Institute for Prospective Technological Studies

THE FUTURE IMPACT OF ICTs ON ENVIRONMENTAL SUSTAINABILITY

Editors:
Carlos Rodríguez Casal, Christine Van Wunnik, Luis Delgado Sancho, Jean Claude Burgelman and Paul Desruelle

Authors:
Lorenz Erdmann (IZT), Lorenz Hilty (EMPA/FHSO), James Goodman (Forum for the Future), Peter Arnfalk (IIIEE)

AUGUST 2004

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
Joint Research Centre

Technical Report EUR 21384 EN

European Commission

Joint Research Centre (DG JRC)

Institute for Prospective Technological Studies

http://www.jrc.es

Technical Report EUR 21384 EN

Printed in Spain

EXECUTIVE SUMMARY

Information and Communication Technologies (ICTs) not only constitute an industry in their own right but they also pervade all sectors of the economy, where they act as integrating and enabling technologies. ICTs have a profound impact on society, and their production and use have important consequences for development in economic, social and environmental areas. The extent to which ICTs also affect progress towards environmental sustainability in an economy is an issue that is still under debate. There is, however, increasing evidence that significant opportunities and threats are involved. These deserve more research and more attention in energy, climate change and technology policies.

The Institute for Prospective Technological Studies (part of the Joint Research Centre - European Commission) has commissioned a study entitled 'The Future Impact of ICTs on Environmental Sustainability', which aims to explore (qualitatively) and to assess (quantitatively) the way that ICTs will influence environmental sustainability between now and 2020. This study is the first quantitative projection to be carried out on how ICTs could affect the environment in the European Union. In order to estimate the effects of ICTs on a set of five environmental indicators, the project team adopted an innovative methodology combining qualitative scenario-building and quantitative modelling.

The general conclusion was that ICTs can modify the value of these five indicators. ICTs could improve the situation, reinforcing positive effects in the environment, or they could worsen the situation. This suggests that environmental policies have to be designed to ensure that ICT applications make a beneficial contribution to environmental outcomes, and, at the same time, suppress rebound effects. There are significant opportunities for improving environmental sustainability through ICTs, which can rationalise energy management in housing (or facilities), make passenger and freight transport more efficient, and enable a product-to-service shift across the economy.

The methodology used in the study had five steps. Firstly, a set of environmental indicators was chosen and the economic sectors and ICT applications with the greatest impact on these indicators were identified. For this purpose, the project team adapted the indicators that were developed in response to the conclusions of the European Council in Gothenburg, obtaining the following:

1. volume of transport relative to gross domestic product,
2. modal split of transport,
3. energy consumption and share of renewables,
4. greenhouse gas emissions,
5. municipal waste collected but not recycled.

The impact of telecommunications (equipment and services) and information technologies (defined as the combined industries of hardware for office machines, data processing equipment, data communications equipment, software and services) on these indicators was analysed.

The second step was to gather data for use in later stages of the project by means of an extensive review of the literature on environmental impacts of selected ICT applications: ICT industry,[1] ICT use,[2] e-business,[3] virtual mobility,[4] virtual goods,[5] waste management,[6] intelligent transport systems,[7] energy supply,[8] facility management[9] and production process management.[10]

[1] ICT industry including manufacturing and services

[2] ICT use, including entertainment, communication, data processing and home networks

[3] e-business comprises e-commerce plus e-based and/or e-supported activities

[4] Virtual mobility refers to teleworking, virtual meetings and teleshopping

[5] Virtual goods refers to the dematerialisation potential of ICT for information goods (examples are the use of e-mail and the reading of e-books instead of using letters or reading books)

Three kinds of impacts and opportunities were considered:

- those created by the physical existence of ICTs and the processes involved (first order effects),
- those created by the ongoing use and application of ICTs (second order effects), and
- those created by the aggregated effects of large numbers of people using ICTs over the medium to long term (third order effects).

The third step was to develop three consistent scenarios for the development of ICTs and the environment, including future uncertainties, by choosing highly unpredictable factors likely to influence the development and use of ICTs in the future. As each of these factors can be varied over several levels, it would be easy to create hundreds of scenarios, even from this small set of factors. In order to avoid this, specific combinations of factor levels, perceived as internally consistent, were sought. The table below shows the combination of uncertain factors for the three scenarios.

Uncertain Factor	**Scenario A "Technocracy"**[11]	**Scenario B "Government First"**[12]	**Scenario C "Stakeholders democracy"**[13]
Technology Regulation	Incentives for innovation	Government intervention	Stakeholder approach
Attitudes to ICTs	Moderate, conservative	Receptive	Highly receptive
ICTs in business	High level of cooperation	High level of competition	Between A and B
Attitudes to the environment	Moderate / controversial	High awareness and interest	High awareness and interest

In the fourth and fifth steps, results were obtained using the refined and quantified scenarios. The project team created a simulation model[14] to quantify the impact of ICTs on the selected environmental indicators. A unique aspect of the applied methodology was the combination of qualitative scenario making and quantitative modelling. This led to projections of future impacts and the identification of areas where policy interventions could have a positive effect. Finally, recommendations for action were drafted and then discussed and validated by a panel of experts.

RESULTS

It is possible to estimate the isolated effects of ICTs on different indicators. However, the most important information is not the direct impact of ICTs on one indicator, but the whole picture, including the evolution of all the indicators in relation to the development of ICTs.

[6] ICT impacts on the amount of daily waste (ICT waste, effect of virtual goods and demand for packaging) and has the potential to increase efficiency of collection and sorting systems.

[7] Intelligent transport systems, or telematics, for which there is not a clear definition but includes control and guidance, road pricing, parking, assistance, freight and fleet control and management.

[8] Energy supply changing due to initiatives to foster renewables and Green House Gas and by liberalised electricity markets.

[9] ICT is one measure to reduce energy consumption of buildings. Facility management targets space heating, water heating, cooling, lighting, cooking and electric appliances.

[10] ICT for production process control is used to increase production yield and to minimise energy demand.

[11] Government and business collude to produce high speed, growth-focused technology development

[12] Heavy-handed government steers technology development to favour social outcomes, while business competes to exploit a slowing market

[13] A positive environment for sustainable development, with all eyes on what ICT can deliver, but outcomes are not always straightforward

[14] Simulations are based on a System Dynamics model

The following figure presents the development of environmental indicators envisaged in the scenarios by the end of 2020. The figures are percentage increases or decreases from the base year (2000). The length of the bars indicates the uncertainty of the findings, as a result of both future scenario variation and data uncertainty. There are two bars per indicator: the upper (dark blue) bar shows the results for projected ICT development, the lower (light grey) bar shows the results for the "ICT freeze" simulations (i.e. ICT applications remain at the same level as in 2000). The impacts shown are aggregated values of all ICT applications considered in all the scenarios simulated.

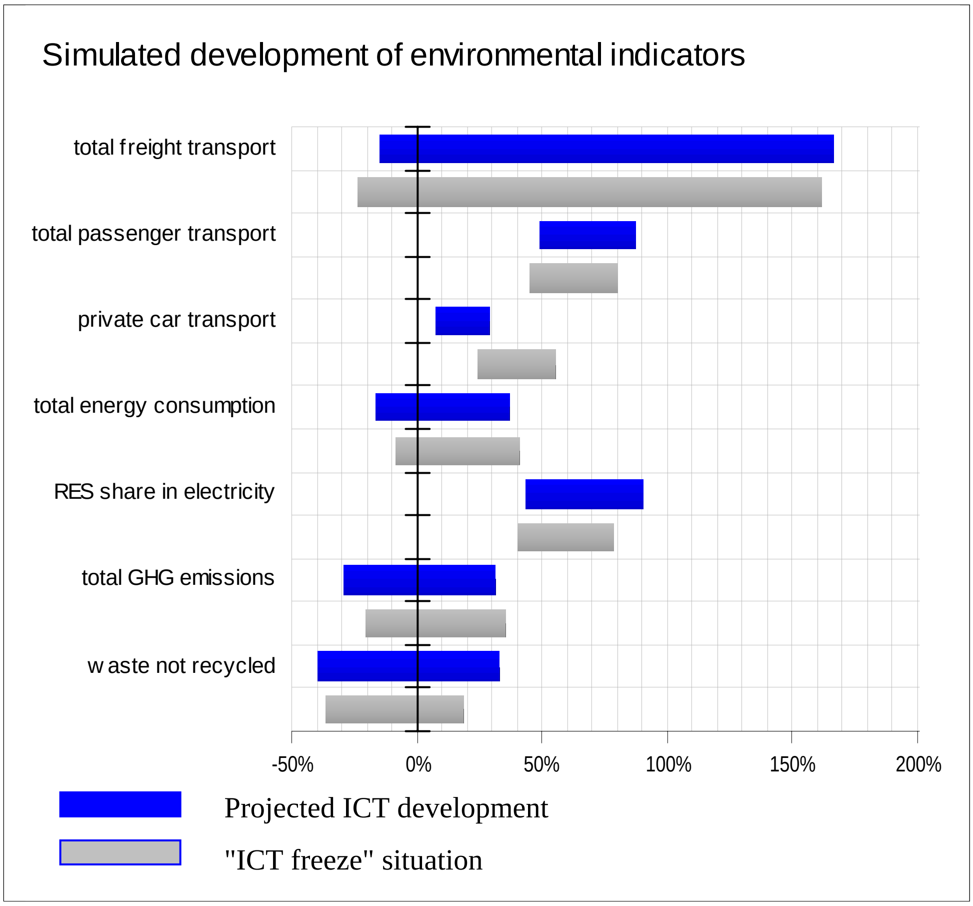

Figure: Simulated development of environmental indicators by 2020.

This model also takes into account rebound effects, which occur when efficiency gains stimulate new demand that counterbalances or even outweighs positive environmental gains. For example, the efficiency improvements (time, fuel, energy) made possible by technological advances are counteracted by an increasing demand (growing consumption volumes) of energy, products, services, passenger and freight transport. In the model, rebound effects are managed by determining *elasticities*, quantified by assigned numbers, for example by determining the proportion of savings that are offset by increased consumption, or vice versa. Another rebound effect is *rematerialisation*, e.g. virtual information products are accessed via the Internet and then printed out or burned onto a CD. Rebound effects should be acknowledged and addressed by all policies, and especially ICT policies, which aim to increase efficiency.

RECOMMENDATIONS

1 & 2. Freight and passenger transport.

ICT-related efficiency improvements in transport need to be combined with demand-side management in order to achieve an overall reduction in environmental impact. Time reduction and network capacity increases achieved by Intelligent Transport Systems will pave the way for more demand for transport, unless measures are taken to limit growth. The research indicates that the internalisation of environmental externalities, in particular raising energy prices and fuel prices, could bring demand down to a level where transport is no longer linked to economic growth. The option of complementing such measures by including transport in emissions trading schemes also seems reasonable.

Moreover, Intelligent Transport Systems (ITS) could support public transport by:

- directing the research focus and allocating resources to multi-modal, seamless travel and public transport supported by intelligent transport systems;
- increasing the attractiveness of public transport by developing and implementing systems for tailor-made information, such as adaptive time-tables, route-planning, and so on;
- in the case of passenger transport, providing prerequisites for ICT-supported work (such as wireless internet access) during train travel and on public transport.

Virtual mobility applications will not automatically generate significant transport savings unless policy initiatives are introduced to support this. Promotion of virtual meetings is probably the most effective e-application for reducing the environmental impact of passenger transport. Attention should also be given to a potential increase in passenger transport caused by a growing number of mobile workers. Specific policy recommendations are:

- to promote development of affordable and reliable broadband access;
- to promote the establishment of corporate policies and agreements for efficient e-work and
- to establish policies and routines for virtual meetings and, at the same time, increase the cost of passenger transport, which would encourage a shift towards the “virtual” alternatives.

3. Energy consumption and the share of renewables

Suggested energy measures apply to both energy consumption and the supply side.

ICTs could play two main roles in energy consumption. Firstly, they could support energy saving measures in buildings and could have an important impact on the rational use of heating energy. Although it is highly uncertain under what conditions “soft” measures supported by ICTs (such as intelligent heating systems) operate effectively and satisfactorily for users, this issue deserves consideration because of the high levels of energy consumed. Heating accounts for roughly 30% of total energy consumption, and the most effective “hard” measures only apply to the small numbers of buildings that are renovated or newly built annually. “Soft” measures, even though they are less effective, have the advantage of being, in principle, applicable to every building. Secondly, ICTs could also influence the demand side by encouraging more sustainable consumption patterns. These would avoid the rebound effect of increased consumption which would outweigh positive effects.

On the supply side, the deployment of ICT support systems for decentralised electricity generation from renewable sources and the use of small Combined Heat and Power devices are recommended. The development of low-cost metering and communication systems for the electricity grid, making small-scale electricity production easier to operate and maintain and more cost-effective than conventional approaches, is also recommended.

4. Greenhouse gas emissions

The recommendations for greenhouse gas emissions are cross-cutting, as they concern energy use in industry, transport and housing. This study’s main findings suggest the need for ICT-supported monitoring and reporting schemes, and the adjustment of consumption of energy and transport to a sustainable level. They also suggest that research into ICT-supported measures for the reduction of greenhouse gas emissions (to find more cost-effective ways than the more traditional investment in energy savings) should be promoted. For instance, ICT-based demand-side management measures could be prioritised, making it possible to adjust consumption of energy and transport to a sustainable level using economic instruments.

5. Municipal waste collected but not recycled

ICTs affect waste volumes, both in the generation and management of waste electrical and electronic equipment, and the management and recycling of municipal solid waste. It is foreseen that the 6th Environmental Action Programme objective to break the link between economic growth and increases in municipal solid waste will be achieved. However, ICTs would add significantly to non-recycled municipal solid waste if no measures are found to limit the growth of ICT waste. Recommended actions include:

- Further enhancement of the implementation of the 1994 Directive on Packaging Waste, by developing incentive systems for teleshopping retailers to reduce packaging waste (e.g. by designing their product, retail and shipping systems in ways that reduce the need for and use of packaging).
- Reduction of the amount of waste electrical and electronic equipment by:
    - providing incentives for producers to design and sell ICT products with a long life-span, thus reducing the churn rate.
    - effectively implementing the Directive on waste electric and electronic equipment[15] which is based on the extended producer responsibility principle. This would encourage product designers and producers to minimise the waste stream, particularly if producers are held responsible for managing the waste of their own products;
    - limiting sales models that make ICT products of little or no value in a short period of time, such as subsidised mobile phones and subscription packages; and
    - extending the depreciation time for ICT equipment (minimum time to 'write off' ICT equipment investments).
- Adaptation of the policy to limit the environmental impacts of trends towards "pervasive computing" and electronics embedded in non-traditional ICT products, which are not covered by the current policy framework (e.g. Directives on Waste Electrical and Electronic Equipment and Restriction of Hazardous Substances[16]).
- Support for intelligent systems for recycling and other forms of recovery, thereby decreasing the waste fraction that goes to final disposal and incineration.

Crosscutting issues

The influence of ICTs on potential material and energy savings in production processes, leads to the following recommendations:

- Customers should be supplied with sufficient information to enable them to take environmentally aware decisions when selecting not only ICT products, but also services. This could include product declarations, energy-labelling and eco-labelling schemes. This information should cover the whole life-cycle impact and make it possible to benchmark the environmental performance of different products and services.
- Direct attention should be given to the product design stage, and to strengthening industrial designers' capacity to take environmental considerations into account. This could be realised by promoting demonstration projects that involve actors from the entire life-cycle chain in finding sustainable solutions for product and service design. The increased dissemination of information on cost-effective, energy- and material-optimising ICT solutions for industry, paying special attention to reaching small and medium enterprises, would also be advisable.

[15] Directive 2002/96/EC on Waste Electric and Electronic Equipment, of 27th January 2003.

[16] Directive 2002/95/EC on Restriction of Hazardous Substances in Electrical and Electronic Equipment, of 27th January 2003.

- The promotion of efficiency improvements in industry should be combined with the stimulation of innovation, placing particular emphasis on the shift towards product-service systems (also called functional thinking) which do not sell the product itself, but rather the service that is offered by the product. Although there are widely diverging opinions concerning an ICT-based product-to-service shift and its possible energy saving and dematerialisation effects up until 2020, it is again the significant potential for change that makes this issue important. In the model, almost every output turned out to be directly or indirectly linked to the product-to-service shift variables, mainly freight transport performance, but also waste and the energy used by the industrial sector.

