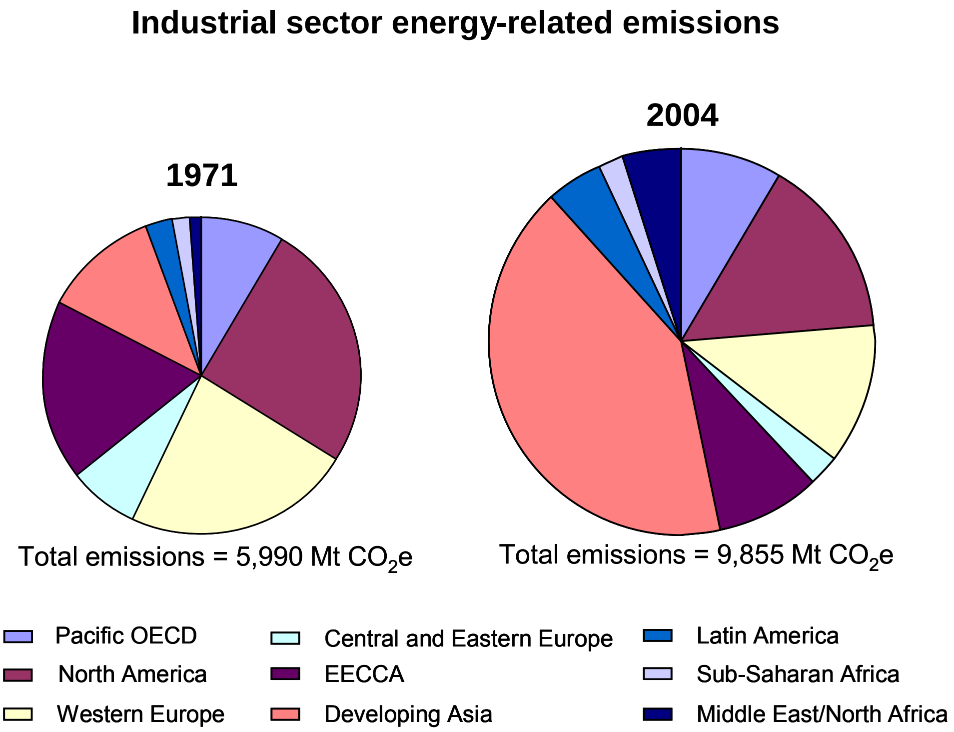

Figure 12: Industrial Sector energy-related emissions in 1971 and 2004[73]

Typically, when compared to other sectors of the economy, industrial processes tend to require more energy, and thus more GHG emissions, per unit of output. In addition to emitting CO_2 for energy production, industry also emits significant quantities of other GHG gases such as CH_4, N_2O, SF_6 and CFCs. However, over the past 20 years industry's overall share of global emissions has declined, due to increasing energy efficiency, lower growth of GHG intensive sectors, improved control over production processes, which reduce losses of GHGs, and also to a faster growth in emissions from other sectors (e.g. transport).

A major driver for GHG emission reductions in the industry sector are the changes occurring in downstream sectors (e.g. through shifts in consumer preferences and increases/decreases in demand for digital/dematerialized products). These processes will not be discussed in this section, as they are discussed in section 4.3 above. This section will instead focus on improvements in energy efficiency and in reduction in GHG emissions generated within the industry sector itself.

Despite continuous efficiency improvements, energy intensity in most industrial processes is still 50%, or more, higher then the theoretical minimum determined by the laws of thermodynamics. Moreover major

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[73] IPCC AR 4 chapter 7, referencing Price et al. 2006

differences occur within sectors with average energy uses typically much higher than the ones possible with best available technologies[74]

The opportunities to decrease GHG emissions by increasing efficiency in the industry sector are therefore significant and the IPCC estimates that the global emission reduction potential available in 2030, at a cost of US$ 100 per ton of emission reduction or less, will be between 2,000 and 5,100 Mt CO_2e. The largest proportion of this potential (between 1,300 and 3,400 Mt CO_2e) is available in developing nations.

Leveraging ICT to improve efficiency and reduce GHG emissions in production processes may play and important role in both developed and developing countries to achieve the potentials identified by the IPCC.

ICT solutions that help achieve increase efficiency and reduce GHG emissions are typically designed to improve the data availability and the control over the use of resources and energy, and the manufacturing processes as a whole, thus increasing production flexibility, reducing waste, improving productivity and quality and enabling more innovation over time. Furthermore, improved IT technologies can help improve the design of industrial processes and plants to reduce energy consumption or reduce by-product GHG emissions.

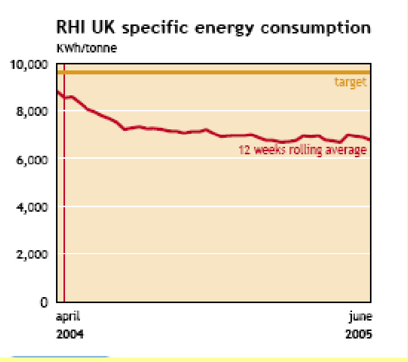
ERDEMİR	**Erdemir** is Turkey's largest iron and steel producer, and accounts for 1.7% of Turkey's entire energy consumption. The company used IT applications to bring together all its control systems under one switch, and to provide an on-screen Plant Information System as a means of monitoring energy consumption. This has resulted in energy savings of up to 5%, and an early-warning system for any anomalies or leakages within the system.[75]
JACOB FRUITFIELD Food Group	Irish food producer **Jacob Fruitfield** set up an Energy Monitoring System to tackle deficiencies identified in an energy audit. The system has helped reduce gas consumption by 9%, provided better understanding of consumption patterns, and has instilled greater energy awareness among staff.[76]
	The UK ceramics manufacturer **RHI refractories** UK increased the number of gas submeters from four to ten to ensure that 90% of the site gas consumption and 81% of total energy consumption was monitored. A weekly cycle of data collection and analysis was adopted with cycles ending on Fridays to ensure good correlation between energy consumption data and weekly production data and to provide accurate information of each week's performance. By using the data from the submeters, the site engineers are able to 'drill down' to the energy consumption of specific items of process plan to identify variances between target performance and actual performance and to implement and monitor best practices. The company has realised cost savings of £164,000 per year in reduced gas consumption which is equivalent to 12,750,000 KWh/annum against year 2000 baseline

Table 34: Examples of ICT solutions in industrial production

The table below summarizes the channels through which ICT can reduce GHG emission in production processes.

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[74] IPCC AR 4 chapter 7 referencing IEA 2006a

[75] Case study discussed by ebusiness-watch www.ebusiness-watch.org/events/documents/WS080207_Energy_Press-Release.doc

[76] Case study discussed by ebusiness-watch www.ebusiness-watch.org/events/documents/WS080207_Energy_Press-Release.doc

ICT applications	Impacts on GHG emissions (direct and emission emissions)						
	Buildings	**Industrial production**	**Waste**	**Transportation**	**Energy supply systems**	**Impacts on land**	**Other impacts**
Smart Production							
Industrial production							
Site-wide EMS	Reduced floor space heat and electricity in industrial buildings	Less heat and electricity					Increased efficiency can lead to increased emissions due to: price reduction leading to higher consumption, increased profits leading to higher investments, higher disposable income leading to higher consumption
WiFi-stock & flow	Reduced floor space heat and electricity in industrial buildings		Less waste	Reduced km traveled			
Advanced sensors and controls	Reduced floor space heat and electricity in industrial buildings	Less materials, heat and electricity	Less waste				
Process intensification & integration	Reduced floor space heat and electricity in industrial buildings	Less materials, heat and electricity	Less waste	Reduced km traveled			
Software assessment tools	Reduced floor space heat and electricity in industrial buildings	Less materials, heat and electricity	Less waste	Reduced km traveled			

Table 35: Industrial production – ICT applications and channels for GHG reduction

Analysing the potential aggregate impact of ICT and energy efficiency and GHG emissions in the industrial sector is particularly difficult as:

- There is a large variety in the types of processes utilized in industrial production
- The analysis of the literature did not identify any bottom-up study that assessed the aggregate impact of energy efficiency improvements generated by ICT applications within industry.
- More 'traditional' energy efficiency studies on the industrial sector do not provide sufficient data to distinguish the 'ICT related contribution' from the more 'traditional' energy efficiency improvements. Some studies distinguish improved control systems, but other options are harder to identify in these studies, while also 'chain' effects are hard to quantify (e.g. impact of CAD/CAM or process design software packages on the design of processes and plants).
- Data on industrial production and technology use in the industrial sector are lacking sufficient detail on ICT use

A report that looked at opportunities associated with efficiency gains and GHG emission reductions thanks to ICT use in production processes is the AeA report. The authors of this report indicate that productivity improvements derived from ICT may reduce industrial energy use by 20% per dollar of production. Building on this assumption the report estimates that carbon dioxide emissions from within the EU might be reduced by about 200 million metric tonnes of carbon per year. Unfortunately the AeA report does not provide further detail on the definitions and assumptions used in the calculation and in particular for the value estimated for the energy efficiency gain and the expected timeline of such gains.

The difficulty in assessing the conclusion reached by the authors of the AeA report lays in the fact that, as highlighted above, innovations and energy efficiency improvements in the industry sector can come from a broad variety of strategies, and that, in most cases, such strategies include ICT components that are incoupled with, or part of, more 'traditional' efficiency improvement strategies.