The existing and developing policy framework (the Proposal for a Directive establishing a framework in which eco-design requirements for energy-using products are defined[17]) should address these issues and support implementation. The implementation of this policy framework would help in advancing many of the recommendations suggested here. In the light of the project findings, the suggested integrated product policy framework should stress the issues of promoting dematerialisation and suppressing re-materialisation. Systems for monitoring and following-up progress should also be put in place.

CONCLUSIONS AND FUTURE RESEARCH

Even if the direct impact created by the physical existence of ICTs is negative, their overall impact on environmental sustainability may vary, depending on the applications and the aggregated effects of large numbers of people using ICTs. If ICTs are to enable a decrease in absolute energy consumption, policy must be designed so that it promotes the environmentally positive impacts of ICTs, whilst inhibiting the negative ones.

On the one hand, significant opportunities for improving environmental sustainability lie in the potential impact of ICTs on the rational use of heating energy, and the support of decentralised electricity production from renewable sources and its important role in the product-to-service shift.

On the other hand, ICT applications that make freight and passenger transport more time efficient (cheaper or faster) will immediately create more traffic and possibly more energy consumption. There is no empirical evidence for assuming anything other than a strong price rebound effect here, which could have severe environmental consequences in terms of energy use and greenhouse gas emissions.

As a great deal of uncertainty still exists, further research is necessary for a fuller understanding of the role of ICTs in meeting environmental policy goals. A holistic approach is needed, encompassing the following areas:

- e-materialisation: the shift from products to services, dematerialisation and rematerialisation;
- Intelligent transport systems’ impact on increasing transport performance and promoting a shift from the use of the private car to public transport;
- ICT equipment’s electricity consumption in the domestic and tertiary sector;
- efficiency in electricity generation and distribution;
- ICT-supported facility for the management of energy savings;
- the use of a virtual utility to promote renewable energy and combined heat and power;
- ICT-supported systems for recovery and recycling of municipal solid waste in general and waste from electrical and electronic equipment in particular.

[17] Proposal for a Directive COM(2003) 453, establishing a framework for the setting of Eco-design requirements for Energy-Using Products and amending Council Directive 92/42/EEC.

PREFACE

The Institute for Prospective Technology Studies (IPTS) of the Joint Research Centre of the European Union commissioned a study on "The future impact of ICT on environmental sustainability" to be carried out by a consortium of institutes consisting of:

- Institute for Futures Studies and Technology Assessment (IZT),
- Swiss Federal Laboratories for Materials Testing and Research (EMPA),
- The Forum for the Future,
- International Institute for Industrial Environmental Economics at Lund University (IIIEE).

The project started in January 2003 and was completed in April 2004.

This report summarises the methodology used and the main findings of the project. Readers who are particularly interested in the methodology should read Chapter 2. The main project findings on the future impact of ICT on environmental sustainability are condensed in Chapter 3. Readers with limited time, or those who are interested in the call for action, should read the conclusions in Chapter 3.3 and the policy recommendations in Chapter 4.

More detailed information is available in the interim reports.[18]

Valuable contributions were made by the experts who took part in the scenario validation and model validation workshops, as well as those interviewed in the scenario building process and contacted via mail and telephone for policy consultations. A list of project contributors can be found in the Annexes.

Editorial support from Ms Patricia Farrer and Mr. Duncan Gilson is gratefully acknowledged.

[18] available at: http://fiste.jrc.es/Pages/mobility.htm

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

1 INTRODUCTION

At the European Council in Gothenburg (June 2001) the European Union adopted a common strategy for sustainable development as an integral part of the EU strategy for the transition to a knowledge-based economy. Information and communication technologies (ICT) play a key role in this transition.

There are signs that ICTs can have an important impact on environmental sustainability, but solid evidence is scant. There are many individual case studies on the impact of ICT on isolated aspects of sustainability, such as electricity consumption, but no coherent research on the full range of impacts has been carried out to date.

The Institute for Prospective Technological Studies (IPTS) of the European Commission's Joint Research Centre commissioned a project entitled "The future impact of ICT on environmental sustainability" to explore qualitatively and to assess quantitatively the way that ICT can influence future environmental sustainability.

The Commission reports to each Spring European Council on progress on implementing the Sustainable Development strategy. The Commission proposed a small number of headline performance indicators for this purpose to the Barcelona European Council in spring 2002. However, the selection of indicators has changed every year since.[19] For 2004, although all the structural indicators continue to be assessed by Eurostat,[20] it has been agreed to report on only two environmental indicators for the coming three years.

To define environmental sustainability the project takes as a reference the six indicators that were developed in response to the conclusions of the European Council in Gothenburg and reported to the Spring European Council in March 2002:

- greenhouse gas emissions
- energy intensity of the economy
- volume of transport to gross domestic product
- modal split of transport
- urban air quality
- municipal waste collected, landfilled and incinerated

Additionally the share of renewables in electricity consumption is considered.

ICTs in this project are defined as information technology plus telecommunications equipment and telecommunications services. Information technology refers to the combined industries of hardware for office machines, data processing equipment, data communications equipment and of software and services (EITO 2002).

The study has an explorative character as there are no similar/equivalent quantitative studies for the EU yet. Geographical coverage is the European Union member states (EU 15) plus acceding countries (AC 10). The time horizon is 2020.

[19] see: http://europa.eu.int/eur-lex/en/com/cnc/2003/com2003_0585en01.pdf

[20] see: http://europa.eu.int/comm/eurostat/Public/datashop/print-product/EN?catalogue=Eurostat&product=struct-EN&mode=download

2 METHODOLOGY

The objectives of the project are ambitious and an ambitious combination of approaches has been used in order to achieve them. The methodology can be divided into five steps. The first step was to identify the economic sectors and ICT applications with the greatest impact on the environmental indicators chosen. The second step was to establish the data on which to base the project as a whole through an extensive literature review on the environmental impacts of the selected ICT. The third step was to develop three consistent scenarios for the development of ICT and the environment dealing with future uncertainties. The fourth step was to feed the scenarios into a simulation model, realised in High-Level System dynamics. This led to estimates for the future impact of ICT on the environmental indicators and the identification of critical areas where policy interventions could have a positive effect. The fifth and final step was to develop policy recommendations, which were then reviewed and validated by a panel of experts. The main project limitations are discussed in Annex II.

2.1 Scope and data gathering (steps one and two)

ICT interacts with the environmental indicators in three ways (Forum for the Future 2002):

First order effects: The impacts and opportunities created by the physical existence of ICTs and the processes involved.

Second order effects: The impacts and opportunities created by the ongoing use and application of ICTs.

Third order effects: The impacts and opportunities created by the aggregated effects of large numbers of people using ICTs over the medium to long term.

The scope of the study covers all three kinds of effects, with an emphasis on understanding the second and third order effects (as this is where impacts are likely to be greatest). The possible alternative approach (Romm *et al.* 1999, Schneider 2001, Kuhndt *et al.* 2003), which distinguishes between growth, structural and technology effects, has not been chosen for three reasons: firstly data for macroeconomic decomposition analysis is insufficient; secondly, although there is a growth and a structural change effect, the specific contribution of ICTs is highly uncertain; and thirdly the environmental effects of ICT cannot be sufficiently understood from this perspective to derive concrete policy recommendations.

In view of the fact that ICTs are becoming increasingly pervasive, a series of scoping steps was carried out to limit the project scope to a reasonable extent, within the given time and budget restrictions.

The first scoping step investigated the impact of ICTs on combinations of economic sectors and the European Commission's headline environmental performance indicators (see Chapter 1). Highly sensitive sector-environmental indicator combinations were identified based on the assessments of the project team.

An analysis of the sector contributions to the environmental indicators and a screening of the impact of ICTs on sector/indicator-combinations led to the following choices, presented in table 2-1.

Table 2-1: Sector-environmental indicator combinations assumed to be highly sensitive to ICTs

Economic sector	**Transport/ GDP**	**Modal split**	**Energy/ GDP**	**Share of Renew-ables**	**GHG emissions**	**Urban Air Quality**	**Non-recycled MSW**
Transport	xxx	xxx/+	*		*	+	
Industry			xxx		*	+	xxx
Domestic			xxx		*		xxx
Agriculture						+	
Energy industry			xxx	xxx	*	+	
Tertiary			xxx		*		xxx

xxx: chosen sector/indicator-combination, *: covered indirectly, +: high impact, but not chosen

The "urban air quality" and "modal split of freight transport" indicators were not investigated further, as they depend very much on local and regional conditions. It would be necessary to model daily emission patterns and the transmission of airborne substances in order to assess the impact on urban air quality and this is far beyond the scope of the present project. A significant share of freight transport, 45%, travels via inland water ways and short sea shipping (EEA 2000). Assessing the impact of ICT on the modal split of freight transport would require a geographical resolution of transport flows, which again would require considerable extra resources.[21]

In the second narrowing step an extended screening of ICT applications with specific regard to the selected sector-environmental indicator combinations was carried out, based on a broad range of scientific literature. The cross-cutting character of ICT applications led us to disregard the economic sector perspective. Table 2-2 lists the main interactions between key ICT applications (first column) and the environmental indicators (first row). The most significant combinations yielded a number of selected areas for further analysis (marked 'xxx'). These selected areas, together with the indirectly covered areas (marked '*'), confine the scope of the project.

Table 2-2: Scope of the project

ICT field	**freight transport volume**	**passenger transport volume**	**modal split**	**energy consumpti on**	**Share of renew-ables**	**GHG emissions**	**non-recycled MSW**
First order effects							
ICT industry				*		*	*
ICT use				xxx (d, t)		*	xxx (d, t)
Second and third order effects							
E-business	*			xxx (d, t, i)		*	xxx (d, t)
Virtual mobility		x		xxx (d, t)		*	
Virtual goods	*			*		*	*
Waste management	*						xxx (i)
Intelligent transport systems	xxx	xxx	xxx	*		*	
Energy supply				*	xxx	*	
Facility management				xxx (d, t)		*	
Production process management	*			xxx (i)		*	*

xxx: chosen combination, *: covered indirectly; d: domestic, i: industry, t: tertiary
note: the environmental indicators were modified for practical reasons (see 2.1 for explanations)

[21] A comprehensive analysis of freight transport intensity of production and consumption has been published recently (Gleave 2003).

For each of the ten ICT fields, a fact sheet was prepared, including definition and scope, data on diffusion, data on environmental indicators, variables, and external factors. These fact sheets, which explore important factors and uncertainties, provide the basis for the scenario-building and the modelling, as well as containing useful information for the policy analysis.[22]

For comprehensive information on the scoping and data gathering process please refer to the interim reports "Identification and global description of economic sectors" and "Script".[23]

2.2 Scenarios (step three)

There are numerous methodological approaches to help understand future developments in ICTs, such as forecasting and Delphi studies. In view of the complexity and uncertainty of future developments, the scenario methodology was selected as being the most appropriate way of assessing the future impact of ICTs on environmental sustainability. Three plausible scenarios describing alternative future courses of ICT until 2020 were defined, taking the complex interactions of economic, social and ecological factors and variables into account.

The scenario development process identified the most important factors likely to influence the development and use of ICT in the future. This process was based on expert interviews and desk-based research. Out of these factors, the most uncertain ones (classified as highly unpredictable) were used to create the difference between the three scenarios: Technocracy, Government First and Stakeholder Democracy.

Table 2-3: Uncertain factors and their combination for scenario frameworks

Uncertain Factor	Technocracy Scenario	Government first Scenario	Stakeholder democracy Scenario
Technology Regulation	Incentives for innovation	Government intervention	Stakeholder approach
Attitudes to ICT	Moderate, conservative	Open and accepting	Highly accepting
ICT in business	High level of cooperation	High level of competition	Between A and B
Attitudes to the environment	Moderate / controversial	High awareness and interest	High awareness and interest

Assuming that each uncertain factor can be varied over several levels, it would easily be possible to create hundreds of scenarios even from this small set of factors. In order to avoid combinatorial explosion, scenario development looks for specific combinations of factor levels that are viewed as internally consistent. To ensure consistency and to validate assumptions, the scenarios were validated and adjusted by a panel of experts.

The scenarios were based around the identification of a selected number of variables, categorised as external, internal and output variables. The causal relationships between these variables was estimated and validated and used firstly to characterise the description of the scenarios and secondly to provide a basis for the model used in the refinement and quantification step.

The scenarios are described in detail in the interim report "Scenarios". [24]

[22] A total of 212 identified variables are listed, and the relationships between the variables explained. An additional 26 different external factors are also listed.

[23] available at: http://fiste.jrc.es/pages/mobility.htm

[24] available at: http://fiste.jrc.es/pages/mobility.htm

2.3 Refinement and Quantification (step four)

The scenarios were refined and quantified by creating and running a simulation model for the impact of ICTs on selected environmental indicators. This task also included the estimation of model parameters based on data collection and expert consultation. The modelling exercise aimed to find the most important variables for the future impact of ICT on environmental sustainability. These variables served as the basis for policy recommendations.

Figure 2-1 illustrates how the model translates the future scenarios and data on ICT and its environmental impacts into the future impact of ICT on the environmental indicators.

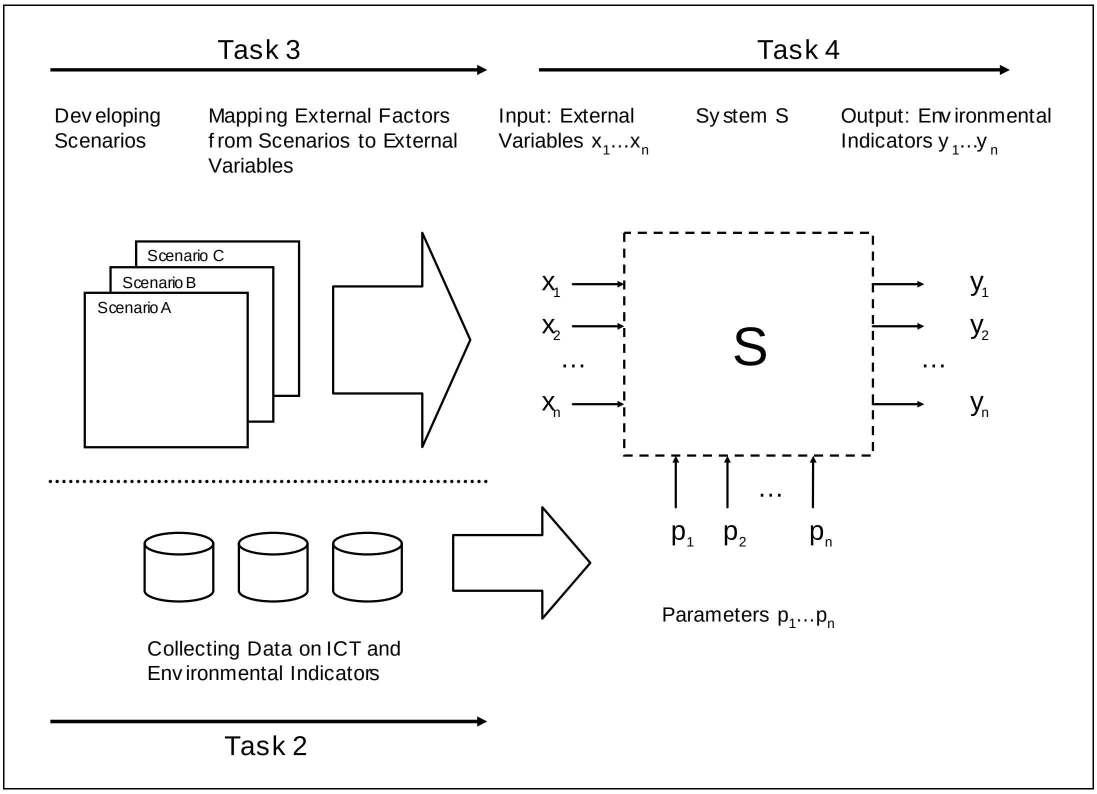

Figure 2-1: Translation of the future scenarios and data on ICTs and their environmental impacts into the future impact of ICTs on the environmental indicators

It was necessary to create a causal model of the system in order to quantify net impacts of the interacting variables. The model was implemented in High-Level System Dynamics[25] using the System-Dynamics-based simulation system *PowerSim Studio Academic 2003.*

The year 2000 is the starting point for the simulation. A lot of data is needed for initial values, and data availability and consistency for 2000 is considerably higher at present than for later years. This is due to the fact that some data is not measured on an annual basis and other data is only available with a considerable time lag.

The geographic scope of the data used for as input to the model is restricted to the EU 15 in order to perform simulation runs with complete data. Unfortunately, data availability for the ten acceding countries is not yet sufficient to extend the geographic scope of the simulation. However, the model itself is not specific to any geographic region.