Since market forces provide a strong incentive to reduce costs and pursue energy efficiency strategies, and since ICT has been a major enabler for innovation and efficiency improvements in industrial production, it can be argued that a 20% gain on current emissions is realistic target and can be achieved in a relatively short time frame, however, it remains a question whether all the savings can be attributed to ICT.

Even when taking more conservative assumptions than the ones indicated by the AeA report, ICT emission reductions associated to ICT deployment in industrial sectors can be significant. If for example we credit to ICT applications 5 to 30% of the emission reductions postulated by the IPCC, the minimum GHG emission reduction associated to ICT would be MtCO2e 100, which would be achieved in a scenari of low ICT impact and few GHG emission reductions achieved in the industrial sector, but could raise to 1,500 MtCO2e with higher ICT impact in and GHG emission reductions (see table below)

	Baseline GHG emissions 2030 MtCO2e	Potential GHG emision reductions 2030 MtCO2e	Low ICT contribution to efficiency gains	Higher ICT contribution to efficiency gains	Potential GHG emision reductions MtCO2e	AeA's report estimate (20% of baseline emissions)
OECD countries	4,243	470 - 1100	5%	30%	24 – 330	849
Economies in transition	1,540	250 - 510	5%	30%	13 – 153	308
Developing Nations	7,617	1300 - 3400	5%	30%	65 - 1020	1,523
Global	13,400	2000 - 5100	5%	30%	100 - 1530	2,680

Table 36: GHG emission reduction from industrial activities

The table above highlights that the largest proportion of GHG emission reductions opportunities will likely be developing countries. More detailed analysis of the emission reduction potentials available at country and sector level thanks to ICT would be appropriate to better quantify the opportunities, set priorities and articulate strategies, Currently, however, this is seriously constrained by the limited amount of relevant data available in both developed and developing countries. The uncertainty associated to the analysis presented above is high.

Innovation in the industrial sector (due to ICT) will result in productivity benefits and hence price reductions, which may contribute to the so-called rebound effect. Risks of negative rebound effects are therefore intrinsic with improvements in production processes. However, it is hard to estimate the potential size of the rebound effect. Analyses of the rebound effect of energy efficiency improvement in the literature show varied results, but generally estimate the rebound effect to be limited.

The emission reduction potentials estimated by the IPCC and discussed above focus exclusively on improvements in efficiency of industrial processes. IPCC did not assess potential economy-wide structural changes or the emission reductions that can potentially stem from radical changes in the business models of industrial companies. In particular dramatic improvements appear to be possible with a shift from 'an economy of good and purchases to a service-based economy'[77].

To date the achievement of such transition has been impeded by a series of barriers and lock-in effects present in technology, policy and market structures that evolved over the last three centuries, following the industrial revolution. ICT is radically changing these structures and, by dramatically reducing the costs of producing and using information, provides the opportunity to truly deliver an economy of services. Such a transition would enable the industrial sector to reduce the amount of natural resources utilized to deliver the services required by end users and to systematically design services that conform to principles of industrial ecology[78].

These changes could be transformative and dramatically reduce the GHG footprint of the industrial sector and of the products used by end users. While ICT can play a key role in achieving these results, the ICT sector alone will not be able to deliver the transition (or at least not in the timeframe required to address climate change). A suitable policy framework must be built, to provide incentive structures that promote the desired transition, and fully leverage the potential offered by ICT.

When considering the speed of implementation of desired ICT applications is should be noticed that even though market forces provide a strong incentive to reduce costs and pursue energy efficiency strategies, barriers may still limit or slow the adoption of more modern ICT technologies. Barriers may for example be:

- Cognitive – managers may not be aware of most advanced solutions
- Institutional – regulations may be designed around established (less efficient) business practices
- Systemic – e.g. a country may lack the ICT infrastructure needed to implement most advanced solutions
- Financial – funding sources for required upfront investments may not be available

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[77] Hawken Paul, Lovins Amory, Lovins Hunter Natural Capitalism, the next industrial revolution

[78] For a definition of industrial ecology see http://en.wikipedia.org/wiki/Industrial_ecology For a description of Industrial Ecology concepts and approaches see L. W. Jelinski, T.E. Graedel, R. A. Laudise, D. W. McCall, and C. K. N. Patel, "Industrial Ecology: Concepts and Approaches", *Proc. Natl. Acad. Sci. USA* 89(3):793-797 (1992) http://www.pnas.org/cgi/reprint/89/3/793

Policies to improve ICT adoption in industrial processes are therefore vital to reduce GHG emissions. They may include:

- The collection and dissemination of information about best practices of ICT use for GHG emission minimization in production processes
- Capacity building and training on ICT use in production processes and on the associated GHG benefits
- Technology transfer policies designed to benefit developing countries or sectors that are lacking in required technologies
- Standards to quantify and document the GHG emissions associated with individual products
- Funding mechanisms for ICT investment with GHG benefits
- Set up appropriate data collection systems that are able to regularly gather the statistical the data needed to assess and monitor progress in this field.
    - Existing data on the GHG impact of technology in production processes are relatively lacking, also because existing statistical systems are not designed to assess these factors (e.g. in the US EIA requires a considerable amount of time to collect and analyze key data on energy consumption trends by sector).

4.5 Energy supply systems

Energy supply systems determine the fuel mix utilized to deliver energy services to end-users and directly generating GHG emissions. The GHG intensity associated to the energy used by end-users is also influenced by the losses occurring in energy transportation and distribution systems. Any improvement in these systems can lead to significant reduction in GHG emissions.

Information and communication technologies (ICT) deliver major advancement and opportunities to improve processes and operational control in energy supply systems. Improving the ability to monitor and control the system enables increased deployment of renewable energies and larger numbers of distributed generators without endangering the reliability of the power system. The European Technology Platform SmartGrids (www.smartgrids.eu) states in its Vision Document:

> "Today's electricity networks provide an essential service for society. They have been built in order to assure access to every single customer to electricity according to a vertically integrated scheme with centralised generation, distributed consumption, limited interconnection capabilities between the control areas, and commercial and regulatory frameworks that are not harmonised for mutual advantage. In response to new challenges and opportunities, electricity networks have started to evolve into a more decentralised scheme, with many actors involved in generation, distribution and operation of the system. However, there continues to be a major role for high voltage bulk-transmission systems for the foreseeable future. Challenges to be addressed include the technical and commercial integration of decentralised and centralised systems, the operational management of intermittent and variable power generation sources, and the strengthening of the trans-European network where there are power flow constraints to trading." [EUROPEAN COMMISSION, Directorate-General for Research, Sustainable Energy Systems: European Technology Platform, SmartGrids - Vision and Strategy for Europe's Electricity Networks of the Future; Brussels 2006]

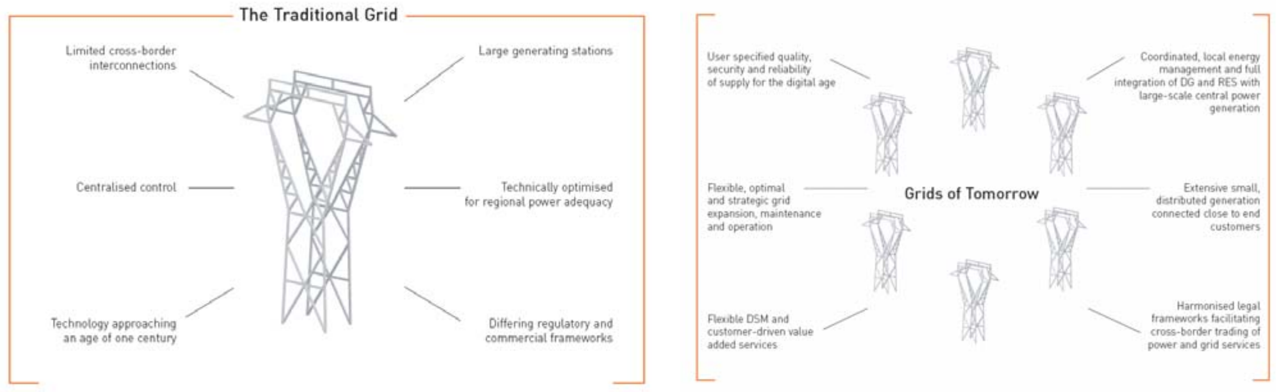

Figure 13: The evolution of electricity grids according to the SmartGrids Vision

With respect to the increasing role of renewable sources and ICT this vision paper highlights that energy supply structures will have to:

- improve opportunities for the integration of RES and high efficiency distributed generation (DG);
- adapt to the intensive use of two-way telecommunications to allow the participation of the different stakeholders, namely the customers;
- increase remote control and automation both at the generation level (DG control) and at the customer level (demand-side management, DSM).

For this purpose, ICT applications and services will impact all areas of power supply (1) power generation, (2) transmission of power over large distances and (3) distribution to the end users:

Generation

- Remote monitoring of renewable energy production plants (especially wind farms) in order to optimize the overall energy yield of renewable energy production,
- Perform short term prediction of day-ahead and hours-ahead power feed-in by renewables to avoid additional power balancing efforts and thus optimize overall power system efficiency,
- Pooling and control of different renewable energy production units in form of so-called generation management or 'virtual power plants' to increase overall efficiency,
- ICT as significant component of modern wind, PV and biomass plants themselves in order to increase controllability, reliability and lifetime of the systems.