[25] *High-Level System Dynamics* speeds up the modelling process by providing pre-manufactured high-level components.

Given the uncertainty of the parameters, we created sub-scenarios that exploited parameter uncertainty to maximise or minimise the environmental indicators. These are called “worst case” or “best case” sub-scenarios, respectively. For each environmental indicator all the parameter values are selected within their minimum and maximum boundaries in such a way that the indicator is minimised or maximised. The leading indicator for this optimisation is energy consumption. It turned out that all the other environmental indicators move in the same direction as energy if the best or worst case is approached for energy.[26] A third sub-scenario was created by setting each parameter to the mean of its minimum and maximum values, called the “mean” sub-scenario.

For the sake of comparison, we simulated what would happen if ICTs remained at the same level of development from 2000 to 2020, i.e. if no additional ICTs were installed and existing ICTs were used exactly as in the year 2000 for the subsequent two decades. The results of these “ICT freeze” simulations can be compared to the values using our projected future developments in ICT to 2020. The results are presented in Chapter 3.

Due to the extensiveness and complexity of the modelling methodology and process, the reader is referred to the interim report “Refinement and quantification” for a more detailed explanation.[27]

2.4 Evaluation and Recommendations (step five)

The final step of the project was to conduct a comprehensive review of the results of the entire project, setting them into the current EU policy contexts. This led to a range of detailed policy recommendations, which were then validated in expert interviews with researchers and politicians.

For more information how the policy recommendations were derived please refer to the interim report “Evaluation and recommendations”.[28]

[26] However, we cannot guarantee that the best case and worst case scenarios also represent an optimum for the other indicators.

[27] available at: http://www.jrc.es/home/actions/actions.html

[28] available at: http://www.jrc.es/home/actions/actions.html

3 THE FUTURE IMPACT OF ICTS ON ENVIRONMENTAL SUSTAINABILITY

This Chapter presents our assessment of the impacts of projected ICT development on the chosen environmental indicators, for the EU 15 in 2020. We present our results in three different ways:

- Firstly, we show how each of the environmental indicators is influenced by the ICT applications we looked at, highlighting the role of specific ICT applications where relevant.
- Secondly, we focus on the role of each ICT application within the effects on the environmental indicators in 2020.
- Thirdly, we identify eleven critical areas where ICT applications have a significant effect on the environmental indicators, and rank them in order of significance. These tie in with the recommendations for policy action suggested in Chapter 4 of this report.

We then end this Chapter by discussing two cross-cutting issues: the matter of rebound effects and the results that might be expected for the ten EU accession states.

3.1 The impact on the environmental indicators

Figure 3-1 shows two versions of the simulated development of the environmental indicators to 2020, in terms of a% increase or decrease on their values in the year 2000. The dark blue bars show the results of the simulation for our projected development of ICT. The lighter grey bars show our estimated impacts if ICT distribution and use remained as it was in 2000.

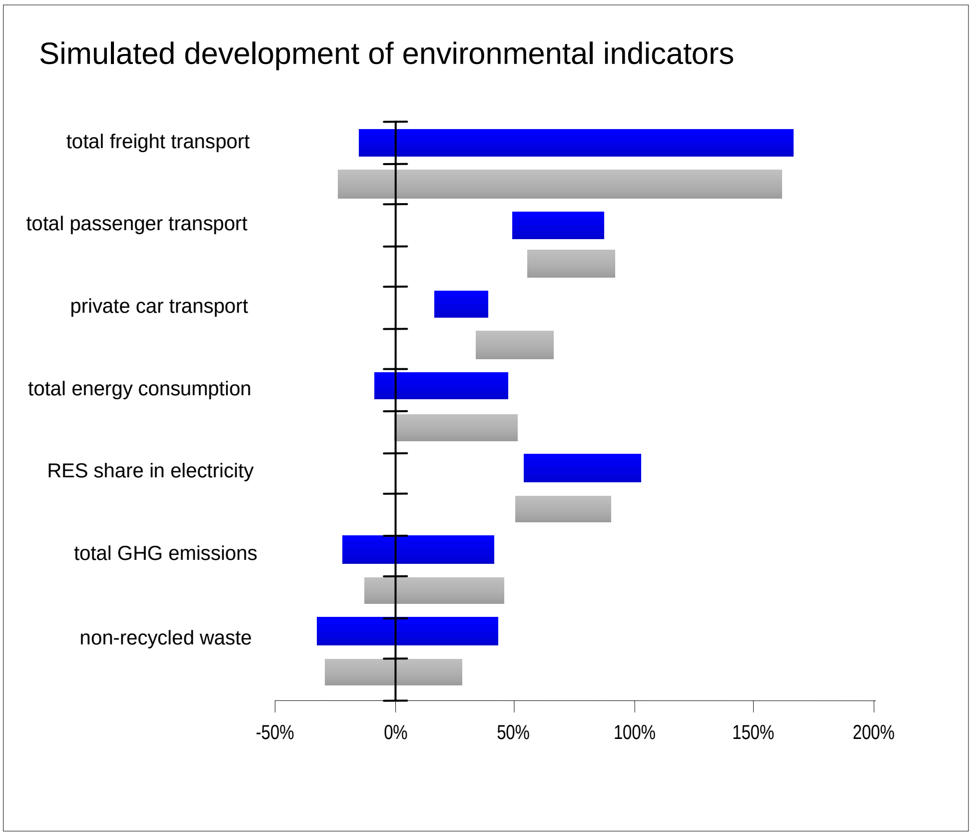

Figure 3-1 Simulated development of environmental indicators by 2020 as a percentage increase or decrease against their values in the base year (2000).

- The length of the bars indicates the uncertainty of the results that is caused both by future scenario variation and data uncertainty. There are two bars per indicator, the upper (dark blue) bar showing the results for the projected ICT development, the lower (light grey) bar showing the results for the so-called "ICT freeze" simulations (i.e. ICT applications remain on the level of 2000).

The Figure shows that, taken overall:

- Total freight transport could be higher in 2020 as a result of the projected development of ICTs;
- Total passenger transport could also be higher in 2020 as a result of the projected development of ICTs;
- Projected ICT developments could slow the increase in private car transport;
- There is a reducing effect on changes to energy consumption as a result of future ICTs;
- Future ICTs could stimulate generation of energy from renewable sources, thereby increasing its share of the energy supply;
- There is a slight downward effect on the amount of greenhouse gases emitted; and
- Future ICTs can both contribute to the growing amounts of non-recycled municipal waste and contribute to reducing non-recycled municipal waste.

As can be seen, the variation caused by ICTs is small compared to the overall uncertainty in most cases. However this small effect is an aggregation of the effects of a number of different ICT applications. If single ICT applications are looked at, much stronger impacts can be observed than that of ICTs as a whole. This phenomenon occurs as the impacts of several ICT applications partly cancel each other out. Hence, when we disaggregate the impacts of separate applications (as we do later in this Chapter) we can see that some applications have much more dramatic effects.

The range of uncertainty is mainly due to uncertainties about future trends and current data. The highest uncertainty is found for freight transport performance. This is for two reasons. Firstly, the product-to-service shift fostered by virtual goods is based on highly uncertain data, but has a high influence on the throughput of the whole economy. Secondly, freight transport is highly sensitive to fuel prices. Fuel prices might rise considerably if external costs are internalised, but whether this will happen in the EU until 2020 is highly uncertain. The first argument also applies to non-recycled municipal waste, energy consumption and consequently greenhouse gas emissions, but to a lesser extent.

The following Sections explain these findings in more detail.

3.1.1 Freight transport performance

Freight transport performance is defined as the product of freight tonnages and the distances transported (measured in tons x kilometers, tkm). Freight transport performance is closely linked to changes in the throughput of economic activity as well as in changes in industrial structure, production/distribution organisation and logistics. The particularly strong growth in road transport results from its speed and flexibility in meeting such demands, and also its ability to service out-of-town factories and shopping centres.

As shown in Figure 3-1, according to our simulations, freight transport performance could more than double on worst-case assumptions, but slightly decrease on best-case assumptions as a result of future developments in ICTs. A decoupling of freight transport and GDP depends highly on the future path followed. The high degree of uncertainty over the development of freight transport does not imply that the future impact of ICTs on this indicator is as uncertain, in particular not for specific applications, as can be seen in Figure 3-2. Figure 3-2 shows the future impact of ICTs on freight transport performance in 2020, overall and broken down into five components. The Figures refer to the percentage by which our projected ICT will influence this indicator to 2020 (as opposed to the development of the indicator if ICT diffusion and use stayed as it was in 2000).

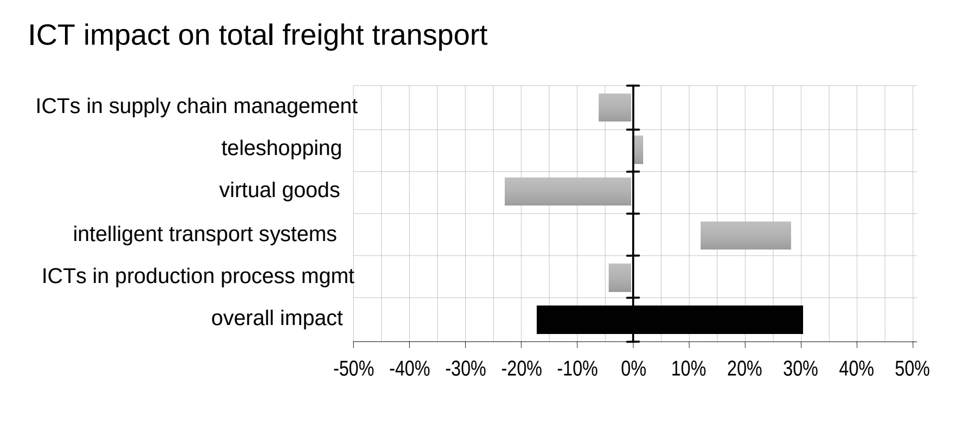

Figure 3-2: The future impact of ICTs on freight transport performance 2020.
- broken down into five components. The bars cover the full range of uncertainty of the results, including the difference between the future scenarios as well as the uncertainty of data that have not varied between the scenarios (but for best-case and worst- case optimisation). Note that there is no trivial way of deriving the overall impact (represented by the black bar at the bottom) from the grey bars, because there are interactions between the ICT effects.

The overall future impact shown at the bottom is the result of a combination of five effects we have considered in our model: ICT-based supply chain management, teleshopping (which also has an effect on passenger transport, see 3.1.2), the role of ICT as an enabler for a shift from material goods to services (virtual goods), intelligent transport systems, and ICT-based production process management. The chart shows these five components in detail.

Supply chain management, production process control and virtual goods can avoid a part of freight transport growth. Intelligent transport systems (ITS) contribute significantly to an increase in freight transport performance because they make transport faster, more flexible and cheaper, inducing additional demand. Less important are the freight transport effects of teleshopping.

Additional data and causal relationships derived from the model (see the fourth and fifth interim report for more details):

1. Under best-case assumptions, ICTs can avoid up to 17% of future freight transport, mainly as a result of the dematerialisation of the economy. A shift from products to services (virtual goods) and material efficiency gains in industrial production (production process management, PPM) lead to reduced material throughput, which in turn reduces freight transport demand. The potential is high but also highly uncertain, which to a large extent explains the large span of the overall future impact of ICTs on freight transport (-17% to + 31%).
2. Higher *materials* efficiency enabled by ICT-based supply chain management (SCM) can *avoid* a maximum of about 6% of future freight transport performance. This does not include rebound effects of higher *transport* efficiency (see next item).
3. ICT applications such as ITS, making freight transport more cost efficient (i.e. cheaper), lead to a full rebound effect and create more freight transport (and higher energy consumption, see 3.1.3).[29] Higher transport efficiency is the key ICT effect increasing freight transport in 2020. This increase is in the range of 12% to 28%.
4. ICT induced settlement dispersion accounts for longer transport distances. Induced freight transport for teleshopping at the level of 1 hour per week is in the order of magnitude of 1% -

[29] We treat the transport efficiency effect of SCM as a part of the ITS effect. This has the advantage that the materials efficiency effect of SCM can be clearly observed.

2% of total future freight transport. The parameters on which this result are based are highly uncertain, however.[30]

Conclusion:

We have to conclude that even under best-case assumptions ICTs are not the key factor that could stabilise increases in freight transport. There are other factors, in particular energy prices, which have greater influence on transport development. But in conjunction with –and guided by– other transport policy elements ICTs can be a significant factor.

The question "Are we moving in the right direction?" (EEA 2000) leads to the following call for action:

- Maximise the decreasing impact of SCM, PPC and virtual goods on freight transport performance.
- Minimise the increasing impact of ITS (intelligent transport systems) on freight transport performance.

3.1.2 Passenger transport performance and modal split

Passenger transport performance is defined as the product of number of passengers and the distance they are transported (measured in persons x kilometres, or pkm). In this report we use private car passenger transport performance, which can be compared to total passenger transport performance as an indicator for the modal split. The full details of the modal split are documented in the fourth interim report.

Passenger transport performance and the modal split are closely connected to individual time usage patterns, mobility requirements and wishes as well as transport infrastructure. The strong growth in road transport is a result of the speed and flexibility it offers in meeting mobility demand, and also its ability to reach out of town shopping centres and off-the-beaten-track leisure and holiday destinations.

As can be seen in Figure 3-1, total passenger transport performance is expected to increase by roughly 50% - 80% between 2000 and 2020. Passenger transport performance is not coupled as tightly to GDP as freight transport performance. The increase would be less without ICTs. So the overall future impact of ICTs on passenger transport will be to produce an increase.

Here again, the overall ICT impact is the net outcome of effects in opposing directions that have to be examined individually. Figure 3-3 shows the impact of our projection of developments in ICTs on passenger transport levels in 2020, compared to expected levels if ICT diffusion and use remained as in 2000.

The impact of ICTs on passenger transport performance is characterised by a number of counteracting forces, which may have stimulating, generating, reducing, or substituting effects. As a result, the aggregated impact of ICTs on passenger transport performance (black bar at the bottom of Figure 3-3) is small, ranging from 0 to 4% of future transport.

ICT has three main interactions with physical transport: (1) virtual mobility (telework, teleshopping, virtual meetings), which, according to our model, serves as a sort of "pressure relief valve" when travel time exceeds an acceptable limit; (2) applications of ICTs that make physical transport more efficient, especially ITS; and, (3) better possibilities for time utilisation in traffic due to ICT (time utilisation effect).

---

[30] It is not considered that load factors could decrease due to settlement dispersion and teleshopping, what would lead to more traffic per unit of transport performance (more driven km per tkm).

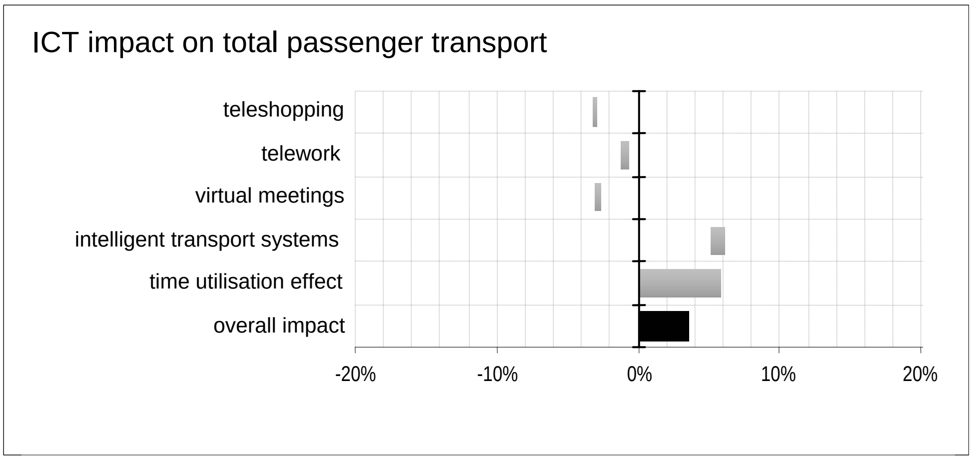

Figure 3-3: The future impact of ICTs on passenger transport performance in 2020.
- broken down into five components. The bars cover the full range of uncertainty of the results, including the difference between the future scenarios as well as the uncertainty of data that have not been varied among these scenarios (but for best-case and worst- case optimisation). Note that there is no trivial way of deriving the overall impact (represented by the black bar at the bottom) from the grey bars, because there can be significant interactions between the ICT effects.

The extent to which virtual mobility (teleshopping, telework and virtual meetings) can avoid additional passenger transport is in the range of 6% to 8% of predicted future levels. Intelligent transport systems (ITS) and the time utilisation effect of mobile ICT applications contribute significantly to passenger transport growth by creating a time rebound effect.

Additional data and causal relationships derived from the model (see the fourth and fifth interim report for more details):

1. Virtual mobility is expected to reduce demand for passenger transport, but the impact does not become significant until the general level of mobility is so high that time travelling passes a threshold of acceptability.[31] In particular, this will happen at some stage if traffic congestion increases due to continued growth of road transport. In this context, virtual modes become attractive as they save time. This will be particularly so if, as ICTs become more sophisticated, they make virtual mobility much more efficient than it is today. Home-based telework can rely on fast and uncomplicated access to data and face-to-face communication, teleshopping has the advantage of providing better market transparency, and virtual meetings may become more convenient than today as more efficient groupware and mediation systems become available. The future impact of teleworking will still be quite low, accounting for an avoidance of about 1% of future passenger traffic (all traffic modes). The impact of virtual meetings will be more significant with about 3%. The share of teleshopping is also around 3%.

2. ITS increases the time efficiency of traffic, which implies that more pkm can be achieved in the same time. Consistent with empirical evidence, the model creates a 100% time rebound effect here. That means that direct time efficiency in traffic is used to increase traffic performance. All ICT applications that make passenger transport more time efficient (i.e. increase door-to-door speed) such as ITS, create more traffic, increasing the passenger transport performance in pkm.

3. If the latter effect, time utilisation, is looked at, a similar increase can be observed. This is because time utilisation in traffic for other purposes than travelling (e.g. work) relaxes the time budget and therefore enables more traffic.

[31] This is a direct result of that the model is based on the 'constant travel time hypothesis', assuming that we are willing to accept approximately the same time per person and day on travel (see also Annex II).

Modal Split:

ICT can slow the growth of private car passenger transport, avoiding 10% to 19% of future car traffic, despite the fact that it stimulates the growth of total passenger transport (see Figure 3-1). This potentially surprising result is a consequence of two ICT effects and some basic assumptions of the model. The two effects are intelligent transport systems that substantially increase the time efficiency of public transport and the ICT time utilisation effect that increases the share of activities that can be performed during travel time, but not while driving a car.

There are physical limits to the expansion of car traffic as it needs more space per unit of transport than all other modes of traffic. In conurbations, where space is limited, the car has to compete with buses and light rail, which are much more space efficient. Consequently, if total passenger transport were to expand above a certain threshold, a resurgence in public transport might be expected. Approaching capacity limits of individual transport generally slows down traffic, whereas in collective transport, more users lead to a higher density of the service in space and time.

Users only change traffic modes when there is pressure to do so. This pressure comes from the time budget constraint, if individual mobility grows. Instead of changing to a faster mode of transport, it is also possible to better utilise the time spent in traffic. Different modes of transport offer different time utilisation potentials, and ICT development also creates new potentials. Instead of changing to a faster mode of transport, time pressure can also motivate time utilisation in public transport or the use of virtual modes of mobility.

The future impact of ICTs on the modal split in passenger transport is expected to be considerable. The main impacts are likely to come from the ways in which ITS and ICTs enable more effective use of time spent travelling. ITS could make public transport more efficient and attractive and therefore stimulate a shift from private car to public transport.[32] The ITS efficiency potential is assumed to be slightly higher for public transport than for private cars, because there are many unexploited efficiency potentials in the areas of customer information, flexible demand/supply coordination, infrastructure utilisation, and electronic payments. The same can be said about the time utilisation effect, which is higher for public transport. By contributing more to the overall time efficiency of public transport than to that of private car transport, ITS thus avoids 3% to 9% of future private car traffic. It should be noted that ITS would create about 6% of the overall future passenger transport demand.

Conclusion:

The question “Are we moving in the right direction?” (EEA 2000) leads to the following call for action:

- maximise the positive impact of virtual mobility
- minimise the impact of intelligent transport systems on total passenger transport performance
- maximise the positive impact of intelligent transport systems on the modal split while limiting the growth of total passenger transport performance
- maximise the time utilisation possibilities in public transport while limiting the growth of total passenger transport performance.

3.1.3 Energy Consumption and the share of renewable energy sources in electricity generation

Total energy consumption is closely linked to changes in the level of economic activity as well as changes in transport patterns and energy consumption by buildings. The marked growth in the share of renewable energy sources in electricity generation is mainly being driven by policy incentives.

[32] The following is considered public transport: bus and coach, tram and metro, train.

As shown in Figure 3-1, total future energy consumption could increase by 37% on worst-case assumptions, but decrease by 17% on best-case assumptions. Without our projected development of ICTs, both the best- and worst-case values would be higher, so ICTs have a downward effect on total future energy consumption.

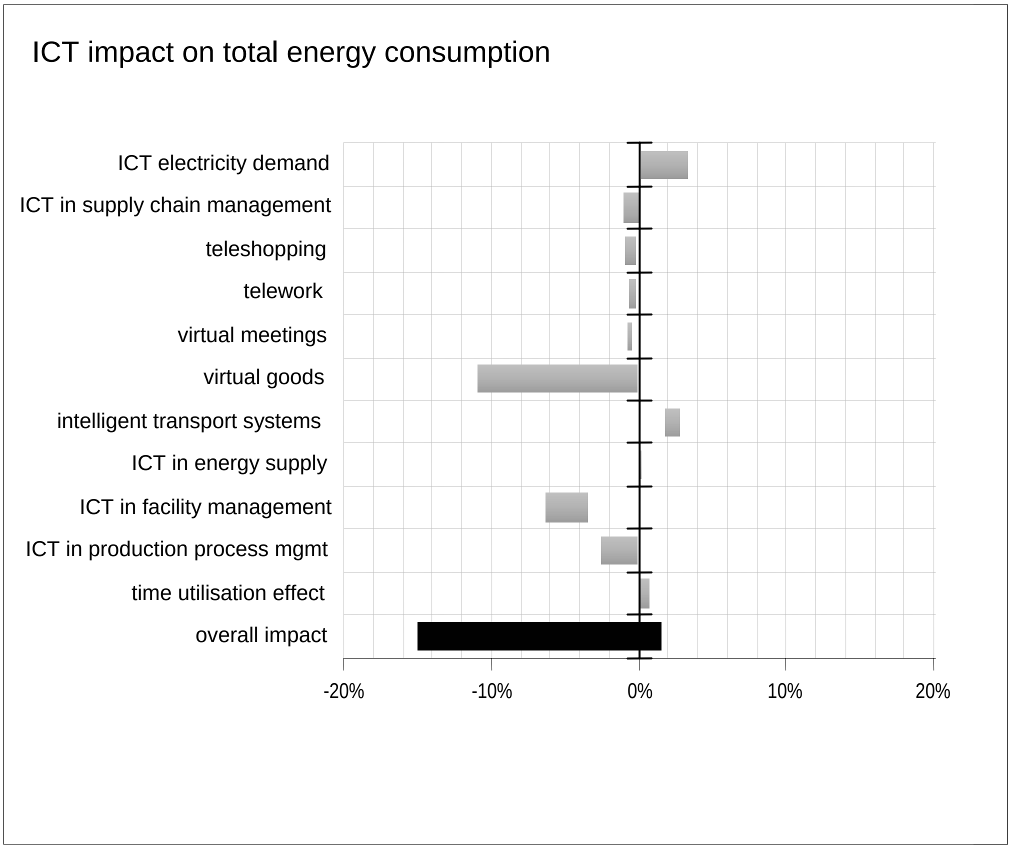

Figure 3-4: The future impact of ICTs on total energy consumption 2020.
- broken down into 11 components. The bars cover the full range of uncertainty of the results, including the difference between the future scenarios as well as the uncertainty of data left unchanged in all these scenarios (except for best-case and worst- case optimisation). Note that there is no trivial way of deriving the overall impact (represented by the black bar at the bottom) from the grey bars, because there can be significant interactions between the ICT effects.

The overall effect of ICTs on energy consumption is the net result of numerous effects working both directions and partially cancelling each other out when aggregated, as shown in Figure 3-4. If ICTs are to enable a decrease in absolute energy consumption despite strong GDP growth and high employment, it is necessary to find a way of promoting the environmentally positive impacts of ICTs, while inhibiting the negative ones. There is no simple overall strategy for minimising energy usage by means of ICTs.

ICTs' electricity demand in the use phase and intelligent transport systems significantly increase total future energy consumption, the latter due to rebound effects in transport demand. ICT-based production process control can avoid a part of total future energy consumption under worst-case conditions. ICT-based facility management and virtual goods are likely to limit total energy demand in 2020 over a broader range. Smaller impacts, which together can add up to a considerable impact potential, are caused by virtual mobility, ICT-based supply chain management and teleshopping.

ICTs can enable decentralised electricity generation, thus favouring the use of renewable energies (RES) and combined heat and power generation (CHP). The future impact of ICTs on RES is estimated to be an increase in their share of the total electricity supply of between 2 and 7%. On best-case assumptions, 9.7% of total energy consumption would be covered by electricity from RES in 2020 (9.3% without ICT). Uses of RES other than for power generation are not covered by the study.

Additional data and causal relationships derived from the model (see the fourth and fifth interim report for more details):

1. The impact of ICTs on the total energy used for *freight transport* in particular can be either positive or negative, ranging from -17% to +31% in 2020 depending on whether best or worst case conditions obtain. ICT slows down the growth of energy used for *passenger transport* under both best and worst case conditions, although it stimulates the growth of passenger transport performance (pkm). In other words, ICTs increase future passenger transport performance *and* the energy efficiency of passenger transport at the same time, resulting in considerable avoidance of future passenger transport energy, in the range of 6% to 12%. However, both passenger transport and the energy used for it are higher in 2020 than in 2000. This is explained by changes in the modal split (see 3.1.2) as well as higher energy efficiency of road traffic achievable with ITS. Thus ITS produces a rebound effect in terms of traffic (for example, it is unlikely to solve congestion problems), but not in terms of the energy consumed by traffic, at least for passenger transport.
2. in 2020, the share of ICT in electricity consumption could vary between 5% and 23% in the domestic and tertiary sector. The high degree of uncertainty stems from the trade-off between two main trends. While the number of ICT products will increase, as will their usage, at the same time they are likely to become more energy efficient. The maximum expected increase in ICT electricity consumption would make ICT responsible for about 3% of *total* energy consumption in 2020.
3. ICT supports the exploitation of “soft” energy efficiency potentials, including improved heat management in buildings by means of automated systems or by information-based changes in user behaviour. Potentially large energy savings can be made thanks to efficiency gains, as facility heating represents a large share (39% of the initial value) of total energy consumption. The calculated savings range from 3.5% to 6.3% of total energy consumption in 2020.
4. Production and process management has a large energy efficiency potential (assumed at 66%), but the rebound effect, determined by the energy price and the demand elasticity, will counterbalance a huge part of the effect. ICT-based process management has an impact on total future energy consumption, ranging from neutral to -2.5%, depending mainly on the size of the rebound effect.[33]
5. ICTs reduce future industrial energy use by 0% to 37% (0% to –11% of total future energy consumption), depending mainly on how the *energy saving potential of replacing products by services (virtual goods)* is estimated. Opinions on this parameter diverge by a factor of 10. The best case sub-scenario assumes that 50% of energy used for the industrial production of goods could be saved in 2020, because customers increasingly pay to use (rather than own) products, and that this is made possible largely by ICTs[34]. The worst case assumes a product-to-service shift energy saving potential of only 5%. In either case, the dematerialisation of media (which can be viewed as a special case) has an effect below 0.1%. A key variable which influences the product-to-service shift in the model is the so-called pervasive computing indicator.[35]

[33] Energy consumption in the ICT industry is not separated from that of other industries in this project. The *production* phase of ICTs is not considered to be significantly different from average industrial production with respect to the environmental indicators (see Annex II). The current contributions to primary energy demand (and CO_2-emissions) are estimated to be of the magnitude of 0.5 – 2%. Future development of energy consumption will be determined by counteracting trends, on the one hand increased demand for ICT and on the other hand ongoing miniaturisation of ICT and continued shift of production to countries outside the EU. The net effect is unknown.

[34] ICT is assumed to be 75% responsible for this.

[35] This indicator is combined of several internal model variables describing the take-up of highly dematerialised, mobile, energy-efficient ICT, in particular head-mounted displays. It is assumed that the diffusion of pervasive computing technologies facilitates the exploitation of the product-to-service-shift potential by reducing transaction costs. For this

6. ICT-based SCM (supply chain management) could save 1.1% of total energy consumption under optimistic assumptions in 2020.[36]
7. Electricity used for all forms of virtual mobility (telework, teleshopping, virtual meetings) will be in the range of 0.04 to 0.05% of total energy consumption. The limiting future impact of each form of virtual mobility on total energy consumption is clearly below 1%. The aggregate effect of all three forms of virtual mobility is between 1% and 2.4%. The effect of saving (heated) office and store space due to telework and teleshopping, which is accounted for here, is in the order of magnitude of 0.1% of total future energy consumption. This is a factor of 10-100 below the estimated impact of intelligent heating systems and home automation.
8. It is assumed that ICT is an enabling factor for RES and CHP to a certain degree, because the RES and CHP potentials are partly based on a decentralisation of power generation, which requires ICT-based management of distributed systems. The impact of ICT on energy supply mainly makes it more efficient in terms of allowing more (small) CHP plants to connect to the grid, increasing the share of CHP in electricity production by 13%. The impact of ICT on the future *share* of renewable energy sources (RES) in electricity production ranges from an increase of 2% to 7%. Other RES applications (hydrogen-propelled cars, RES in domestic heating and so on) were not included because of their limited affinity to ICT. The calculated effect on total energy consumption in 2020 is near 0 (a 0.0% to 0.17% *increase*), because it is assumed that energy demand will respond to higher energy efficiency with a strong rebound effect.

The overall impact of ICTs on future energy consumption will be the net outcome of *decreasing energy use* both in domestic and tertiary sector non-electric heating and industry, and *increasing energy use* in both domestic and tertiary electricity consumption and transport. Increasing electricity demand in the domestic and tertiary sector can pay off in terms of total energy. This is the case as far as it is a consequence of a structural change effect, reducing industrial energy use at the cost of increasing energy consumption in the tertiary (service) sector. It follows that energy savings arising from the use of ICTs should not simply be offset against the electricity energy demand of ICTs sector by sector as the overall structural change effect has to be taken into account.

Conclusion:

The question “Are we moving in the right direction?” (EEA 2000) leads to the following call for action:

- maximise positive (energy-saving) impact of ICT-based soft energy efficiency measures in buildings and production process management
- maximise positive impact of a product-to-service shift, leading to a higher share of virtual goods in consumption
- maximise positive impacts of SCM (supply chain management) and virtual mobility
- maximise ICT-enabled decentralised electricity generation by CHP and renewables
- minimise the negative direct impact of ICTs electricity use, without hindering the product-to-service shift
- minimise the increasing impact of ICTs on total freight and passenger transport demand
- maximise positive impact of ITS on energy efficiency and modal split of passenger transport while limiting total passenger transport growth.

reason, the pervasive computing indicator can increase the speed at which the product-to-service shift takes place (see also Annex II).

[36] It should be noted that the energy effect of e-business is not only that of teleshopping and supply chain management, but also effects on customer relationship, leading to a better matching of supply and demand. The total energy effect of these implications is likely to be higher than that of teleshopping and SCM. However, the model is limited to teleshopping and SCM and does not take other effects into account.

- maximise positive impact of time utilisation in public transport on modal split while limiting total passenger transport growth.

3.1.4 Greenhouse gas emissions

Total greenhouse gas emissions (GHG) consist of GHGs from electricity production (power generation), from non-electric heating in the domestic and service sectors, from energy use in the industrial sector, from transport and from waste incineration. All emissions are calculated based on cumulative emission factors from a Life Cycle Assessment database (Ecoinvent 2003).[37] Emissions of non-CO_2 GHGs (CH_4, N_2O, SF_6, HFCs, HCFCs) are converted to CO_2-equivalents according to their relative global warming potential.

As shown in Figure 3-1, total future GHG emissions behave similarly to total future energy consumption. Emissions could increase by 32% under worst-case assumptions, but decrease by 29% under best-case assumptions. Without ICTs, both the best- and the worst-case values would be higher, so the overall impact of ICTs is to reduce future GHG emissions.