Transmission

- Monitoring power transmission lines (especially power line temperature monitoring) in order to increase power transmission capacities and thus the share of power generation from renewables.

Distribution

- Wide-area moitoring of power systems in order to allow increasing numbers of high-efficiency distributed generators without compromising power system reliability,
- Demand-side management for better matching electricity generation and demand and allowing higher shares of variable power generation from renewable energy sources

Figure 14: ICT application in electrical grids

Future energy production, transportation and distribution systems will likely include a broader variety of systems, both large and small scale, a much larger degree of flexibility than today's, centralized and low energy supply variety, systems (see picture below).

Figure 15: Visual impression of ICT being integral part of SmartGrids (Source: SmartGrids Vision)

Power generation close to the consumer contributes for a substantial reduction of GHG emissions in power systems. A quantification of the effect is made in AeA 2007:

> "Compared to conventional steam production systems that achieve a mere 37 percent (or worse) efficiency, the efficiency of new combined heat and power systems approach 75 percent. If Smart grid technology facilitated a mere five percent increase in electric generation capacity from the more energy efficient combined heat and power systems, CO2 emissions could be reduced by as much as 20 million tonnes [in Europe][79].

The reduction of losses in power transmission and distribution in future SmartGrids has been estimated by the European Commission:

> One of the crucial benefits of a coordinated development of the transmission and distribution grids and the integration of efficient/renewable generation in the network is the relief of cost effective generation constrained by network bottlenecks. (…) The electricity losses reduction is the benefit here translated both in terms of CO2 emission reduction (sustainability advantage) and fossil fuel avoidance (security of supply gain). It is estimated that efficiency gains on the transmission network may bring about a 1% decrease in electrical losses (compared to electrical energy demand) in 2020. (…) If the maximum potential is realised, the electricity grids could avoid up to 30 Mt/year CO2 in 2020[80].

ICT is an enabling technology and thus prerequisite for increasing shares of renewable energies in the power system. It is a matter of fact that in many cases the transmission and use of electricity from high efficiency distributed generators (DG) and renewable energies is only made possible through ICT.

Three applications shall be shown in detail:

- Dynamic line rating with temperature monitoring
- Wide-area monitoring and protection systems
- Demand-side 'optimization' of electricity consumption

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[79] AeA 2007 – John A. 'Skip' Laitner, Karen Ehrhard-Martinez Advanced Electronics and Information Technologies: The Innovation-Led Climate Change Solution

[80] Source: COMMISSION STAFF WORKING DOCUMENT: A European Strategic Energy Technology Plan (SET-Plan) - TECHNOLOGY MAP.
http://ec.europa.eu/energy/res/setplan/doc/com_2007/2007_technology_map_en.pdf

4.5.15 Dynamic line rating with temperature monitoring

The momentary electrical current carrying capability of overhead lines is determined by the line's sag which in turn depends on the conductor temperature and, hence, also on the ambient weather conditions such as wind speed, air temperature and irradiation. These weather conditions are usually regarded by Transmission System Operators (TSOs) as fixed values that represent the worst case. Based on the worst case, the allowed maximum power capacity is determined by the network operators according to international standards.

However, generation by wind power increases obviously with rising wind speeds. Since the wind tends to cool the overhead line's conductors the line's sag is reduced and the transmission line in respective areas can carry more power. It was shown that increase of transmission capacity correlates significantly with an increase of wind generation.

This correlation can be used through different online capacity rating methods: measuring of conductor temperature, metering of weather conditions or monitoring of the mechanical tension along the transmission line route. Also the installation of temperature or line sag sensors at certain sections of the transmission line is possible. The application of these methods can increase the transmission line capacity by up to 50 percent. [81]

Case Study – Temperature monitoring of overhead lines by E.ON

In September 2007, E.ON Net, one of the four German transmission system operators (TSO) presented the results of a one year field test with dedicated focus on increased wind power penetration. In the respective area in the North of Germany substantial curtailment of wind power had been required during the last years because of the mismatch between installed wind capacity and nominal transmission capacity of the existing overhead lines. Measured with speeds and other weather data from specific sites were send to the TSOs control center. It turned out that transport capacity of a 110 kV line could temporarily be increased to up to 150 % of its nominal power and, hence, this approach led to a reduction of wind generation curtailment events of over 80 % in the region considered. Thanks to these promising results, dynamic line rating with temperature monitoring is to be applied also in further 110 kV-circuits in the German federal state of Schleswig-Holstein from now.

Table 37 Case study. Temperature monitoring of overhead lines by E.ON. Source E.On press release http://www.eon-netz.com/frameset_german/news/news_release/news_release.jsp

4.5.16 Wide-area monitoring and protection systems

If system limitations can be calculated for actual conditions rather than off line, the system can be operated closer to actually applicable limitations. These calculations require on-line measurements of actual loading, generation, and transmission system status. On-line dynamic security assessment may substantially reduce conservative assumptions about operational conditions. Hence, powerful and monitoring-based system state estimators can increase the actual transfer capability of a power system.

From a CO_2 emissions reduction standpoint the benefits are twofold:

- In all cases where rising electricity demand in power systems up to now automatically led to a need for building new power lines, the ICT-induced increase in power transfer capabilities mitigates the construction of new power lines and the CO2 emissions associated with this construction efforts. This is especially the case in China.

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[81] California Energy Commission, "Development of a Real-Time Monitoring/Dynamic Rating System for Overhead Lines", by EDM International Inc., December 2003

- In cases where the power system penetration of renewables with variable power output (especially wind energy) is limited by power system security considerations, wide-area monitoring and protection systems allow the installation of more renewable energies, thus enabling reduced CO2 emissions of the electricity generation. This will increasingly be the case in power systems all over the world.

The TSO China State Grid started deploying wide-area monitoring systems in 2002. Today, China has installed 10 central computers with 200 to 300 PMUs in five regional and five provincial power systems.

In Europe, collaboratively exploited state estimators covering the control areas of several neighbouring TSO's may improve system performance, flexibility and robustness, in particular in relation to fluctuating load flows as a consequence of variable power generation from renewables.

The technologies for wide-area monitoring of electrical devices and power system assets are mature. Nevertheless, the introduction of innovative technologies by power system operators has to overcome regulatory barriers, such as responsibility allocation to different system operators involved[82]. Those barriers have successfully been overcome in China.

4.5.17 Demand-side 'optimization' of electricity consumption

Potentially, demand-side activities offer promising options to improve the match between instantaneous generation and demand and hence to facilitate integration of RES in power systems.

Relevant aspects are:

- Dynamic pricing and time-of-use implementations that are based on variable pricing to customers.
- Demand bidding structures that allow direct participation of customers offering load reduction.
- Aggregation of many smaller demand-side resources (e.g., less than 1MW) for market participation
- Transparency and real time information about GHG emission associated with power production and consumption
- A link between GHG emissions and energy price (e.g. through a carbon price)

Routes of introducing demand-side measures are (1) the expansion of the already existing controllability of load (e.g. large industrial consumers) gradually towards populations of small scale applications (e.g. private consumers) and (2) via further development of utility – consumer data exchange from automatic meter reading to two-way communication.

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[82] CESI, ITT, ME, RAMBØLL: Study on Energy Infrastructure Costs and Investments between 1996 and 2013 (medium-term) and further to 2023 (long-term) on the Trans-European Energy Network and its Connection to Neighbouring Regions; TEN-Energy- Invest; October 2005

Case Study – "Energy management System for increased end-user participation" by utility MVV Energie, Mannheim, Germany

The utility MVV Energie is testing a residential energy management system in a real low-voltage grid of the "Am Steinweg" estate in Stutensee near the city of Karlsruhe, Germany. It provides power to 101 private households. A 29 kW photovoltaic system, a 40 kW combined heat and power station and a battery container which can supply 100 kW for one hour are connected to the grid. A communications unit, which is connected to the central computer, is located at each generator.

With the energy management system, grid operators can accommodate distributed generators even in "weak" grids without taking complicated construction measures. Data can be transferred between the communications units and the central computer via the Internet protocol TCP/IP in many different ways: network, GSM/GPRS, wireless LAN, modem or even via the power cables using Powerline. "The hardware configuration is extremely flexible. Distributed generators can even act like a large power station: Many small generating systems are then connected in such a way that they can replace a large power plant. The research institute Fraunhofer ISE also tested another grid-control variant successfully, which was called "Washing with the sun". Some households received an SMS message whenever excess photovoltaic power was available. They received a bonus of 50 euro cents per kWh. "The residents found it positive that they could actively help to protect the atmosphere with simple measures", commented Sebastian Gölz, a psychologist at Fraunhofer ISE.

The evaluation of annual heat and electricity demand at the settlement Stutensee show a reduction of 5 percent in comparison with the reference case electricity from public grid, without flexible price signals plus residential heating in individual households (burning natural gas). Normalized to 100 households, the investigated ettlement Stutensee used 1,900 MWh heat and electricy, instead of 2,000 MWh (reference case).[83]

Table 38: Case study "Energy management System for increased end-user participation". Source press release "Communications instead of copper - Fraunhofer ISE electronics manages new energy sources in existing grids" http://www.ise.fhg.de/press-and-media/press-releases/press-releases-2006/communications-instead-of-copper

A more active management of end-users demand is also possible, utilizing integrated solutions that optimize energy use and minimize waste.

4.5.18 Channels and opportunities for GHG emission reductions

The channels through which ICT applications in energy supply systems can influence GHG emissions are reported below.