[37] *Cumulative emissions* means that the full supply chain of energy is included, which yields emission values that are generally higher than the direct emissions. However, the life cycle of the energy supply *infrastructure* (e.g. construction of refineries and power plants) is excluded from the cumulative emissions.

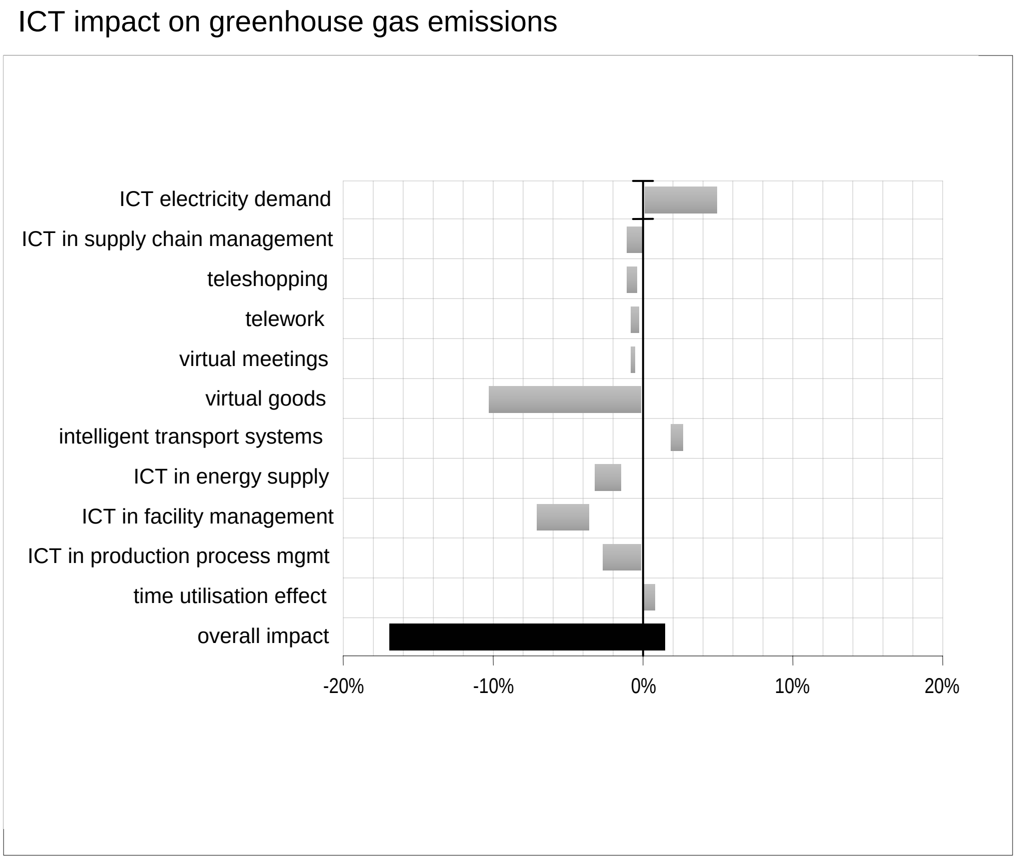

Figure 3-5: The Future impact of ICT on total cumulative greenhouse gas emissions 2020.
- broken down in 11 components. The bars cover the full range of uncertainty of the results, including the difference between the future scenarios as well as the uncertainty of data that have not been varied among these scenarios (but for best-case and worst- case optimisation). Note that there is no trivial way of deriving the overall impact (represented by the black bar at the bottom) from the grey bars, because there can be significant interactions between the ICT effects.

Under best case conditions ICTs can contribute significantly to reducing total future GHG emissions. The impact of ICTs on overall GHG emissions is closely linked to energy consumption, as only energy-related GHG emissions are considered. A change in GHG emissions out of proportion to energy consumption could occur due to a change in the electricity mix (e.g. the share of nuclear power and RES). Another relevant factor influencing the overall GHG intensity is the modal split of passenger transport.

Future GHG emissions would be higher without ICTs. Specifically, without ICT-based facility management they are predicted to be 3.5% to 7% higher; without ICT-based production process management up to 2.5% higher; and without an ICT-based product-to-service shift (virtual goods) between 0% and 10% higher. As these aspects show similar behaviour to total energy consumption, in the discussion that follows we focus on changes in the electricity mix and in the modal split of passenger transport, which are two important variables influencing overall GHG intensity.

Additional data and causal relationships derived from the model (see the fourth and fifth interim report for more details):

1. Improved energy supply efficiency and changes in the electricity mix are two important factors influencing overall GHG emissions. A corresponding decrease in future GHG emissions will result from the 2% to 7% ICT-induced increase in RES, as well as the fact that ICTs will promote CHP growth (given that improved energy efficiency in CHP leads to less fossil fuel use). The overall GHG impact of ICTs on the electricity supply is 1.5% to 3.1% of

the total GHG reduction in 2020. The effects of ICTs on other energy supply systems are not covered. Rebound effects of higher supply efficiency, which stimulates demand, are included.

2. The contribution of passenger transport emissions decreases mainly because the growth of private car transport slows down and the modal split shifts towards a higher share of public transport (see 3.1.2), which consumes less energy per pkm on average. The effect on GHG emissions is amplified by the change of the electricity mix, because a significant part of public transport is based on electricity.

ICT reduces the GHG emissions *per MJ electricity* by 2% to 6% and *per pkm* by 7% to 12%. It is important to note that a decrease in GHG emissions per MJ or per pkm does not imply that absolute GHG emissions caused by electricity generation or passenger transport, respectively, decrease; they can still increase due to growing demand that compensates for the lower emission factors.

Conclusion:

The question "Are we moving in the right direction?" (EEA 2000) leads to the following call for action:

- the same measures as for reducing total energy consumption (see 3.1.4 above), with top priority given to measures targeting the modal split and electricity mix.

3.1.5 Non-recycled municipal solid waste

Non-recycled municipal solid waste (MSW) is the residual fraction burnt in incinerators or placed in landfill. Municipal solid waste is generated by households, commercial activities and other sources whose activities are similar to those of households. The amount of MSW is closely connected to the material throughput of the economy as well as to changes in household consumption patterns. The fraction that is not recycled depends on the technical, economic, legal and behavioural conditions for recycling.

As shown in Figure 3-1, future non-recycled MSW could increase by 33% on worst-case assumptions or decrease by 40% under best-case assumptions. In either case, MSW and GDP would decouple. Without the projected developments in ICT, the upper value would be lower, so ICT adds significantly to non-recycled MSW if no measures are found to limit the growth of ICT waste.

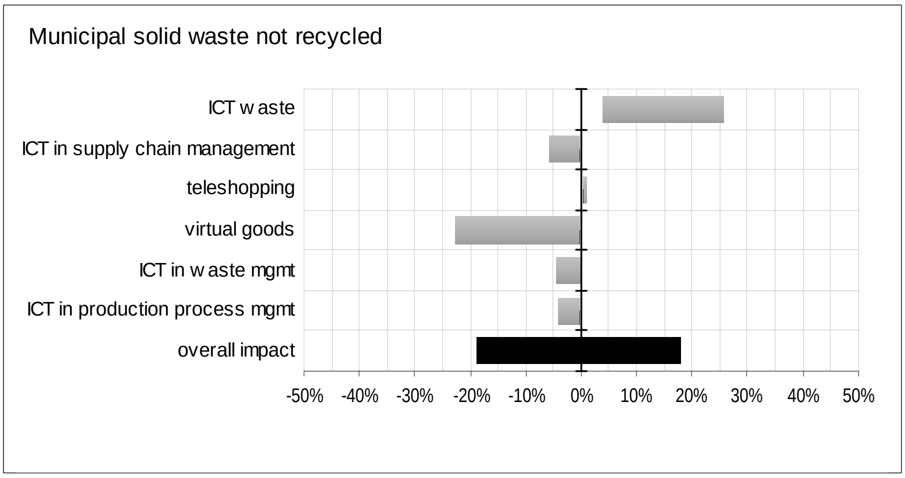

Figure 3-6: The Future impact of ICT on non-recycled municipal solid waste in 2020.
- *broken down in five components. The bars cover the full range of uncertainty of the results, including the difference between the future scenarios as well as the uncertainty of data that have not been varied between these scenarios (but for best-case and worst- case optimisation). Note that there is no trivial way of deriving the overall impact (represented by the black bar at the bottom) from the grey bars, because there can be significant interactions between the ICT effects.*

ICT waste is the only environmentally negative effect of ICT on this indicator, as Figure 3-6 shows.

Additional data and causal relationships derived from the model (see the fourth and fifth interim report for more details):

1. MSW in total grows slower than GDP as a consequence of the decrease in the material intensity of the economy. The decrease in material intensity is mainly being driven by the product-to-service shift and a more efficient use of materials by production and supply chain management (SCM). On best-case assumptions, the product-to-service shift could result in a reduction of as much as 23% in non-recycled MSW volumes.[38] However, there is a high degree of uncertainty surrounding the extent of this product-to-service shift.

2. Additional packaging waste from teleshopping is projected to reach below 1% of non-recycled MSW.

3. ICT waste, like waste from electrical and electronic equipment in general, is expected to increase at a rate about three times faster than the average for municipal waste. The uncertainty over ICT-waste originates from limited knowledge about how far some types of ICT devices will dematerialise (e.g. how far head-mounted displays will replace monitors) and about the future average useful life of ICT devices. The simulations accounted for high potential ICT waste flows, but still resulted in a total MSW growth rate *lower* than GDP in all scenarios. However, the ICT fraction of MSW deserves special attention because of its toxic nature. The contribution of ICT waste to future Non-recycled MSW ranges between 4% and 26% in 2020, depending mainly on the future diffusion rate of ICTs, their future useful life expectancy, the recycling of ICT waste and other framework conditions.

4. The impact of ICT-based waste management on the amount of Non-recycled MSW is based on the idea that MSW recycling is facilitated by more intelligent technologies. This effect could prevent a maximum of 4.5% of future non-recycled MSW.

Conclusion:

The question "Are we moving in the right direction?" (EEA 2000) leads to the following call for action:

- maximise the positive impact of ICT-based supply chain management, ICT-based production process control and the role of ICT in enabling a product-to-service shift (virtual goods).
- minimise negative direct impact of ICT waste without hindering the contribution of pervasive computing to a product-to-service shift.
- maximise positive impact of ICT-based recycling
- minimise negative waste impacts of teleshopping.

3.2 The impact of different ICT applications

We have looked so far at the impact of all ICT studied on single environmental indicators, but the call for action to optimise single indicators shows some conflicting strategies. A closer analysis of the results reveals some interesting policy implications.

To identify conflicting goals and spillovers we map the future impact of ICT on the seven environmental indicators in the Table below, indicating if EU policies are counteracted or supported by ICTs.

[38] The impact of the product-to-service shift on MSW was distinguished from other ICT effects in a special simulation run. The ICT impact ranges from – 27% to + 6%. The increase value can be explained by high rematerialisation rates.

Table 3-1: The future impact of ICT on environmental sustainability indicators in 2020

	Total freight transport	**Total passenger transport**	**Private car transport**	**Total energy consump.**	**Share of renewable electricity**	**Green-house gas emissions**	**Non-recycled municipal solid waste**
Potential impact to:	reduce tkm	reduce pkm	reduce%	reduce TWh	increase%	reduce CO_2-eq. Mt	reduce Mt
Primary effects of ICTs	-	-	-	☹	-	☹	☹
ICTs in supply chain mgmt.	☺	-	-	☺	-	☺	☺
Tele-shopping	☹	☺	😐	😐	-	☺	😐
Telework & virtual meetings	-	☺	☺	☺	-	☺	-
Virtual goods	☺		-	☺	-	☺	☺
ICTs in waste mgmt.	-		-	-	-	-	☺
Intelligent transport systems	☹	☹	☺	☹	-	☹	-
ICTs in energy supply	-	-	-	😐	☺	☺	-
ICTs in facility mgmt.	-	-	-	☺	-	☺	-
ICTs in production process mgmt.	☺	-	-	☺	-	☺	☺
Mobile ICTs time utilisation effect	-	☹	☺	😐	-	😐	-

☹: The projected impact on the environmental indicator is environmentally unfavourable

☺: The projected impact on the environmental indicator is environmentally beneficial

😐: The projected impact on the environmental indicator is small or environmentally neutral (the effect is less than $\pm$1%)

- : The combination was not projected

If we have a look at the different ICT applications we can conclude that:

1. The direct impact of ICT use is negative by definition as a first order effect of ICTs. Indicators affected negatively are electricity consumption, greenhouse gas emissions and non-recycled municipal solid waste.

2. Supply chain management is estimated to have a neutral or limiting impact on future freight transport performance, on non-recycled municipal solid waste, and on energy consumption and greenhouse gas emissions. No conflicting tendencies are noticeable, but rebound effects have to be considered (see 3.4.1). Production process management and virtual goods show similar impacts. However the high data uncertainty of the product-to-service shift has to be taken into account. The effect of pervasive computing as an enabler of the product-to-service shift might be overestimated.

3. The picture for teleshopping is far more heterogeneous. Teleshopping is likely to reduce growth of passenger transport performance, to increase freight transport performance and increase the quantity of non-recycled municipal solid waste. All these future impacts are relatively small, in the magnitude of 1%. Teleshopping is both a special type of e-business and a mode of virtual mobility.

4. The virtual mobility characteristic of teleshopping shows the same impact patterns as telework and virtual meetings. They have a potential to limit the growth of future passenger transport performance and hence also energy consumption and greenhouse gas emissions.

5. ICT-based waste management limits the growth of future non-recycled municipal solid waste, without being assumed to conflict with other goals significantly, as the impact of longer end-of-life distances is considered to be negligible.

6. The impact of intelligent transport systems is to reduce the performance of freight and passenger transport in 2020, while stimulating the share of transport accounted for by the private car. As a consequence future energy consumption and related greenhouse gas emissions are still increasing. The negative impacts of ITS (integrated transport systems) can be explained by the assumption of strong rebound effects (see 3.4.1)

7. Energy supply efficiency improvements supported by ICT, for example an increase in the share of electricity production from renewable sources, lead to a limitation of total future energy consumption and greenhouse gas emissions. However it should be mentioned that infrastructure has not been included in our calculations. This effect might offset the benefits of ICTs. The same applies to the rebound effect (see 3.4.1).

8. Facility management supported by ICTs has considerable potential to reduce future energy consumption and therefore avoid greenhouse gas emissions. No conflicting tendencies are noticeable, but rebound effects have to be considered (see 3.4.1).

9. The time utilisation effect addresses the possibility for multi-tasking in passenger transport, especially to work with ICTs. On the one hand it supports a positive shift to public transport, but on the other hand it provides incentives to expand passenger transport performance.

3.3 Areas of impact ranked by significance

Below we highlight eleven critical areas where ICTs applications have a significant effect on the chosen environmental indicators, and rank them in order of significance. These eleven areas are a point of reference for the recommendations that we make in Section four. We have also assessed the uncertainty that is associated with the impacts. Uncertain impacts are listed in the rank order as if they were certain (i.e. as potential impacts), but the uncertainty is indicated.

1. ICTs have a large potential impact on the rational use of heating energy. Although it is highly uncertain under what conditions “soft” measures supported by ICT (such as intelligent heating systems) really operate effectively and satisfactorily for users, this issue deserves consideration because of the high potential that is addressed: Heating accounts for roughly 30% of total energy consumption, and the most effective “hard” measures apply only to the small annual share of

buildings that are renovated or newly built. “Soft” measures, even if they are less effective, have the advantage that they could in principle be applied everywhere, i.e. in every building. The use of ICT applications for heat management should therefore be a priority for future research and development.

2. The activity level of modern economies is still coupled to a rapid throughput of material extending from resource extraction, to products, and to waste. The more the economy grows, the higher the activity level, the faster the physical mass flow through the system. Many environmental indicators are coupled to the mass flow, most directly freight transport and waste. Although there are widely diverging opinions concerning the ICT-based product-to-service shift and its possible energy saving and dematerialisation effects, it is again the high potential for change that makes this issue important. In our model, almost every output turned out to be directly or indirectly linked to the product-to-service shift variables. These included freight transport performance, waste and the energy used by manufacturing industry. The high degree of sensitivity of our model to the product-to-service parameters may reflect an important aspect of reality, if our model is not too inaccurate. So it is worth investigating if networks and new types of ICT applications (such as pervasive computing) can play an enabling role for new types of service.