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[83] Personal communication with Dr. Christof Wittwer (Fraunhofer Institut für Solare Energiesysteme ISE), 20 Dec. 2007

	Impacts on GHG emissions (direct and emission emissions)						
ICT applications	Buildings	Industrial production	Waste	Transportation	Energy supply systems	Impacts on land	Other impacts
Energy supply systems							
Electricity generation							
Remote monitoring of renewable energy plants					Incresed efficiency of renewable energy plans		
Virtual power plants					Incresed efficiency of renewable energy plans		
Prediction services for power in-feed from renewable energy					higher market share and revenues to renewable energy providers		
ICT components in individual renewable energy plants					Increased efficiency and higher market share to renewable energy		
Grid improvements							
Smart grid and remote load control					Increased share of renewable energy without jeopardizing system security		
Distribution							
Wide-area monitoring of power systems					Increased market share to renewable energy and larger numbers of small generators close to the consumers		More information on opportunities to gain energy efficiency and to use renewable energy may lead to change behavior in end users and further efficiency and renewable energy deployments
Demand side management	Fewer hours of operation of devices and more efficiency				Increased market share to renewable energy and larger numbers of small generators close to the consumers		

Table 39: Energy Supply Systems – ICT applications and channels for GHG reduction

For quantifying the benefits associated with the use of ICT in energy supply, the baseline of the methodology will be the level of electricity generation from renewables, which is being limited either by power system adequacy margins or by power system security margins.[84]

The reduction of emissions is determined by the

- increase in installed capacity of renewables being enabled by ICT applications,
- the associated electricity generation depending on local (wind, solar ,etc.) resource
- grid emissions factors of conventional electricity generation displaced by renewables.

The following calculation refers to wind power capacity increase, which would be limited by network constraints and to be counter-measured by ICT, mainly network monitoring and dynamic line rating:

	Projection of installed wind power capacity 2020 [MW] [85]			ICT-enabled wind capacity growth 2010 - 2020 [MW][86,87]			Emission reduction through ICT-enabled wind power 2020 [MtC02][88]		
	low	Medium	high	low	Medium	high	low	Medium	high
OECD North America	43,304	166,855	283,875	2,650	13,776	24,824	3.7	19.2	34.6
OECD Europe	142,000	175,400	241,279	6,500	9,824	15,840	9.1	13.7	22.1
OECD Pacific	5,300	33,859	91,667	280	3,079	8,671	0.4	4.3	12.1
	-								
FSU and Eastern Europe	7,000	7,462	13,217	670	710	1,291	0.9	1.0	1.8
China	11,402	40,738	168,731	690	3,352	16,151	1.0	4.7	22.5
East Asia	4,895	27,274	70,577	390	2,616	6,946	0.5	3.6	9.7
South Asia	6,300	38,557	60,918	29	2452	4,372	0.2	3.4	6.1
Middle East	2,400	8,587	24,221	190	809	2,372	0.3	1.1	3.3
Latin America	6,198	53,606	99,627	300	5,039	9,639	0.4	7.0	13.4
Africa	1,999	8,044	16,803	130	734	1,610	0.2	1.0	2.2
Total	230,798	560,382	1,070,915	11,828	42,391	91,716	16.6	59.0	127.7

Table 40: Calculation of emissions reduction through ICT-enabled wind power installations, in cases where power system capacities for accepting wind power are not sufficient

ICT measures are not the only way of increasing the amount of renewable energy in case of power system limitations. Building new power lines for increasing the capacity of transmission and distribution networks seems to be the most obvious alternative. In this case, all environmental impacts of these infrastructure extensions have to be taken including the GHG emissions associated with building and

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[84] Presently, grid access regulation for renewable energy systems complete prevents their grid interconnection , if requirements for the reliable power system are not met. Grid access regulation that allows grid interconnection and only temporarily limits the operation of RES (e.g. “wind farm curtailment”) is not taken into account as reference, as it depends on and applies ICT.

[85] Projections according to Global Wind Energy Council (GWEC), Greenpeace Internation: Global Wind Energy Outlook 2006, Brussels, Sept. 2006

[86] Based on the assumption that 10% of projected wind capacity increase 2010-2020 is enabled by ICT.

[87] The annual production is based on GWEC capacity factor assumptions. The percentage refers to the average proportion of the year during which they will be generating electricity at the equivalent of full capacity. From an average capacity factor 2005 of 24 %, the scenario assumes that improvements in both wind turbine technology and the siting of wind farms will result in a steady increase. Capacity factors are also much higher out to sea, where winds are stronger and more predictable. The growing size of the offshore wind market , especially in Europe, will therefore contribute to an increase in the average. The scenario projects that the average global capacity factor will increase to 25 % by 2010 and then 28 % by 2020.

[88] The grid emissions factor of 0.6 t CO_2 per MWh electricity generation has been applied unchanged from the source document Global Wind Energy Council (GWEC), Greenpeace Internation: Global Wind Energy Outlook 2006, Brussels, Sept. 2006

erecting the power lines. The fact that power line extensions have lead times in the range of 15 years in another important factor when valuating the beneficial effects of ICT in energy supply systems.

4.5.19 Conclusions and policy implications

Whereas several of the solutions described in this section are by and large technically feasible, they are not of broad dissemination. The following activities could improve the adoption of these solutions:

- Further technological development to perfect some of the solutions and help achieve cost reductions
- Education and information initiatives to help increase awareness and understanding of the opportunities available
- Remove regulatory barriers that hinder the roll out of innovative solutions e.g. because of antiquated network operations standards, or of rigid dispatching or price regulations
- Policies that provide incentives to demand side monitoring services, e.g. instituting white certificates systems, increasing the 'GHG liability' of developers, mandating transparent labelling systems, differentiating taxation rates for energy use.

4.6 Knowledge, behaviour and policy

As enabler of information management and exchange, and provider of superior analytical tools, ICT can play a significant role in the creation of the knowledge needed to identify and implement effective policies and strategies. Public policies addressing climate change could therefore become more effective. Moreover when context-relevant information is provided to end users and consumers, behavioural changes can occur, which can lead to changes, also dramatic, in GHG emissions.

Electronic labelling captures the idea that ICT enables customers to collect and analyse a significant amount of information about products they intend to purchase. This characteristic can be leveraged to provide, when a purchase takes place, tailored information about the climate change impact of individual products, thus empowering conscious buyers to make more informed decisions. As the costs of information decrease, thanks to IT, and demand for market transparency increase, the ranking of different products in relation to their climate impact can become easier and, if costumers can receive this information at the moment of their purchase, their awareness can raise, their purchasing behaviour can better reflect their values and lead to larger market shares for climate friendly products. Existing paper based labels (such as the EU Energy label or Energy Star) already offer some static and summary indicators on energy performance for a sub group of products, labels with information on the GHG footprint of individual products are also emerging in the market. Allowing similar data to fully migrate on digital formats, integrating existing indicators with additional information, generalizing the use of these data to a broader set of products and integrating existing data with additional tools (e.g. to personalize the weights given to different factors by different consumers) can dramatically increase the weight given to of environmental components in purchasing decisions.

For policy makers **simulation and analysis tools** – e.g. analytical models to assess the possible impact of different policies – can dramatically improve the policy making process. Models are already and systematically used in policy making. Their level of sophistication, and their efficacy, can increase as underlying ICT technologies and infrastructures (including real time data collection infrastructures) improve. With a broader availability of data and more sophisticated simulation tools, the impacts of proposed policies can be assessed more rapidly and in more detail, thus leading to the formulation of policies that best meet policy goals.

Benchmarking and education tools can be a key instrument to identify areas of potential improvement and paths to achieve GHG emission reductions. ICT can facilitate the identification, articulation and use of benchmarks for both policy making in the public sector and strategy development in the private sector.

Perhaps the area where ICT can make the bigger policy impact is through superior **monitoring and evaluation tools**, and the reduction of transaction costs they can achieve. Because of the high costs of data collection and analysis, climate change policies (and environmental policies in general) have historically focused on regulating large scale polluters or corporations, including through the development of blanket-style standard for mass market products. By dramatically reducing transaction and monitoring costs ICT can enable the deployment of more tailored policies, including market based policies, which can target large scale and small scale polluters alike. Integrated tools for climate change policy are also becoming available, improving the insight and efficiency of national and local authorities.