3. All ICT applications that make passenger transport more time efficient (i.e. increase door-to-door speed) will immediately create more traffic and possibly more energy consumption. There is no empirical evidence that anything other than a 100% time rebound effect can be assumed here. If applied to public transport, intelligent transport systems also have the power to increase this type of traffic, which could have an environmental pay off in the form of greater energy efficiency. However, the effect of ICT applications *accelerating* passenger transport is extremely unlikely to be a *decrease* in passenger transport demand. Induced transport demand has severe environmental consequences in terms of energy use and greenhouse gas emissions, although ICTs contribute to lowering the energy and GHG intensity of passenger transport.

4. Mobile work enabled or supported by pervasive computing and other new forms of ICT applications can have a significant effect on passenger transport. Technologies of this kind have the potential to increase the portion of the time people spend in traffic that they can use productively. Time utilisation can create more transport demand and influence the modal split. The effects of ICT on personal time management and time utilisation are underestimated indirect impacts of ICT on the environment.

5. All ICT applications that make freight transport more cost efficient (i.e. cheaper) will immediately create more freight transport and more energy consumption. There is no empirical evidence for assuming anything other than a strong price rebound effect here. By making transport more cost efficient, ICT can create freight transport demand, which has severe environmental effects.

6. ICT can contribute to material savings in industry. There is a considerable potential to save materials by more intelligent process control. The size of the rebound effect is uncertain.

7. ICT generates waste electronic material (e-waste), which can be problematic for disposal or recycling. The most effective ways to reduce e-waste streams are: to replace heavy monitors by head-mounted displays and to counteract the high churn rates of ICT. There would be a significant ecological effect (not only on waste) if the replacement of functioning ICT products by newer ones could be slowed down, or at least not further accelerated. The miniaturisation of ICT reduces the amount of waste; even if this is counterbalanced by a higher number of devices being used in the future, the e-waste stream could be stabilised if the useful lifetime of equipment were extended.

8. Although it is uncertain how much ICT can contribute to decentralised electricity production from renewable sources or small Combined Heat and Power (CHP) devices by making it possible to manage distributed power plants, this issue deserves mentioning because of its potential to avoid a significant part of the greenhouse gas emissions caused by power generation.

9. Teleshopping can create additional packaging waste and additional freight transport, which may counterbalance the passenger transport saved.

10. Virtual meetings (e.g. videoconferencing) can avoid the need for passenger transport, which pays off for long distances and is much more effective than telework in environmental terms. However, virtual mobility does not reduce physical mobility; Rather, physical mobility coming into conflict with time and infrastructure constraints creates demand for virtual mobility.
11. ICT consumes electrical energy and could dramatically increase its share in the near future. However, this effect is not the most significant compared with the others mentioned in this list (positive or negative). If the electricity consumption of ICT is to be reduced, the best way is to promote the trend towards mobile devices and ad hoc infrastructures that need as few stationary devices connected to the mains as possible.

3.4 Cross-cutting issues

There are two cross-cutting issues that affect the results as described above. The first is the rebound effect and the second the question of how our results change if the ten states acceding to the EU in May 2004 are included.

3.4.1 The rebound effect

The efficiency improvements (time, fuel, energy) made possible through technological improvements are counteracted by increasing demand (growing consumption volumes) for energy, products, services, passenger and freight transport. In the model this is managed by determining *elasticities*, quantified by assigned numbers, for example by determining what proportion of savings are counteracted by increased consumption, or vice versa. For instance, a price elasticity value of -0.5 means that demand will decrease by 10% if prices increase by 20%, or that the demand will increase by 10% if prices are 20% lower. Another rebound effect is the *rematerialisation* effect, which could be exemplified by virtual information products such as information accessed via the Internet being printed out or burned on a CD. For a list of all elasticity and rematerialisation values assigned for the consumption of commodities, see Annex V.

Rebound effects need to be acknowledged and addressed by all policies which aim at increased efficiency, especially ICT policies.

3.4.2 Accession countries

Our simulation of the impact of ICT on the environmental indicators has been limited to EU 15, because of a lack of suitable data for the 10 accession countries.[39] Their economies show some particular characteristics, which will also have implications for the impact of ICT on the environmental indicators. Expected high GDP growth, inducing increased consumption of commodities (including ICT products), and very strong transport growth, are the environmental downside trends in the new Member States. Improved material and energy efficiency in industry, including the energy industry, a shift to less polluting energy sources and more energy efficient and less polluting vehicles, are important environmentally positive trends. ICTs will play a role for the acceding countries in all of these areas, and the role is likely to be more prominent than for EU 15, as a dramatic change in the economic structures is expected as a result of accession.

To some extent the causal mechanisms of our model can be applied to the accession countries as well. However, the following assessments are rather tentative.

[39] The ten acceding countries are: Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Czech Republic, Slovakia, and Slovenia. Bulgaria, Romania, and Turkey might join in the future.

Freight transport performance

The basic causal relationships embedded in the model will also hold for EU 25: increasing transport distances as GDP grows, rebound effects compensating for efficiency gains that reduce transport costs. The benefits of dematerialisation are counteracted by expansion in geographic space.

Passenger transport performance and modal split

The basic causal relationships could not be reproduced for the EU 25, because we assumed that in the EU 15 car traffic is fairly close to saturation point and that infrastructure capacities will not be expanded to allow a further doubling of car traffic. This is unlikely to hold for the new Members States. Hence, the impact of virtual mobility in some new Members States might be smaller than in the EU 15. If included in a simulation this would possibly lead to a higher share of private car traffic and higher energy consumption per pkm at the end of the period.

Energy consumption and the share of renewables:

The basic causal relationships will also apply here: energy intensity can be reduced by investments in heat insulation in the domestic and tertiary sector, which is especially effective in the new Members States because of the large share of the domestic and tertiary sector in energy consumption (48.1%). Industry will reduce energy demand if energy is not too cheap. A shift away from physical products towards services could save a lot of energy but it is difficult to quantify exactly how much. Despite the potential for savings, total energy demand could grow rapidly if freight and passenger transport grow faster than GDP, which is likely to happen if there are no reasonable limits to transport growth. The new Members States are still heavily reliant on the availability of cheap, but polluting energy sources. ICT-induced integration of renewables and CHP therefore has considerable potential, but has to compete with other fuels.

GHG emissions

Huge potential GHG emissions reductions could be made in the accession countries. ICTs can contribute to achieving this potential, especially in the energy industry. If no attempt is made to change the electricity mix and the modal split to encourage low GHG emissions per unit of energy used, the GHG trends for the EU 15 discussed above could look worse in the EU 25, even under the assumption that energy efficiency potentials are well exploited.

Non-recycled municipal solid waste

In the case of this indicator, the assumptions in which our model is based are not specific to the EU 15. Hence, GDP growth and rebound effects will counteract efficiency gains by virtual goods, supply chain management and production process control. E-waste will be a small but fast growing fraction as well. The specific recycling processes, however, are beyond the scope of the investigation.

The approximate nature of these arguments suggests that an improved data basis should be a focus for any extended impact assessment.

4 RECOMMENDATIONS

The analysis of the impact of future ICT development on the chosen environmental indicators, and the identification of critical areas in the relationship between specific ICT applications and the indicators, suggests a wide range of policy recommendations. The recommendations we outline in this Section are based on the project findings and have been put through an intensive process of consultation and validation with experts in the field (see Annex III). They suggest measures that if taken could maximise the environmentally positive contribution of future ICT to the environmental indicators.

The recommendations are structured according to the most relevant policy areas, and not according to environmental importance. However, we refer back to the eleven critical areas identified in Section 3.3 as these provide the basis for identification of the recommendations.

The areas of ICT industry and production process control are covered here by a section on industry, and a section on transport covers the passenger and freight transport areas. Where applicable, recommendations are repeated in more than one area. The recommendations are primarily directed towards policymakers at the European and national levels, but also have relevance for corporate leaders and academics.

Recommendations that are relevant across the different policy areas are presented separately.

4.1 Industry

These recommendations primarily target the ICT industry, but apply also to other sectors of industry. The first four recommendations are aimed at promoting reduced resource consumption and waste generation through e-materialisation, miniaturisation, and a reduction in churn rate. Issues specific to waste reduction are discussed in Section 4.7. The recommendations for industry relate in particular to the critical areas ranked two and six in Section 3.3.

ICTs' influence on the potential material and energy savings in production processes, leads to the following recommendations:

- Promote dissemination of information on cost-effective, energy- and material-optimising ICT solutions for industry, placing special emphasis on reaching SMEs.
- Combine the promotion of efficiency improvements in industry with the stimulation of innovation, placing particular focus on the shift towards functional thinking and PSS.

The existing and developing policy framework (e.g. IPP and EuP) should be adequate to address these issues and support implementation:

- Direct attention towards the product design stage, and strengthen industrial designers' capacity to take environmental considerations into account. This could be achieved by means of demonstration projects to promote eco-design in companies, expanding eco-design in education, developing and providing simple and easy-to-use design eco-design tools and manuals for free or at low cost.
- Implement the IPP policy framework would help advance many of the recommendations suggested here. In the light of the project findings, the suggested IPP framework should stress the issues of promoting dematerialisation and suppressing re-materialisation. Systems for monitoring and following-up progress should be put in place.
- Supply customers with sufficient information to enable them to take environmentally conscientious decisions when selecting ICT services as well as ICT products. This could include product declarations, energy-labelling and eco-labelling schemes. Such information should cover the whole life-cycle impact and make it possible to benchmark the environmental performance of different products and services.

- Promote green public ICT procurement, by raising understanding and awareness among public authorities of how to select solutions for ICT product and service systems which have a minimum environmental impact over their life-cycle.
- Promote environmentally sound and economically viable innovations, with special attention on the potential gains enabled by the shift from products to services. This would include:
  a) reducing life-cycle impact by applying the principle of extended producer responsibility;
  b) promoting projects that collaboratively involve actors from the entire life-cycle chain in finding sustainable solutions for product and service design;
  c) improving the dissemination of successful sustainable innovation case studies to companies;
  d) developing mechanisms for understanding, quantifying, and sharing investment risk among actors and with society at large.

4.2 Transport

The following Section provides suggestions on how to realise ICTs' potential to reduce the negative environmental impacts of passenger and freight transport. The recommendations for transport relate in particular to the critical areas ranked three, four, five and ten in Section 3.3.

- Promote the use of ITS (integrated transport systems) to support public transport, by:
  a) directing the research focus and allocating resources to multi-modal, seamless travel and public transport supported by ITS;
  b) providing prerequisites for ICT-based work during train travel and in public transportation (such as wireless internet access);
  c) increasing the attractiveness of public transport by developing and implementing systems for customised information, such as personal time-tables, route-planning, and so on.

- the efficiency improvements in transport brought about by the use of ICTs must be combined with demand side management in order to achieve an overall reduction in environmental impact. Journey time reduction and network capacity increases achieved by ITS will open the door to greater transport demand unless measures are taken to limit it. Our research indicates that the internalisation of environmental externalities, in particular raising energy prices and fuel prices, could bring demand levels down to a point where transport is decoupled from economic growth. The option of complementing such measures by including transport in emissions trading schemes seems reasonable.
- Virtual mobility applications will not automatically generate significant transport savings unless policy initiatives are introduced to support this. Detailed recommendations are listed for each e-application in Section 4.3. Promotion of virtual meetings is probably the most effective e-application at reducing the environmental impact of passenger transport. Attention should also be given to a potential passenger transport increase due to a growing numbers of mobile workers.

4.3 Virtual Mobility

Specific policy recommendations are provided for e-work and virtual meetings. These relate in particular to the critical areas ranked three, four and ten in Section 3.3.

- Promote the use of **virtual meetings** in business, by:
  a) establishing policies and routines for virtual meetings;
  b) establishing routines for reporting business travel and its environmental impact;
  c) increasing the cost of passenger transport (taxation of fuel), particularly by air and car, so as to encourage a shift towards the virtual alternatives;
  d) promoting the development of affordable and reliable broadband access.

- Promoting an eco-efficient design of patterns of **e-work**, by:
  a) facilitating ICT based mobile e-work in trains and long-distance public transport;
  b) banning the use of mobile phones in cars without proper hands-free equipment;
  c) promoting the establishment of corporate policies and agreements for efficient e-work
  d) encouraging employers to set up e-work arrangements in ways that
     i) enable and encourage teleworking so as to reduce commuting and the use of office space;
     ii) do not duplicate equipment;
     iii) encourage digital handling of all working documents.
  e) making employers increasingly take on the environmental and economic responsibility for the travelling they do while commuting;
  f) promoting development of affordable and reliable broadband access;
  g) reducing or removing subsidies for commute travel by car.

4.4 Facility management

The recommendations for facility management relate primarily to the critical area ranked number one in Section 3.3.

- Promote an increase in the use of ICT-mediated, cost-effective energy saving measures in buildings, by:
  a) including such measures in demonstration projects in each member state to show BAT (best available technology) and economic feasibility, as well as actively communicating these to the relevant stakeholders, including architects, construction companies, property developers, landlords and tenants;
  b) creating economic incentives for producers of new houses and buildings to install energy saving measures (e.g. such as facilitating pay-per-use of heating and air-conditioning);
  c) directing R&D funds towards developing efficient and cost-effective energy-saving measures, as the potential is large but uncertain;
  d) distributing the results of cost-benefit analyses for different energy efficiency investments to help identify the most efficient measures.

4.5 Energy

Suggested energy-related measures concern both energy supply and consumption. Energy efficiency is also covered by other sections. These recommendations relate in particular to the critical areas ranked one, eight and eleven in Section 3.3.

Supply side:

- Promote the deployment of ICT support systems for decentralised electricity production from renewable sources or small CHP devices, by:
  a) directing funding towards R&D examining how ICT systems can coordinate demand for heat and electricity, and the supply of electricity by CHP plants;
  b) supporting virtual utility, encouraging the development of low-cost metering and communication systems for the electricity grid, making small-scale electricity production easier to operate and maintain, as well as more cost-effective than conventional approaches.

Demand side:

- Promoting ICT-based energy saving measures in buildings. These measures have a potentially large impact on the total energy consumption (this is discussed in Section 4.4).
- Promoting energy efficient products and services, particularly a shift towards mobile ICT devices and ad hoc infrastructure that needs as few stationary devices connected to the mains as possible.

This could be obtained by establishing public (non-proprietary) technical standards. A parallel can be drawn to establishing the TCP/IP protocol family, which made the Internet possible. The energy-saving effect of these devices will have to be set in relation to the overall environmental impact of a shift towards these products.

- Stimulating different ICT energy saving measures will have to be complemented with actions to tackle rebound effects if a reduction in total energy consumption is sought. As discussed in Section 4.2 concerning the case of transport, adjusting energy prices is an effective way of curbing the rebound effect, but this measure could also have other, less desirable effects on the economy.

4.6 Greenhouse gas emissions

The recommendations for greenhouse gas emissions have a cross-cutting character, as they are closely connected to energy use in industry, transport and housing and are therefore indirectly linked to all of the critical areas presented in Section 3.3. Our findings suggest the following measures:

- Promoting research into the implementation of ICT-supported measures for GHG emission reductions that can be accomplished in more cost-effective ways than by more traditional investments in energy saving, and promoting the dissemination of related knowledge and best-practice.
- Promoting the development of ICT-supported, cost-effective monitoring and reporting schemes that enable transport to be included in emissions trading schemes.
- Prioritising ICT-based demand-side management measures, making it possible to adjust energy consumption and transport demand to a sustainable level using economic instruments.

4.7 Waste

ICTs' impact on waste volumes includes generation and management of WEEE (waste electronic and electrical equipment) as well as the management and recycling of MSW (municipal solid waste). These recommendations relate in particular to the critical areas ranked two, seven and nine in Section 3.3.

- Counteract the high churn rates of ICT products to reduce material and energy consumption as well as reducing waste electric and electronic equipment (WEEE), moving towards meeting the target of the 6th EAP to decouple waste volumes from economic growth, by:
  a) providing incentives for producers to design and sell ICT products with a long life-span;
  b) effectively implementing the WEEE Directive, which is based on the EPR principle. This would encourage product designers and producers to minimise the waste stream, particularly if the producers are held responsible for managing the waste resulting from their own products;
  c) limiting sales models making ICT products of little or no value in a short period of time, such as subsidised mobile phone and subscription packages; and
  d) extending the depreciation time for ICT equipment (minimum time to 'write off' investments in ICT equipment).
- Adapt policy for limiting environmental impacts from the trends of pervasive computing and electronics embedded in non-traditional ICT products, which do not come under the scope of the current policy framework (e.g. Directives for WEEE and RoHS).

B2C e-commerce: teleshopping

- Further enhance the implementation of the 1994 Directive on Packaging waste, developing incentive systems for teleshopping retailers to reduce packaging waste, e.g. by designing their products and retail and shipping systems in ways that reduce the need for and use of packaging.

- Adapt systems for managing teleshopping packaging waste, including trans-boundary packaging.

Waste management

- Support intelligent systems for recycling and other forms of recovery, thereby decreasing the waste fraction that goes to final disposal by landfill or incineration.

4.8 Cross-cutting issues

Some policy recommendations relate to several different sectors, ICT areas, or applications.

4.8.1 Acceding countries

Most of the recommendations provided above are relevant for the acceding countries. However, the following issues may be highlighted:

- Accelerate adaptation of national policies to the requirements of the WEEE (waste electronic and electrical equipment) and RoHS (restriction of hazardous substances) Directives and to implement end-of-life systems for electronics, to manage the anticipated explosive growth in ICT equipment in these countries.
- Direct ITS investments towards improving the public transport system by making it more effective, attractive and mobile work-friendly, thereby maintaining the relatively high share of public transport compared to private vehicles use.

4.8.2 Research and development

This project has identified areas where the development of ICT could have a significant impact, but where a great deal of uncertainty still exists. Further research in these areas is necessary for a fuller understanding of the role of ICT in meeting environmental policy goals. The areas are:

- e-materialisation: the shift from products to services, dematerialisation and rematerialisation;
- ITS's impact on increasing transport performance;
- ITS's impact on promoting a shift from passenger cars to public transport;
- ICT equipment's electricity consumption in the domestic and tertiary sector;
- efficiency in electricity generation and distribution;
- energy savings through ICT-based facility management;
- the use of virtual utility promoting RES and CHP;
- ICT-based systems for recovery and recycling of MSW in general and WEEE in particular.

4.8.3 Rebound effects

ICTs help us by making resource and energy consumption more efficient. Rebound effects counterbalance these effects by increasing consumption. Therefore, the decisive question of whether ICT will actually help us to create sustainable production and consumption systems comes down to whether ICT will be able to influence the demand side towards more sustainable consumption patterns.

REFERENCES

Behrendt, S. *et al.* (2003): Eco-Service Development. Reinventing Supply and Demand in the European Union. Greenleaf Publishing, Sheffield (UK)

Ecoinvent (2003). Swiss Centre for Life-Cycle Inventories (Ecoinvent centre). Ecoinvent data v1.0. Dübendorf (CH)

EEA (2000). Environmental signals 2000. Environmental assessment report No. 6. European Environment Agency, Copenhagen (DK)

EITO (2002). European Information Technology Handbook 2002. European Information Technology Observatory EITO

Forum for the Future (2002). The impact of ICT on sustainable development. In: European Information Technology Handbook 2002. European Information Technology Observatory EITO

Gleave, S. D. (2003). Freight transport intensity of production and consumption. IPTS Report EUR 20864 EN. IPTS, Seville (ES)

Hilty, L. *et al.* (2003): Das Vorsorgeprinzip in der Informationsgesellschaft: Auswirkungen des Pervasive Computing auf Gesundheit und Umwelt. Zentrum für Technikfolgen-Abschätzung beim Schweizerischen Wissenschaftsrat. TA 46/2003. Bern (CH)

Höjer, M. and Mattsson, L.-G. (2000). Determinism and backcasting in future studies. In: Futures(32): 613-634

Kuhndt, M. et al. (2003). Virtual dematerialisation: ebusiness and factor X. Digital Europe. Wuppertal (DE)

Romm, J. *et al.* (1999). The Internet and Global Warming - A Scenario of the Impact of E-commerce on Energy and the Environment. The Center for Energy and Climate Solutions

Schneider, K. (2001). The 'new economy' and the energy sector. ABARE Current Issues 01(4):11

GLOSSARY

AC 10 refers to the ten countries joining the EU on 1st May 2004. These were Cyprus, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, and Slovenia.

CHP - Combined Heat and Power generation is different from normal power generation in that the heat produced as a by-product of electricity generation is also utilised.

D - Domestic sector of an economy, accounting for the activities of households.

E-Business refers to commercial transactions that use interactive media (e.g. Internet, Digital TV) to supply, order and/or use goods and services, together with activities within a company that use or are supported by electronic communications (e.g. teleworking, teleconferencing, ...).

EU 15 stands for the European Union of 15 member states which existed prior to 1st May 2004. The Members States were Belgium, Denmark, Germany, Greece, Spain, France, Ireland, Italy, Luxembourg, Netherlands, Portugal, United Kingdom, Austria, Finland, and Sweden.

EU 25 stands for the EU with its current 25 member states (EU 15) and the 10 new Member States (AC 10) which joined on 1st May 2004.

Facility management covers the whole range of ICT-related “soft measures” to reduce energy the consumption by buildings. By contrast, “hard measures” such as insulation are not covered.

First order effects are the impacts and opportunities created by the physical existence of ICTs and the processes involved.

GDP - Gross Domestic Product is a widely used macroeconomic indicator. It is used here when calculating a variety of environmental indicators such as energy intensity and volume of transport relative to GDP.

GHG - Greenhouse Gas Emissions are the emissions of CO_2, CH_4, N_2O, SF_6, Hydrofluorocarbons and Hydrochlorinated Fluorocarbons into the atmosphere. They are usually converted to CO_2-equivalents according to their relative global warming potential.

I – Industry sector of an economy, accounting for the production of physical goods

ICTs are defined as information technology plus telecommunications equipment and telecommunications services. Information technology refers to the combined industries of hardware for office machines, data-processing equipment, data-communications equipment and of software and services.

IHS & HA - Intelligent heating systems and home automation as ICT applications belong to the broader field of facility management.

ITS - Intelligent transport systems are ICT applications that aim at making transport more efficient. To a varying extent, they affect all transport modes, such as road transport and rail freight.

MSW - Municipal solid waste is generated by daily household activities, and in activities in the industry and tertiary sector similar to those in households.

Pervasive computing is a vision of computing everywhere and anytime. Pervasive computing is likely to become real in the next decade because of ongoing miniaturisation, wireless networking and sensor technology and falling ICT prices.

PPM or production process management covers all “soft measures” supported by ICT to reduce energy consumption of processes, such as good housekeeping and energy management systems.

Product-to-service shift denotes an effect in the economy whereby ownership of products for private use is being increasingly replaced by services. Examples include renting machinery, car sharing, and computer pooling.

Rebound effects occur when expected efficiency gains do not lead to savings in material, time or money. The rebound effects of ICT are among its third order effects.

RES - Renewable energy sources, such as solar energy, wind energy, tide energy, biomass conversion and geothermal energy, are not depleted over time, unlike non-renewable resources.

SCM - Supply chain management is the management of the supply chain to enhance efficiency and profitability. It makes extensive use of ICTs.

Second order effects are the impacts and opportunities created by the ongoing use and application of ICTs.

Teleshopping is a special form of demand-side e-business, allowing the purchase of goods via the Internet or mobile devices, which also changes physical mass flows.

T - Tertiary sector, the services sector of an economy.

Third order effects are the impacts and opportunities created by the aggregated effects of large numbers of people using ICTs over the medium to long term.

The *time utilisation effect* refers to the fact that using time spent in traffic for other purposes than travelling (e.g. work) relaxes the time budget, making more time available for other activities.

Virtual goods stands for both the digitisation of physical products and the product to service shift, which enables other forms of use of physical goods.

Virtual mobility denotes ICT applications that have a potential to reduce passenger transport. Telework, virtual meetings and also teleshopping are facets of virtual mobility.

Waste management, supported by ICT, optimises the separation of different waste fractions as a prerequisite for separate treatment, such as recycling.

ANNEX I: PROJECT TEAM AND IPTS STAFF INVOLVED

The consortium of institutes:

Institute for Futures Studies and Technology Assessment (IZT)

Siegfried Behrendt
Lorenz Erdmann
Christine Henseling
Felix Würtenberger

Swiss Federal Laboratories for Materials Testing and Research, Sustainable Information Technology Unit (EMPA-SIT) and University of Applied Sciences Solothurn Northwestern Switzerland (FHSO):

Mathias Binswanger (FHSO)
Lorenz M. Hilty (EMPA/FHSO)
Roland Hischier (EMPA)
Martin Lehmann (EMPA)
Thomas Ruddy (EMPA)
Patrick Wäger (EMPA)

International Institute for Industrial Environmental Economics at Lund University (IIIEE)

Peter Arnfalk
Carl Dalhammar
Oksana Mont
Luis Mundaca
Andrius Plepys
Naoko Tojo

Forum for the Future:

Vidhya Alakeson
James Goodman
Britt Jorgensen

Institute for Prospective Technology Studies (IPTS)

Panayotis Christidis
Juan-Carlos Ciscar
Luis Delgado
Paul Desruelles
Peter Eder
Carlos Rodriguez
Christine van Wunnik

ANNEX II: PROJECT LIMITATIONS

Implications of the methodological approach

As ICT becomes increasingly pervasive and interacts with a seemingly infinite number of economic, social and environmental factors and variables, a pragmatic approach has to be applied in order to assess the future impact of ICT on environmental sustainability.

The scope of the project has been limited by (1) the ICT applications chosen and its environmental effects investigated, (2) the three future scenarios described, and (3) the system boundaries of the model.

(1) Although we investigated a considerable number of ICT applications, we only chose those which seem to have a considerable environmental impact. Apart from possible misjudgements it must be noted that many small impacts might collectively have a big impact. The selection of ICT applications is based on the current state of knowledge. The overall conclusions drawn in this project are related to the specific set of ICT applications and their environmental effects. The selection of 'hotspots' is an attempt to identify the most critical areas where ICT has an impact on the environmental indicators selected with a view to developing sensible and practical policy recommendations. To some extent however, we have had to 'look for the keys around the lamp-post, because that is where the light is'.

(2) The future uncertainties were dealt with in three scenarios. These were designed to be plausible and internally consistent. However, even the small set of uncertain factors used to create the difference between the scenarios can be combined to create hundreds of possible scenarios. Although the three scenarios described are internally consistent, no statement can be made about other potentially more realistic future developments. The scenario narratives are mapped on to external variables, without considering discontinuities, such as technological breakthroughs and 'wild cards'. As the scenarios are quantified in the model these selected future paths determine the results of the impact of ICT on the environmental indicators to a high degree.

(3) The complex nature of the task has led to the following system boundaries for the model:

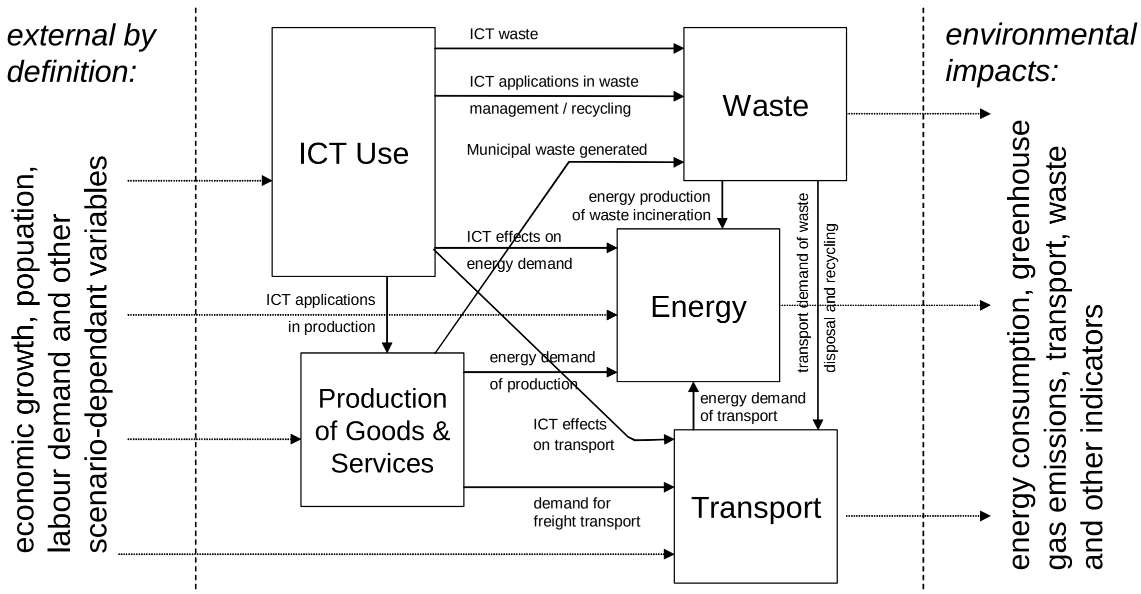

Figure 0-1: Simplified scheme of the system boundaries of the model

Let us use the example of economic growth to explain the difference between external (left side in Figure 0-1) and internal variables (centre of Figure 0-1) more precisely. Treating economic growth as an *external* variable means defining the boundary of the system under study in such a way that economic growth *becomes part of the system's outside world*. The consequence of this decision is that in studying the system, we will be able to deal with *impacts of economic growth on ICT and on the environment*, but *not* with *impacts of ICT or the environment on economic growth*. One might argue that this creates an unrealistic view because economic growth may be influenced, for instance, by the manufacture of ICT hardware and the provision of ICT-related services. However, this causal link is treated on the scenario level. In this particular example, it is indeed the case that the scenarios assuming more technology-friendly conditions also assume a higher rate of economic growth.

There is a basic problem behind this "division of labour": most phenomena are interdependent, i.e. if A has an impact on B, usually B also has an impact on A. This is the case with technology and growth, supply and demand, the knowledge of the teacher and the knowledge of the student, etc. In order to build a causal model, it is necessary to treat some interdependencies as causal "one-way streets", and the system boundary is in fact the line along which this cut is made. There is no alternative to this procedure: otherwise, the entire world would have to be modelled in order to answer the simplest questions.

As a consequence of the system boundaries some environmental indicators are simplified. Freight and passenger transport intensity (tkm/€ GDP, pkm/€ GDP) are replaced with freight and passenger transport performance (tkm, pkm). The same applies to energy intensity (TWh/€ GDP), which is replaced by energy consumption (TWh). Non-recycled municipal solid waste expressed in kg/capita is expressed in kg only, as ICT is assumed to have no impact on the number of inhabitants.

On the output-side (right in Figure 0-1) we focus on the direct impact of ICT on freight and passenger transport and on the modal split in passenger transport. Energy consumption of transport is derived indirectly. Direct impacts of ICT on energy consumption, of cars for example, are not taken into account. Although ICT contributes to more efficient combustion technology it is assumed that this effect is small compared to changes in transport performance, because the greater efficiency of cars is mainly dedicated to achieving higher performance rather than lower fuel consumption. In the same way we derived the values for greenhouse gas emissions indirectly from energy supply and consumption, transport performance and the modal split, without taking direct impacts of ICT on greenhouse gas emissions, e.g. higher conversion rates of methane into CO_2 by ICT, into account. As the model has no geographical resolution it was decided not to include the environmental indicators modal split of freight transport and urban air quality, which highly depend on local conditions (see Chapter 2.1).

A general objection against causal modelling is that there is usually a lack of data that would be needed to quantify all the causal relationships represented in the model, and that, for this reason, too many uncertain assumptions. The counter-argument is that ignoring a causal relationship is no less an assumption than introducing one without having sufficient data to quantify it. If there is some evidence for a causal link, ignoring it is usually worse than making a good guess. This is reflected in the frequently quoted phrase "it is better to be roughly right than precisely wrong." We include many causal relationships in our model that have never been considered before. Stating them explicitly makes them accessible for scientific and political discourse, which in turn can create new insights.

Basic assumptions

The assumptions the model is based on are documented in the fourth interim report "Refinement and quantification". The most important assumptions are repeated here because they address issues that may be covered in a different way by other models, and have substantially influenced our results.

(1) *The ICT industry is not specific.* There is little evidence that the ICT sector is atypical, e.g. that energy intensity and CO_2-emissions of the ICT manufacturing sector are significantly below the

average (e.g. Kuhndt *et al.* 2003). ICT industry is therefore considered to have no specific impact on the environmental indicators as compared to other industries. So we have assumed that the environmental effects of the ICT industry are roughly comparable to those of average industrial activity. Furthermore, ICT production is of decreasing importance within the EU. For these reasons, the model focuses on the role of ICT as an *enabling technology*, i.e. a technology that enables processes in almost any sector to become more efficient (e.g. in terms of time or natural resources) and induces structural and behavioural changes mainly as a consequence of the increased efficiency. The assumption is that this enabling effect of ICT and the subsequent impacts on environmentally relevant processes is more significant by far than the direct impact of the ICT industry on the environment. This means that we focus on second and third order effects and, in particular, do not model the ICT sector.[40] In addition, the use and disposal of ICT (a part of the first order effects) is also covered, but restricted to electricity consumption in the use phase and a rough estimate of the amount of e-waste in the disposal phase.