The table below describes some examples of ICT applications that are affecting knowledge, behaviour and policy

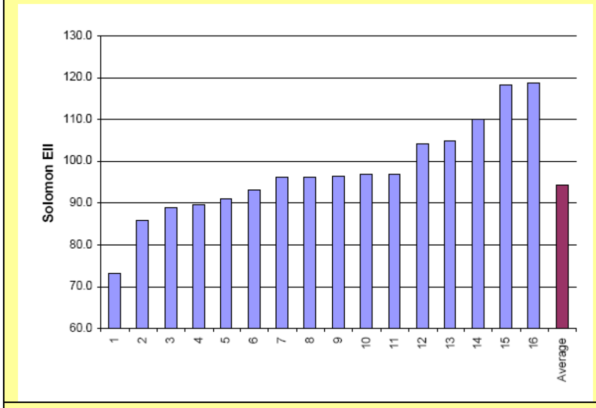
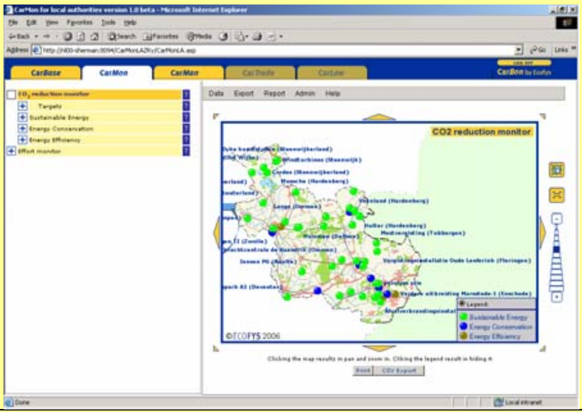
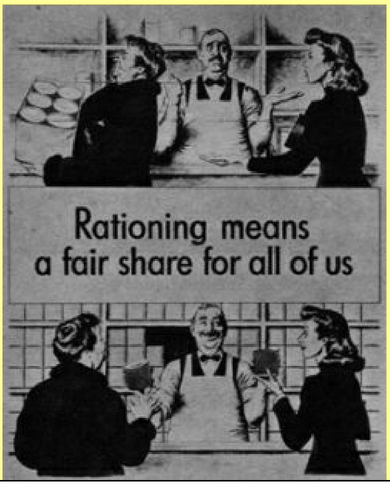
	In the oil & gas sector Solomon Associates[89] has created and maintains an extensive database of practices and benchmarks which is on-line accessible to Solomon Associate's clients. Thanks to information made available by Solomon's database, oil and gas companies can learn about best practices and about their relative performance vs. key benchmarks. Thanks to the insight enabled but the database, significant efficiency improvements take place across the industry.
	Dutch province of Overijssel has utilized a set of integrated software tools to assess the renewable energy and energy efficiency potential available in the region, evaluate costs and GHG impacts of different projects and monitoring the policy roll out in the province.
	The Tyndall Center for Climate Change Research has proposed a domestic tradable quota system, based on the allocation of GHG emission allowances to individual citizen[90]. The implementation of this new and highly sophisticated instrument will only be possible if transaction costs are dramatic reduced. ICT is the key enabler to achieve such goal and the Tyndall Center is currently studying and articulating the requirements for such ICT system

Table 41: Examples of ICT use for knowledge, behaviour and policy improvement

The table below summarizes the channels through which ICT applications that enhance knowledge and empower behaviour and policies affect GHG emission

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[89] http://www.solomononline.com/

[90] Richard Starkey & Kevin Anderson Domestic Tradable Quotas: A policy instrument for reducing greenhouse gas emissions from energy use, http://www.tyndall.ac.uk/research/theme2/final_reports/t3_22.pdf

ICT applications	Channels for direct emission or drivers for indirect emissions						
	Buildings	Transportation	Complementary services and products	Industrial production	Energy supply systems	Impacts on land	Other impacts
Knowledge & behaviour							
Consumers							
Electronic labelling	Higher market share to efficient buildings.	Higher market share to more efficient vehicles	Less waste	Higher market share to less CO2 intensive products	Higher renewable energy deployment	More green spaces and terrestrial C sequestration	More market share to social responsible investment
Policy and corporate strategy							
Simulation and analysis tools	More effective policy making	More effective policy making	More effective policy making	More effective policy making	More effective policy making	More effective policy making	
Benchmarking and education systems	Constant improvement	Constant improvement	Constant improvement	Constant improvement	Constant improvement	Constant improvement	
Monitoring and evaluation tools	More effective and efficient policy implementation	More effective and efficient policy implementation	More effective and efficient policy implementation	More effective and efficient policy implementation	More effective and efficient policy implementation	More effective and efficient policy implementation	

Table 42: Knowledge, behaviour and policy improvement - Channel for GHG emissions reductions

Estimating quantitatively the potential GHG emission reductions associated with ICT solutions discussed in this session is highly complex and existing studies have not attempted to undertake this task.

The sections above highlighted several opportunities for virtual cycles that can lead to sustained GHG emission reductions, while identifying counterbalancing risks of rebound effects that could lead to GHG emission increases. By increasing knowledge, changing behaviour and improving policies, the ICT applications discussed in this section can play a critical role in activating and maintaining the virtual cycles while managing and mitigating the risks of rebound effects.

Knowledge Behaviour, Policy & low carbon feedbacks

Benchmarking systems enable companies to better assess their carbon performance and identify gaps. ICT based simulation tools are used to design better processes, and to set up systems for real time feedback with customers, improving service delivery. This includes providing information on the carbon footprint of the products and service supplied (e-label). Among customers the awareness on climate change problems increase, and so does the support for climate change policies. The availability in the market of e-labels, which quantify the carbon footprint of individual products, facilitates the introduction of more aggressive and innovative climate change policies, such as a “carbon added tax” for retail products. The experience gained with e-labels is leveraged to set up appropriate monitoring and evaluation systems for the carbon added tax.

As a catalyst for positive carbon feedbacks these ICT solutions can therefore produce dramatic impacts on the GHG emission profile of both developed and developing countries, enabling lasting and widespread change in culture, behaviour policy making and policy implementation.

This may provide the opportunity to radically alter the basic functions of societies and economies, changing GHG emission drivers, and achieving lasting results in terms of GHG emissions reductions.

Policy makers can play an active role in exploiting the opportunities offered by ICT in this area by:

- actively seeking to improve, digitalize and create flexible context-dependent labelling systems,
- actively seek to promote benchmarking systems to improve GHG performance,
- take advantage of ICT to activate flexible and targeted, market-based policies that anticipate risks of rebound effects
- take advantage of ICT to activate policies that accurate price negative externalities such as GHG emission reductions.

5 A pragmatic approach for action: achieving the first billion tonnes of GHG emission reduction, while building low carbon feedbacks

The analysis undertaken above highlights that there is a wide variety of ICT applications that may enable a more efficient use of energy and lower GHG emissions.

The contribution of different ICT applications may vary greatly from sector to sector and from country to country.

Whereas different emission reduction scenarios and paths are possible, it is apparent that, at global level, opportunities for GHG emission reductions are significant. This provides ample scope to identify a set of ICT applications on which to build strategies that can achieve sustained reductions of GHG emissions over time.

Below we articulate a strategy that focuses on identifying a set of ICT solutions that are already available and that can deliver a billion tonnes of GHG emission reductions, while providing a stepping stone for building virtual cycles that can enable further reductions over time.

Following the approach developed by Pacala and Socolow in 2004[91], we divided the 1 bn tons target into ten equal 'wedges', where a wedge represents the deployment of an ICT application that reduces the emissions of CO_2 in the atmosphere by 100 $MtCO_2e$. Each of the wedges represents an effort to scale-up current ICT applications in areas where opportunities of broader, longer term improvements are also available.

We leveraged the analysis performed in section 4 and identified ICT solutions that could produce at least one wedge. The table below defines each of the solutions, shows what each of the wedges represents in terms of emission reduction effort and highlights key issues for the successful deployment of the ICT application. The wedges are built on ICT solution that are already available or under development but that would require broader utilization. The selected wedges are not an exhaustive list of the mitigation solutions that ICT can deliver.

Based on the trajectories for GHG emission reductions calculated for 2030, and discussed in section 4, we believe that an appropriate target date for achieving the first billion tons of GHG emission reductions with these ICT solutions is year 2020 and that even faster results are possible with the implementation of public policies, and private sector strategies, that effectively complement the wedge-delivering-ICT solutions.

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[91] Pacala S. and Socolow R (2004) Stabilization wedges: solvine the climate problem for the next 50 years with current technologies

ICT solutions	Description	What do100 MtCO2e emission reductions mean?	Issues/requirements to achieve the wedge
Smart city planning	Deploy modern simulation and analysis software to improve urban design and planning, maximising energy efficiency	Substitute 6% of km travelled by Light Duty Vehicle with public transportation	Improve design tools and knowledge transfer Improve urban planning processes Remove financial barriers
Smart buildings	Deploy modern simulation and analysis software to improve building design and use smart meters and controls in buildings to improve efficiency and tailor energy use to energy needs	Reduce by 4.5% the GHG emissions from buildings built between 2010 and 2020	Training and capacity building Tailoring ICT tools to more geographies and climates Increase incentives for smart buildings
Smart appliances	Utilize ICT components (Mircroporcessors and ASICs) within appliances to improve efficiency and tailor appliances use with actual needs	By 2020 reduce by about 1% the average GHG emissions deriving from energy use in "legacy buildings"	Clearer labelling and education Benchmarks and standards
Smart work	Leverage the internet and other advanced communication tools to work remotely and avoid business trips or physical commuting	About 13% of car commuters become telecommuters and about then 9% of airplane business trips are substituted by virtual meetings by 2020	Training and education to remove cultural barriers Public administration as leader Remove legal and regulatory barriers Increase the availability of broadband technology in companies and households
Smart vehicles	Implement advanced electronic components in vehicles to improve the energy efficiency of the vehicle and of its driver	A 1.3% average energy efficiency improvement per vehicle by 2020	Support further research Labelling and Standards
Intelligent transport	Deploy advanced sensors and controls, analytical models, management tools, and ubiquitous telecommunications to provide context relevant information that enables less polluting forms of transportation (such as public transportation)	Increase freight occupancy rate by 7.6% by 2020 (increase average load factor from 50% to 54%)	Flexible market based policies Remove legal and regulatory barriers

ICT solutions	Description	What do100 MtCO2e emission reductions mean?	Issues/requirements to achieve the wedge
Dematerialization	Use ICT as a form of services delivery, substituting physical products and interactions – i.e. 'use bits instead than bricks'	Reducing paper use by 13%	Removing administrative and legal barriers (e.g. paper driven processes) Improve availability to ICT infrastructure in developing countries Better life cycle analysis tools Public administration as leader
Smart industry	ICT based controls and knowledge management systems within individual production processes to improve day to day operations, save energy and increase efficiency	Reduce by 1% the total GHG emissions generated by industry	Training and capacity building Standardization and interoperability Benchmarks
I-optimization	Deploy design tools software to forecast and analyse energy use in production processes to optimize the design of new plants or the re-design of existing plants to minimize energy use and GHG emissions	Reduce by 1% the total GHG emissions generated by industry	Training and capacity building Better design software
Smart Grid	Deploy advanced sensors, controls and analysis and communications technologies within electricity networks to enable two way communication between energy users and energy producers and to deliver advanced services such as time of use metering or remote demand management	Reducing by about 1.25% the GHG emissions associated with electricity use in buildings by 2020	Remove administrative and technical barriers Support further research Remove financial barriers
Integrated renewables	Utilize simulation, analytical and management tools to enable a wide deployment of renewable energy, for example removing existing bottlenecks present for in transmission infrastructure or enabling a wider use of distributed generation	Adding 75 GW renewable energy capacity	Develop long term strategies and policies Support further research Remove financial barriers

Together, the selected ICT solutions also offer opportunities for broader impacts, as they can activate virtual cycles, which could lead to substantial reductions in GHG emissions that go beyond the arithmetical sum of the individual wedges. Such transformative changes become possible when the deployment of ICT solutions to optimise energy use and reduce GHG emissions generates a sequence of transformations in energy systems, which leads to deeper and deeper GHG emission reductions (low carbon feedbacks). In particular, virtual cycles can be activated when the implementation/use of an ICT solution that reduces GHG emissions:

- Makes it easier for more of the same solution to be deployed
- Leads to a higher use of complementary ICT solutions, which also achieve GHG emission reductions
- Leads to a broader adoption of organizational structures and processes that require less GHG emissions
- Foster a culture and behaviors that drive society towards lower GHG emissions

The ICT solutions identified above have the potential to achieve these goals and to generate low carbon feedbacks such us the one described below.

Low carbon feedbacks - example

An increase in virtual meetings and telecommuting leads to an increasing demand for smart buildings and a broader use of ICT to obtain products or services (e-commerce, e-government, e-health, etc.). The growing demand of smart buildings stimulates technological development and decreases costs. The growing demand for e-commerce and e-services enables more companies to adopt telecommuting solutions for their employees and to make their offices virtual. With more people working from home and using the net to buy products and services, transportation patterns change while the need for private ownership of a vehicle decreases and services more mixed-use communities are created,. These dynamics are further stimulated by independent improvements in the transportation sector, where, for example real-time context-relevant information about public transportation becomes widespread enabling public transportation services to become highly flexible and increase the quality of service delivered. As mixed-use communities increase in number, awareness and knowledge also increase in the broad society, leading to a growing demand for policies that leverage technology to increase quality of life and reduce GHG emissions (e.g. improved urban planning, real time pricing for car pollution, e-government, etc,) and entire cities become ‘smarter’. At national and international level the ability to cost effectively collect and disseminate information about GHG emissions and impacts enables a widespread use of electronic labels, benchmarking tools, market based policies, and business practices, that further stimulate the adoption of energy saving and GHG reducing applications. These changes facilitate a transition from an economy of goods and purchases to a service-based economy in which the industrial sector can dramatically reduce the amount of natural resources utilized to deliver the services required by end users, designing services that conform to principles of industrial ecology. As these dynamics continue, the price of GHG reducing ICT technologies decrease (in virtue of technological learning and economies of scale and scope) and network effects take place (as more people uses an ICT technology more people are induced to use the same technology) further spreading the adoption of ICT applications that decrease GHG emissions, thus alimenting a positive cycle of ITC implementation and GHG emission reductions.

Virtual cycles, such as the one described above, are possible but are by no means automatic. Risks of negative impacts on GHG emissions exist if an ICT application:

- Produces short term benefits but leads to a prolonged use of and lock-in with GHG emitting technologies. E.g. An IT enabled traffic control system which enables marginal CO_2 reductions, may under certain conditions support a car based transportation system and discourage investment in systems where people would work from home or use public transportation.
- Is poorly implemented and leads to a backlash from users or potential users. E.g. badly implementing teleworking solutions may lead to employees alienation which in turn may lead to a roll back of teleworking solutions, both within and outside (if the failure becomes public knowledge) a company
- Generates a negative rebound effect, if the resources liberated by more efficient ICT technologies (time or income) are used in ways that increase GHG emissions.

Whereas some of the positive and negative dynamics associated to an ICT application are proper of the application itself (e.g. as the number of virtual meeting users increases more non-users are enticed to also adopt virtual meeting solutions) others are driven by the modality in which an application is deployed (e.g. successful telecommuting implementations may lead to further use of telecommuting, e-services, e-commerce, e-health, etc. while failed telecommuting implementations may lead to achieve the opposite) or by the broader socio-economic and cultural environment (e.g. when smart buildings and smart appliances generate energy savings, the additional income available to energy users may result in additional consumption, in a culture that promotes consumption and waste, or may be invested in renewable energy, energy efficiency or environmentally sound initiatives, in a society that promote such investments and discourage over-consumption).

For the ICT applications described above to fully deliver their GHG emission reduction potential it is therefore critical that policies and corporate strategies seek and support positive, GHG reducing, synergies while reducing risks of negative impacts, .

Such policies and strategies may entail:

- Increasing awareness on the GHG opportunities and risks associated with ICT technologies, building capacity within policy makers, business executives, and civil society alike
- Explicitly analysing the opportunities to activate virtual cycles when new ICT technologies or applications are designed
- Requiring an analysis of the risks of negative impacts in early stages of strategy, project or product development
- Implementing strategies to reduce rebound effects and increase the opportunities to achieve virtual cycles when new ICT projects are implemented.
- Introducing broad policies that, when resources (time or money) are liberated by efficiency-enabling ICT applications, automatically provide disincentives for the use of such resources in ways that lead to additional GHG emission. E.g. a policy that increases the cost of electricity as energy efficiency improvements are achieved with ICT

- Systematically perform ex-post evaluation of the deployment of ICT applications to assess if/what virtual cycles were activated, if/what negative impacts occurred, what impact on GHG emissions was achieved

If virtual cycles are fostered and risks prevented the ICT applications discussed above can act as enablers and catalysts and help create a society in which the behaviour of building infrastructures, energy systems, transportation systems, production facilities, workers and consumers is orchestrated to minimize GHG emissions. If this potential is fully achieved the results in terms of GHG emission reductions can be dramatic and go beyond the simple sum of the emission reductions achieved by individual wedges (see figure below).

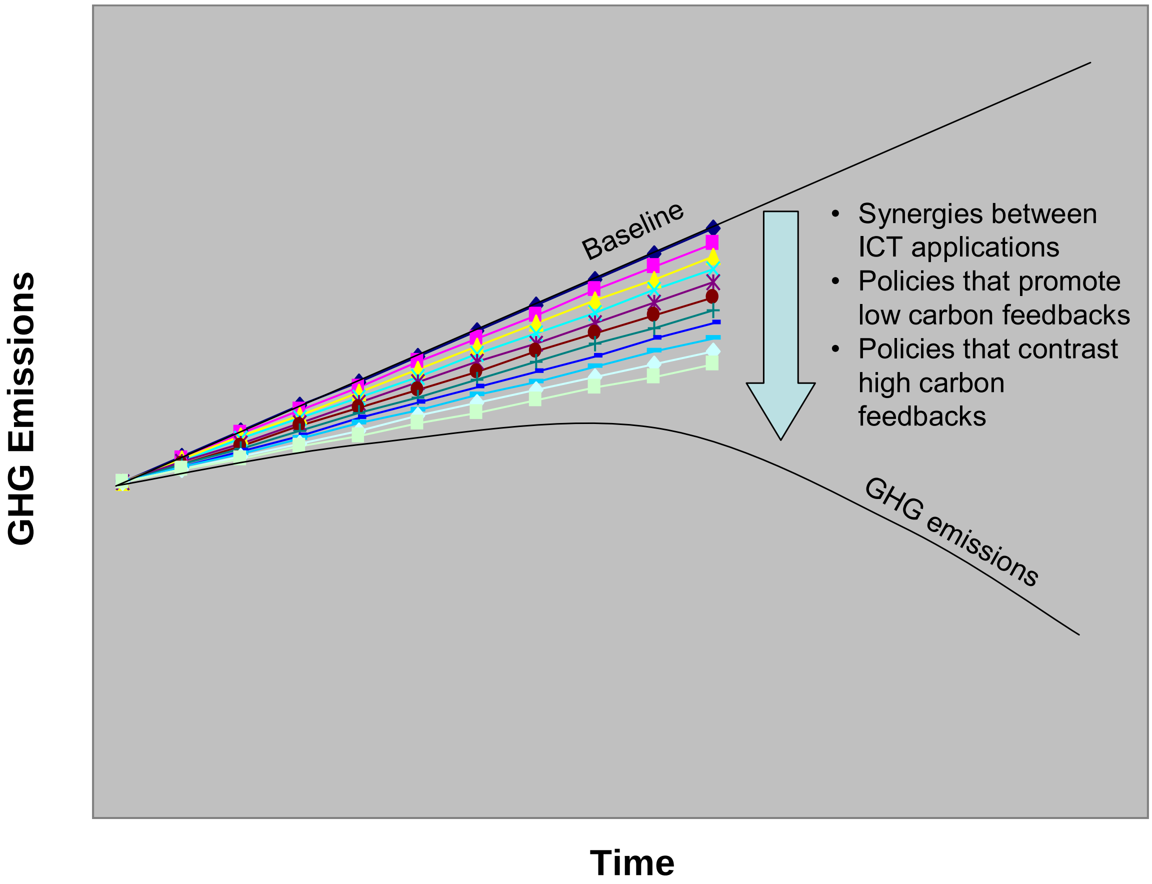

Figure 16: Building on the first billion ton to achieve systemic change and GHG emission reductions

6 Conclusions and next steps

This report assessed and consolidated existing literature on the potential GHG emission reductions achievable with ICT technologies.