(2) *Constant travel time hypothesis.* This states that the average time a person spends travelling each day (i.e. getting from A to B using any mode of transport) is almost constant over time, but distances change depending on door-to-door speed. The hypothesis is supported by several empirical studies, but it is still debated to what extent it holds true, as there are large differences between people's travel time and the average travel time differs significantly between geographic areas. Some empirical studies show changing trends (see e.g. Höjer and Mattsson 2000). However, as far as the trends lead to an increase in travel time, these results provide even more support for our results concerning an increase in mobility. This hypothesis is critical for our results. For example, for intelligent transport systems, which increase the time efficiency of traffic (more passenger transport in the limits of the same time budget), it causes the model to create a *100% time rebound effect*. This assumption was both supported and disputed by the consulted experts.

(3) *Pervasive computing, the near future of ICT.* Ongoing miniaturisation and developments in wireless networking and sensor technology are likely to make the vision of Pervasive Computing (also known as “ubiquitous computing” and “ambient intelligence”) become a reality during the next decade (Hilty *et al.* 2003). Assuming that pervasive computing will be the dominant way of applying ICT in about 10 years' time, we pay attention to the following *second order effects*:

- Goods of any type can be handled more efficiently (e.g. due to transponder technology), which will change production, commerce and freight transport substantially, also with respect to their demand for energy and materials.
- Services of any type can be managed and provided more efficiently, which could lead to a shift from material products to immaterial services in consumption.[41]
- People will be able to carry out a growing part of their activities independent of where they are, which will increase their time utilisation. This will have effects on mobility and the use of goods and services.

ICT induced efficiency gains and related rebound effects, the product-to-service shift and the time utilisation effect all have high potential impacts on the environmental indicators in our model. This is reflected in the simulation results.

---

[40] However, this assumption only applies to the concrete set of environmental indicators in this study. The materials in ICT are often rare and have a considerable toxicity potential, which is not addressed by the environmental indicators. Moving away ICT production from the EU doesn't imply that the ICT industry will have a marginal impact on the environmental indicators, as companies for example will still have representations and design will take place the EU.

[41] As a conclusion from case studies on eco-services there are very specific restrictions on the product-to-service shift (Behrendt *et al.* 2003). Some of these can be relieved by ICT. Although there is no empirical evidence for such a shift so far (e.g. paper consumption has always been increasing), it is still possible that an ICT-based product-to-service will occur in the future, because the *mobile* access to information and services and the possibility to provide *location-based* services creates a new situation for both consumers and service providers.

Data quality and validation

The first order effects of ICT have been analysed on numerous occasions and have been largely addressed by industry and policy. The same is not true for second and third order effects. In some cases, as with the impacts of teleworking for example, there has been exhaustive research activity. In others, as with in-car navigation systems, there has been very little. Third order effects can either be treated in general, or related to applications studied in detail. In the latter case, third order effects compensate secondary effects to a certain degree. It is assumed that this provides a more effective basis for specific policy action, than the general perspective, which in any case can be addressed through general policy. Romm *et al.* (1999) emphasise that the second and third order effects of ICT outweigh the first order effects. However, the third order effects are not accounted for in the calculations.

A detailed review of the data situation in literature for the impact of ICT on environmental sustainability is provided in Annex IV. The analysis identifies input variables and external factors/variables, whose uncertainty has been characterised. It is impossible to sum up all the uncertainties in a suitable form, but they can be pursued in detail in the interim report "Script".

Although the search scheme was comprehensive, there is a certain geographical bias in the references found. Many of the studies evaluated originate from Germany, Sweden, Switzerland and the United Kingdom, representing the countries of the institutes of the project consortium. A wider range could be provided especially by IPTS resources and a web-search in the English language.

Most of the information and data was gathered from case studies, which are very concrete (i.e. a low level of abstraction), but extrapolation to sectors is difficult. On the other hand macro-economic data are too generic (i.e. the level of abstraction is too high) to be interpreted so as to enable policy recommendations to be derived. To satisfy the objectives of the project we looked for a *medium-level of abstraction*. This implied a number of assumptions, documented in the interim report entitled "Refinement and quantification". The impact of data uncertainties on the environmental indicators was assessed quantitatively by sensitivity analysis and covered by the presentation of results in Chapter 3. As the focus of this project is on second and third order impacts of ICT we have compiled the assumed elasticity values in Annex V, to shed light on them for public discussion.

In order to reduce the subjectivity of the assumptions underlying the project, steps were taken to validate the methodology and findings at a number of stages, specifically: at the scenario building stage, during and after the model building stage and at the policy recommendation stage. There has also been intensive cooperation with IPTS involving useful critical feedback at every step of the project (See Annexes I and III).

ANNEX III: EXTERNAL INPUT AND VALIDATION

List of interviewees for the scenario building process

Interviewee	Affiliation
James Wilsdon	Demos
James Crabtree	Work Foundation
Bill Thompson	Go Digital
Ian Pearson	BT Exact
Richard Barrington	Sun Microsystems
John Dryden	OECD

List of interviewees for the policy analysis and validation of recommendations

Interviewee	Affiliation
Peter James	U. of Bradford, UK
Andreas Barkman	European Environmental Agency (EEA), Denmark
Werner Koerte	EMPIRICA, Germany
Marjaan Peeters	U. of Maastricht, the Netherlands
Erik Bohlin	Chalmers University of Technology, Sweden
Justus von Geibler	Wuppertal Institute, Germany
Laimutis Telksnys	Inst. of Mathematics and Informatis, Lithuania
Gunilla Jönsson	Lund Institute of Technology (LTH), Sweden
Eva Heiskanen	Helsinki School of Economics and Business Adm., Finland
Simon Forge	SCF associates, UK
Tony Clark	Swedish Ministry of the Environment
Carl Otto Schallaböck	Wuppertal Institute, Germany
Frieder Rubik	IÖW, Heidelberg, Germany
Dennis Pamlin	WWF, Sweden
Alex Haxeltine	Tyndall Centre for Climate Change, UK
Martin Charter	The Centre for Sustainable Design, Surrey Inst. of Art & Design, UK
Mats Svensson	Lund University, Sweden
Thomas B Johansson	IIIEE, Sweden
Lars Hansson	IIIEE, Sweden
Thomas Lindhqvist	IIIEE, Sweden
Oksana Mont	IIIEE, Sweden
Thomas Kåberger	IIIEE, Sweden
Naoko Tojo	IIIEE, Sweden
Andrius Plepys	IIIEE, Sweden
Luis Mundaca	IIIEE, Sweden

The following external participants and project team members attended the scenario validation workshop held in London on 23rd June 2003.

Participant	Affiliation
Bernard Aebischer	CEPE, ETH Zürich
Mats Olov Hedblom	Ericsson
Julia Hertin	SPRU
Gabor Heves	Regional Centre for Central and Eastern Europe
José Manuel Mendonça	Fundaçao Ilidio Pinho
Joao Pato	ISCTE Centro de Audiovisuais
Hans Schaffers	Telematica Instituut
Christian Seelos	BT Global Services
Laimutis Telksnys	Institute of Mathematics and Informatics
Volker Tuerk	Wuppertal Institut
Christine van Wunnik	IPTS
Vidhya Alakeson	Forum for the Future
James Goodman	Forum for the Future
Lorenz Erdmann	IZT
Lorenz Hilty	EMPA-SIT
Peter Arnfalk	IIIEE

The following external participants and project team members attended the model validation workshop held in St. Gallen on 18th of September 2003.

Participant	Affiliation
Bernard Aebischer	CEPE, ETH Zurich
Isabelle Blanc	Environmental Science and Engineering, EPFL, Lausanne, Switzerland
Thomas Bandholtz	Semantic Web Consultant, Bonn, Germany
Aldo de Moor	Infolab, Department of Information Systems and Management, Tilburg University, The Netherlands
Ruth Förster	Institut für Raum- und Landschaftsentwicklung, ETH Zurich, Switzerland
OlivierJolliet	Group for Life Cycle Systems, Environmental Science and Engineering, EPFL, Lausanne, Switzerland
Kari-Hans Kommonen	University of Art and Design, Helsinki, Finland
Martina Merz	Observatoire Science, Politique, Société, EPFL, Lausanne, Switzerland
Andrius Plepys	IIIEE, Lund University, Sweden
Dietlinde Quack	Öko-Institut e.V., Freiburg, Germany
Paul Desruelle	IPTS
André Richier	Principal Administrator, DG Enterprise, European Commission, Brussels
Christine van Wunnik	IPTS
Peter Arnfalk	IIIEE
Lorenz Erdmann	IZT
James Goodman	Forum for the Future
Britt Jorgensen	Forum for the Future
Lorenz Hilty	EMPA

The following experts have reviewed a draft of the report on “Refinement and quantification”.

Reviewing Expert	Affiliation
Bernhard Aebischer	CEPE, ETH Zurich, Switzerland
Danielle Bütschi	Centre for Technology Assessment, Berne, Switzerland
Panayotis Christidis	European Commission, Directorate-General Joint Research Centre, Institute for Prospective Technological Studies (IPTS), Seville, Spain
Juan-Carlos Ciscar	
Peter Eder	
Carlos Rodriguez	
Christine van Wunnik	

ANNEX IV: DATA ON ICT AND ITS ENVIRONMENTAL IMPACTS IN LITERATURE

	Scope	Data for ICT	Data for environmental impact
ICT industry	ICT equipment, software products as well as IT and carrier services	No general statistics for the number/weight of manufactured goods and frequency of provided services available	ICT impact on macro-economic data cannot be separated; Single case studies inadequate because of heterogeneity of the ICT sector; Profound knowledge on strategies for environmental-friendly ICT industry
ICT use	Server-type, network and client-type devices	EU data only for single devices (e.g. PC) and networks (e.g. LAN in enterprises); Comprehensive data only country-specific (CH, D)	Up to date detailed studies on electricity consumption of ICT for D and USA; Study on energy consumption of data centres and main switches for NL; Rough assessments for total WEEE and lifetimes of devices in general; Hardly any data for pervasive and grid computing
Energy supply management	E-Business in energy markets, virtual decentralised energy generation, GHG emission trading	Country-specific report for e-commerce with electricity (e.g. D); No data for virtual decentralised power stations; GHG emission trading scheme for defined set of companies in EU	Data available for efficiency and fuel switch due to liberalisation in UK, but ICT impact hardly visible; Estimates of Renewables and CHP generation potential for buildings in EU, but ICT impact difficult to assess; Specific impact of ICT on GHG emission trading scheme hardly visible
Energy demand management	Facility Management, Production process control	Poor and highly speculative data for home automation and intelligent heating in the EU; Rough estimations on diffusion of production process control /energy management systems	Rough estimations for changes in total buildings' energy demand due to ICT; Rough estimations for changes in energy demand of industry due to ICT by sector for NL or cross-sector in the whole EU
Virtual mobility	Telework, Virtual Meetings, B2C E-Commerce	Telework monitoring in EU; No comprehensive statistics for virtual meetings; Detailed data for B2C-e-commerce only on country-level	Effects of telework on transport well investigated in case studies and rough assessments for the macro-level; Single detailed study on effects of virtual meetings on transport in S; Several case studies on the effects of B2C-e-commerce on transport
Traffic management	Telematic Systems, Car on demand, Travel information online	Data on single telematic applications (road-based and in-vehicle systems) available for D; Single studies on travel information online and car on demand	Detailed study for the effects of telematic applications in D for all means of transport; many case studies available on telematic systems and car on demand; one detailed study on online travel information
Virtual goods	Digital office, E-Media, e-mail	No general statistics known, one detailed study on e-mail use in UK, D, I and N	Single case studies on digital office; Detailed analysis of dematerialisation potential of electronic media and e-mail available
E-Business	B2B and B2C	B2B E-Business monitoring for EU; Single national surveys on B2C E-Commerce	Highly speculative assessments of productivity gains in industries, increasing number of more profound case studies on resource productivity, amounts of waste, energy demand and transport
Waste management	collection and recycling	No general data on ICT based waste management available	Detailed analysis of weight based collection schemes in DK, but specific ICT effect is small; Data for single ICT based sorting systems, but no general overview

ANNEX V: ELASTICITY AND REMATERIALISATION VALUES

Type of commodity and elasticity	Explanation of the elasticity function	Elast-icity value[42]
	ENERGY	
D&T Electricity Price Elasticity	Economic elasticity of electricity demand with regard to electricity price in the domestic and tertiary sector.	-0.5
D&T Heating Energy Price Elasticity	Economic elasticity of heating energy demand with regard to heating energy price in the domestic and tertiary sector.	-0.1
Industrial Energy Price Elasticity	Economic elasticity of industrial energy demand with regard to energy prices for industrial customers.	-0.5
	CAR	
PCar Fuel Price Elasticity	Economic elasticity of PCar traffic demand with regard to fuel prices.	-0.3
Fuel Consumption PCar Price Elasticity	Elasticity of the average fuel consumption of cars with regard to fuel price.	-0.4
PCar Performance-Speed Elasticity	Elasticity of average door-to-door speed using private cars with respect to the total car performance: (By what percentage will average door-to-door speed decrease if total car traffic in pkm increases by 1%? A decrease of speed is expected because infrastructure capacity limits are approached)	-0.5
	BUS	
BusC Price Elasticity	Economic elasticity of BusC traffic demand with regard to BusC charges.	-0.3
BusC Performance-Speed Elasticity	Elasticity of average door-to-door speed using BusC with respect to total BusC traffic performance. (By what percentage will average door-to-door speed increase if total bus and coach traffic in pkm increases by 1%? An increase is expected because higher demand creates a higher density of service availability in time and space.)	0.5
	TRAM AND METRO (TraM)	
TraM Price Elasticity	Economic elasticity of TraM traffic demand with regard to TraM charges.	-0.3
TraM Performance-Speed Elasticity	Elasticity of average door-to-door speed using TraM with respect to total TraM traffic performance (pkm). (By what percentage will average door-to-door speed increase if total bus and coach traffic in pkm increases by 1%? An increase is expected because higher demand creates a higher density of service availability in time and space.)	0.3
	TRAIN	
Train Transport Price Elasticity	Economic elasticity of train traffic demand with regard to train charges.	-0.3
Train Performance-Speed Elasticity	Elasticity of average door-to-door speed using the train with respect to total train traffic performance (pkm). (By what percentage will average door-to-door speed increase if total train traffic in pkm increases by 1%? An increase is expected because higher demand creates a higher density of service availability in time and space.)	0.5

[42] An elasticity value of -0.5 means that demand will decrease by 10% if prices increase by 20% (or that the demand will increase by 10% if prices are 20% lower).

AIR		
Air Transport Price Elasticity	Economic elasticity of air traffic demand with regard to air fares.	-1.5
Air Performance-Speed Elasticity	Elasticity of average door-to-door speed using air traffic with respect to total air traffic performance (pkm).	-0.1
VIRTUAL MOBILITY		
Price Elasticity for Home-based Telework Equipment	Economic elasticity of home-based telework with regard to the cost of buying and running the equipment needed.	-0.1
Price Elasticity for Virtual Meetings' Equipment	Economic elasticity of virtual meetings with regard to the cost of buying and running the equipment needed.	-0.3
Price Elasticity for Teleshopping Equipment	Economic elasticity of teleshopping with regard to the cost of buying and running the equipment needed.	-0.01
FREIGHT TRANSPORT		
Freight Transport Energy Price Elasticity	Economic elasticity of freight transport demand with regard to energy prices.	-1.5
GOODS AND SERVICES		
Industrial Materials Price Elasticity	Economic elasticity of industrial materials demand with regard to materials prices for industrial customers.	-0.5
Rematerialisation Share Information Products	Which share of the content of virtual information products will be rematerialised by the user (i.e. by printing out information accessed via the Internet or burning it on CDs) in the long term?	0.5
Rematerialisation Material Efficiency Factor	Average material efficiency of the rematerialisation of virtual products in relation to production of material products.[43]	0.3

[43] This factor is supposed to be smaller than 1, because it is known that e.g. printing a book on a personal printer is more material-intensive (i.e. less material efficient) than professional book printing.