The analysis highlighted that a general and shared approach to the analysis of the contribution of ICT is still missing. Existing studies should be considered pioneering in nature and are best at raising awareness on opportunities and issues. They provide different insights on some of the impacts (typically the most direct ones) of different ICT application types or, through case studies, individual ICT applications. However, they are not able to fully capture the multiple influences that ICT applications can have on GHG emissions, especially if they unfold over a longer time period.

The fact that most papers are more suitable for awareness raising than for other purposes reflects the fact that in society at large, but also among experts of ICT and energy, the potential contribution of ICT to achieve GHG emission reductions is not yet well understood. The ability to analyze this phenomenon also suffers from lack of data needed for more rigorous analysis, as existing data collection processes are not designed to gain insight on the interaction between ICT and GHG emission.

Despite these shortcomings the analysis undertaken in section 4 suggests that significant opportunities to reduce GHG emission may be available if climate friendly solutions that leverage ICT systems are more systematically exploited.

	Estimated Incremental Potential for GHG Emissions Reductions Enabled by ICT by 2030 MtC0$_2$		
	low	**medium**	**High**
Smart buildings – ICT in legacy buildings	121	545	969
Smart buildings – ICT for planning and operating new buildings	46	439	832
Transport mode switching enabled by smart urban planning	38	190	380
Telecommuting and virtual meetings (smart work)	68	159	404
In vehicle ICT and intelligent transport infrastructures (smart vehicles and intelligent transport)	581	1,486	2,646
E-commerce and dematerialization	198	927	1,822
ICT for energy efficiency in Industry (improving day by day operations: smart industry and plant and process design: I-optimization)	100	815	1,530
ICT in Energy supply systems (Removal of network constraints – 2020)	17	59	128
Estimated total potential for CO_2 emission reductions	1,168	4,620	8,711

Table 43: Estimated Potential for GHG Emission Reductions Enabled by ICT

ICT technologies do not offer one 'killer application', but a variety of ICT applications that, together, can provide a valuable contribution to the global effort to reduce GHG emissions. Opportunities exist in developed countries but also in developing countries, where it may be possible to leapfrog the GHG-heavy-ICT-poor solutions in use in developed countries and to implement innovative ICT technologies that reduce GHG emissions 'from the get go'.

To harvest this potential section 5 proposed a strategy based on the identification of 10 ICT solutions, each able to deliver a GHG emission reduction wedge on average worth 100 MtCO2e, thus achieving a first billion tons of GHG emission reductions. Taken together, however, the selected ICT applications provide opportunities for synergies and for the activation of virtual cycles that can lead to even greater transformations in energy systems and deeper GHG emission reductions, thus generating emission reductions that go beyond the arithmetical sum of the individual wedges (low carbon feedbacks).

Based on the trajectories for GHG emission reductions calculated for 2030, and discussed in section 4, we believe that an appropriate target date for achieving the first billion tons of GHG emission reductions with these ICT solutions is year 2020 and that even faster results are possible with the implementation of public policies, and private sector strategies, that effectively complement the wedge-delivering-ICT solutions.

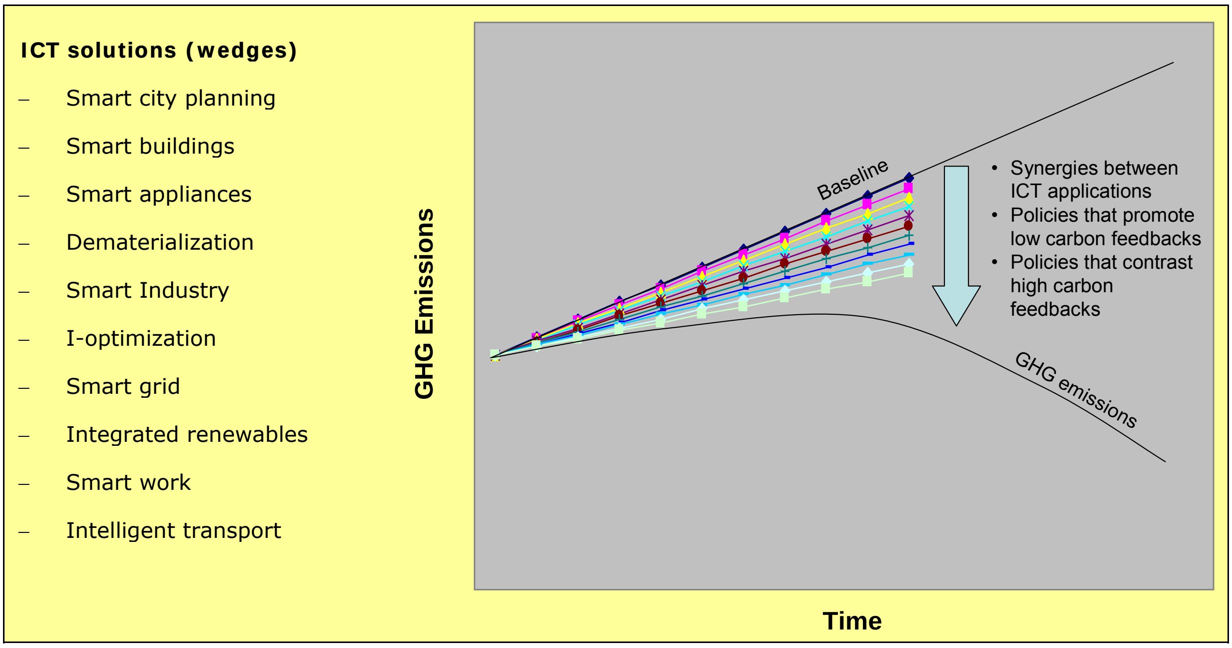

Figure 17: ICT solutions for the first billion ton of GHG emission reductions and to achieve systemic change

The opportunities offered by ICT, however, will not be harvested automatically as, by improving efficiency and productivity, ICT also delivers more free time to workers, lower prices to consumers, higher profits to companies and higher disposable income. The use of these additional resources can lead to higher GHG emissions overcompensating initial gains. The size of this rebound effect, however, will depend on technological and economic development, and on the broader strategies and policies that societies and businesses will pursue. We can construct ICT technologies and use them in a way that reduces our environmental footprint, but we could also build ICT systems that are a factor of environmental destruction.

Thus, additional work is needed to better understand the interactions between ICT and GHG emission but also, perhaps most importantly, to articulate policies and strategies that are able to nurture, disseminate and leverage ICT solutions that help reduce, at societal level and on a global scale, GHG emissions.

To **gain insight** on the interaction between ICT and GHG emissions the following activities are advisable:

- Agree upon a standard classification of ICT services with GHG impact, thus creating a 'shared language' that is conducive to data collection, dialogue, comparison and learning and thus to a more rapid progress (in knowledge, business practices and policy) over time
- Agree on a common approach to allocate the contribution of the savings to ICT vs. other measures
- Set up appropriate data collection systems that are able to regularly gather the statistical data needed to assess and monitor progress in this field.

- Define a set of methodological guidelines that researchers and business people can deploy with more transparency and consistency when assessing individual ICT applications or families of applications – this may include guidelines for dealing with overlapping and double counting, transparency in data collection and assumptions, etc.
- Make a concerned effort to collect relevant data and analyze potential impacts and opportunities in developing countries where the potential GHG benefit of ICT technology may be enormous

To nurture, disseminate and leverage ICT solutions and reduce GHG emissions through **policies and strategies:**

- Promote awareness building and education campaigns targeting business communities and the broader public
- Collect and disseminate information about best practices on ICT use for GHG emission minimization
- Facilitate the widespread adoption of uniform standards of communication and interoperability between different ICT devices with GHG benefits
- Fund technology development initiatives to improve critical ICT solutions or to tailor them to the needs of countries or sectors that are critical for the global GHG emission reduction effort (e.g. the creation tailored ICT tools for the design and planning of energy efficiency buildings in developing countries with high growth and booming construction sectors)
- Implement capacity building and technology transfer policies designed to benefit developing countries or sectors that are lacking in critical knowledge and expertise, but that are key to reduce GHG emissions (e.g. with designers within the building industry, to further increase the use of ICT to reduce the GHG footprint of new building)
- Remove regulatory barriers that hinder the offer of innovative ICT-based services with GHG benefits (e.g. in the energy sector: removing rigid dispatching or price regulations that do not allow real-time differentiation based on GHG emissions, in the administrative field: removing requirements for printed copies of legal documents)
- Leverage actively ICT to develop innovative climate change policies and tools (e.g. for traffic management, GHG emissions monitoring. Information dissemination, etc.)
- Use public procurement, and public services in general, to spur the adoption of ICT applications with positive GHG impacts
- Ensure that appropriate funding mechanisms for ICT investments with GHG benefits exist, especially for activities in developing countries (E.g. Within the Kyoto protocol framework, develop showcase CDM projects with appropriate methodologies)
- Introduce broad policies that, when resources (time or money) are liberated by efficiency-enabling ICT applications, automatically provide disincentives for the use such resources in ways that lead to additional GHG emission.

Overall the research illustrated in this paper shows a growing awareness on the opportunities offered by ICT to reduce GHG emissions. ICT may enable GHG emission reductions in a variety of sectors and through many different channels. A conscious deployment of ICT as an instrument to increase energy efficiency and reduce GHG emissions is just in its early days. This effort, however, can play a key role in our attempt to preserve the integrity of Earth’s climate. The success of this effort does not solely rely on ICT. It also dependents on our ability to orchestrate technological, economic and policy systems that channel ICT towards delivering lasting reduction in our GHG footprint.

Appendix 1 - Analysis of different papers on ICT and GHG emissions

ACI

Topic	**Description**
Report title	Broadband services: economic and environmental benefits
Report sponsor	ACI (American Consumers Institute)
Authors	Joseph Fuhr and Stephen Pociask
On the web at	http://www.internetinnovation.org/Portals/0/Documents/Final_Green_Benefits.pdf
ICT applications analysed	• E-commerce – Consumer and general business market – Business supply chain • Telecommuting • E-materialisation – Saving plastic by downloading music – Savings from US mail – Savings from lower newspaper circulation – Savings from reduction in office paper • Telemedicine • Teleconferencing • Distance learning
Geographic scope	USA
Type of analysis performed	Examples of individual ICT applications. Literature based.
Timeline	Future Potential. Target year 2017.
Baseline clearly discussed	No
Potential overlap and double counting	Moderate
Transparency	Medium/Low
Analysis of rebound effect	Limited
Communicability	Simple
Discussion of uncertainty	No
Policy discussion	No
Savings in tonnes of CO_2	About 1 billion over a 10 year period

AeA

Topic	**Description**
Report title	Advanced electronics and information technologies: the innovation led climate change solution
Report sponsor	AeA Europe
Authors	John “Skip” Laitner and Karen Ehrhardt- Martinez
On the web at	http://www.aeanet.org/aeacouncils/AeAEurope_Energy_Efficiency_Report_17Sep07.pdf
ICT applications analysed	• Lighting • Telecommuting • New logistics and warehousing (freight movement) • Smart grid applications • Building optimisation • Manufacturing process control
Geographic scope	Europe 27
Type of analysis performed	Literature review and ad-hoc estimates based
Timeline	Future Potential. 2020 as potential target year for most important applications
Baseline clearly discussed	No
Potential overlap and double counting	Limited
Transparency	Low - black box inputs
Analysis of rebound effect	No
Communicability	Unclear reference to unpublished papers
Discussion of uncertainty	No
Policy discussion	High level
Savings in tonnes of CO_2	589 Million

AT&T

Topic	**Description**
Report title	Measurement of environmental impacts of telework adoption amidst change in complex organisations: AT&T survey methodology and results
Report sponsor	AT&T
Authors	Robert Atkyns, Michele Blazek, Joseph Roitz, AT&T
On the web at	Not available publicly
ICT applications analysed	· Telework
Geographic scope	US
Type of analysis performed	Case study. Questionnaire used fro data collection.
Timeline	Past 1999 / 2000
Baseline clearly discussed	Yes
Potential overlap and double counting	Very low
Transparency	High
Analysis of rebound effect	No
Communicability	Low
Discussion of uncertainty	Some
Policy discussion	Some
Savings in tonnes of CO_2	43,993

EMPA

Topic	**Description**
Report title	The future impacts of ICTs on environmental sustainability
Report sponsor	EU JRC, IPTS
Authors	Lorenz Erdmann (IZT), Lorenz Hilty (EMPA/FHSO), James Goodman (Forum for the Future), Peter Arnfalk (IIIEE)
On the web at	http://www.empa.ch/plugin/template/empa/*/32708/---/l=2
ICT applications analysed	• ICT in supply chain management • Tele-shopping • Tele-work & virtual meetings • Virtual goods • ICT is waste management • Intelligent transport systems • ICT in energy supply • ICT in facility management • ICT in production process management • Mobile ICT time utilisation effect
Geographic scope	Europe
Type of analysis performed	Model based analysis
Timeline	Future Potential. 2020
Baseline clearly discussed	Yes
Potential overlap and double counting	Unclear
Transparency	Medium/high
Analysis of rebound effect	Yes
Communicability	Complex
Discussion of uncertainty	Yes
Policy discussion	Some
Savings in tonnes of CO_2	Broad range provided (between -15% and +2% of 2020 emissions)

EPA / LBNL

Topic	Description
Report title	Re-estimating the Annual Energy Outlook 2000 forecast using updated assumptions about the information economy
Report sponsor	EPA, LBNL
Authors	John “Skip” Laitner (EPA), Jonathan Koomey, Ernst Worrell, Etan Gumerman (LBNL)
On the web at	http://enduse.lbl.gov/Info/LBNL-46418.pdf
ICT applications analysed	• Industrial commodity production • Transportation • Commercial floorspace • Combined heat and power (CHP) • Voluntary programmes • Structural change • Integrating/rebound effect
Geographic scope	USA
Type of analysis performed	Entire economy top down by sector. Model based. Key variable GHG emission per GDP produced
Timeline	Future Potential Reference/target years are 2010 and 2020
Baseline clearly discussed	Yes
Potential overlap and double counting	No
Transparency	Low
Analysis of rebound effect	Yes
Communicability	Complex
Discussion of uncertainty	No
Policy discussion	No
Savings in tonnes of CO_2	107 million in 2010

ETNO / WWF

Topic	Description
Report title	Saving the climate @ the speed of light
Report sponsor	ETNO, WWF
Authors	Dennis Pamlin (WWF) and Katalin Szomolanyi (Magyar Telekom, ETNO)
On the web at	http://www.etno.be/Portals/34/ETNO%20Documents/Sustainability/Climate%20Change%20Road%20Map.pdf
ICT applications analysed	• Travel replacement: – Teleconferencing – Video conferencing – Others (tele-education, tele-care /remote assistance) • Dematerialisation – Virtual answering machine – Online phone billing – Web-taxation – Other areas (downloading films, videos and music) • Sustainable city planning – Flexi work – Other (flexible car ownership, e-commerce, intelligent heating of buildings, e-business)
Geographic scope	Europe
Type of analysis performed	Examples of individual ICT applications. Literature based.
Timeline	Future Potential. Target year 2010.
Baseline clearly discussed	No
Potential overlap and double counting	Limited
Transparency	Low
Analysis of rebound effect	No
Communicability	Simple
Discussion of uncertainty	No
Policy discussion	Yes
Savings in tonnes of CO_2	50 million

Siikavirta

Topic	Description
Report title	Effects of E-Commerce on Greenhouse Gas Emissions: A Case Study of Grocery Home Delivery in Finland.
Report sponsor	None
Authors	Hanne Siikavirta, Mikko Punakivi, Mikko Karkkainen and Lassi Linnanen
On the web at	http://www.imrg.org/ItemDetail.aspx?clg=Events&cid=wp&pid=wp_Greenhouse_Gas_Emissions_Finland&language=en-GB
ICT applications analysed	• E-shopping of groceries
Geographic scope	Finland
Type of analysis performed	Case studies and modelling.
Timeline	Past 2005.
Baseline clearly discussed	Yes
Potential overlap and double counting	Limited
Transparency	High
Analysis of rebound effect	No
Communicability	Simple
Discussion of uncertainty	Yes
Policy discussion	No
Savings in tonnes of CO_2	0.19 to 0.95 million.

Telstra

Topic	Description
Report title	Towards a high bandwidth low carbon future. Telecommunications based opportunities to reduce greenhouse gas emissions
Report sponsor	Telstra
Authors	Dr Karl Mallon BSc PhD, Gareth Johnston GC. Sust CSAP, Donovan Burton B.Env.Plan (Hons), Jeremy Cavanagh B.Eng - Design and layout by Bethan Burton BSc
On the web at	http://www.telstra.com.au/abouttelstra/csr/docs/climate_full_report.pdf.pdf
ICT applications analysed	· Increased renewable energy · Personalised public transport · De-centralised business district · Presence-based power · Real-time freight management · 'on-live' high definition videoconferencing · Remote appliance power management
Geographic scope	Australia
Type of analysis performed	Ad hoc estimates with case studies.
Timeline	Future Potential. Target year not explicit
Baseline clearly discussed	No
Potential overlap and double counting	Limited
Transparency	Medium/high
Analysis of rebound effect	No
Communicability	Simple
Discussion of uncertainty	No
Policy discussion	Minimal
Savings in tonnes of CO_2	27.3 million

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- conserving the world's biological diversity
- ensuring that the use of renewable natural resources is sustainable
- promoting the reduction of pollution and wasteful consumption

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