THE FUTURE IMPACT OF ICT ON ENVIRONMENTAL SUSTAINABILITY

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1. Project description

An innovative combination of qualitative (scenario-building) and quantitative (High Level System Dynamics) methodologies to shed light on the future importance of ICT developments in policy decisions for environmental sustainability.

2. Abstract

The Institute for Prospective Technology Studies commissioned a research project to estimate the range of potential impacts of ICT on a series of environmental indicators in 2020: greenhouse gas emissions, energy intensity, transport intensity, modal split, urban air quality, municipal waste and share of renewable energy.

A five step methodology was adopted. The first step was to identify and refine the selection of economic sectors most relevant for the environmental indicators selected. The second step was to conduct a comprehensive literature review comprising current understanding of the relationship between ICT and environmental sustainability. Technology developments in and take-up of ICT up to 2020 were reviewed, and the variables and factors affecting ICT development, its take up and impact on the environment, identified. The third step was to use the data gathered in step two and supplement it with qualitative research to develop a set of three plausible scenarios for the development and take up of ICT to 2020, incorporating and supplementing the factors and variables identified in step two. Step four built these same variables into a very comprehensive system dynamics model to simulate the impact of ICT on the environmental indicators for the three different scenarios. The model incorporated many causal relationships that may not have been considered before and was subjected to expert validation and sensitivity analysis. The final step of the project was to review the outputs of the previous four steps and align them to EU environmental policy and goals, giving insight into key areas for present and future policymakers to focus their attention.

A general observation from our research and analysis is that the impact of ICT is roughly between -20 and +30 % across the range of chosen indicators. It can be concluded therefore that the impact of ICT on the environmental indicators is relevant and should be taken into account by environmental policies. ICT areas of key environmental importance include the use of ICT to rationalise energy management in housing (or facilities), to make passenger and freight transport more efficient, and ICT's capacity for enabling a product to service shift across the economy. Policy has an important role to play in realising the positive environmental outcome of the ICT applications, and, at the same time, to suppress rebound effects.

INTRODUCTORY NOTE

This paper is submitted to the EU-US Scientific Seminar on New Technology Foresight, Forecasting & Assessment Methods, 13-14 May 2004, Seville, Spain, under the theme, "Models and voices: how to successfully integrate human (and expert) judgements and formal analytical methods?".

It is based on a project commissioned by the Institute for Prospective Technology Studies (IPTS) and draws on a number of reports that are publicly available on the IPTS website[1], namely:

Task One interim report – Identification and global description of economic sectors
Task Two interim report – Script
Task Three interim report - Scenarios
Task Four interim report – Refinement and quantification
Task Five interim report – Policy recommendations
Synthesis Report.

The Synthesis Report will also be published by the IPTS later in 2004.

[1] http://fiste.jrc.es/Pages/mobility.htm

I. BACKGROUND

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 transition to a knowledge-based economy. Information and communication technology (ICT) plays a key role in the change towards this knowledge-based economy.

There are serious hints that ICT has an important impact on environmental sustainability, but well-founded evidence is scant. There are many single 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 to date been carried out.

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

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.

ICT in this project is 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[2].

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.

[2] EITO (2002). European Information Technology Handbook 2002. European Information Technology Observatory EITO

II. OVERVIEW OF THE PROJECT METHODOLOGY

The objectives of the project are ambitious and an ambitious combination of approaches has been used in order to satisfy them. The methodology can be divided into five steps. The first step was to identify the economic sectors and ICT applications with the greatest potential impact on the environmental indicators chosen. The second step was to establish the data basis for the entire project 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.

1. Scope and data gathering (steps one and two)

In view of the fact that ICT is 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 ICT on combinations of economic sectors and the European Commission's headline environmental performance indicators. 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 ICT on sector/indicator-combinations led to the following choices, presented in table 1.

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

Economic sector	Transport/ GDP	Modal split	Energy/ GDP	Share of renewables in electr.	GHG emissions	Urban Air Quality	MSW not recycled
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 indicators *urban air quality* and *modal split of freight transport performance* were not investigated further, as they depend very much on local and regional conditions. It would have been necessary to model daily emission patterns and the transmission of air borne substances in order to assess the impact on urban air quality and this was far beyond the scope of the present project. A significant share of freight transport, 45 %, is bound to inland

water ways and short sea shipping[3]. Assessing the impact of ICT on the modal split of freight transport would have required a geographical resolution of transport flows, again calling for considerable extra resource.[4]

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 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: Scope of the project

ICT field	**Freight transp. volume**	**Passenger transp. volume**	**Share of private car in passenger transp.**	**Energy cons.**	**Share of renewables in electr.**	**GHG emissions**	**MSW not recycled**
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

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. External factors are of a qualitative nature and cannot be directly used for quantitative calculations (e.g. attitude towards the environment) in contrast to variables (e.g. household internet penetration rate) . These fact sheets, exploring important factors and uncertainties, provide the basis for the scenario-building and the modelling, and also contain useful information for the policy analysis.

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

[4] A comprehensive analysis of freight transport intensity of production and consumption has been published recently – see Gleave, S. D. (2003). Freight transport intensity of production and consumption. IPTS Report EUR 20864 EN. IPTS, Seville (ES).

2. Scenarios (step three)

To deal with future developments of ICT there are many methodologies, such as forecasting and Delphi studies. Acknowledging the complexity and uncertainty of future developments, scenario methodology was applied to assess the future impact of ICT on environmental sustainability. Three plausible scenarios describing alternative future courses of ICT until 2020 were created, 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 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 seeks 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 in a so called base matrix, 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.

3. Refinement and Quantification (step four)

The scenarios were refined and quantified by creating and running a simulation model for the impact of ICT on selected environmental indicators. This work 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.

It was necessary to create a causal model of the system in order to quantify net impacts of interacting variables. System Dynamics proved to be a suitable method for modelling, given the type of problem to be solved here, in a relatively short time. The model was implemented

in High-Level System Dynamics[5] using the System-Dynamics-based simulation system *PowerSim Studio Academic 2003.*

The year 2000 was chosen as the starting point for the simulation. A lot of data was 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 model input was restricted to 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 for any geographic region.

In order to account for the uncertainty of the parameters, we created sub-scenarios that exploited parameter uncertainty to maximize or minimize the environmental indicators. These are called “worst case” or “best case” sub-scenarios, respectively. For each environmental indicator all parameter values were selected within their minimum and maximum boundaries in such a way that the indicator is minimized or maximized. The leading indicator for this optimization is energy consumption. It turned out that all other environmental indicators move in the same direction as energy if the best or worst case is approached for energy. 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 reasons of comparison, we simulated what would happen if ICT remained at the same level of development from 2000 to 2020, i.e. if no additional ICT was installed and existing ICT was used exactly as in the year 2000 for the subsequent two decades. The results of these “ICT freeze” simulation runs were compared to the values using our projected future developments in ICT to 2020.

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 over twenty expert interviews with researchers and politicians.

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

III. HEADLINE FINDINGS

Looking at the relationship between the environmental indicators and the projected ICT for 2020 at an aggregated level, only the share of private cars in total passenger transport performance and the share of renewables in electricity generation are clearly moved towards environmental targets by the ICT applications studied for 2020. However, the other indicators can nevertheless benefit considerably from ICT, because the impact of ICT is in most cases ambivalent and can be directed towards the targets by appropriate policies. The only exception from this is total passenger transport (all traffic modes), which will not grow slower due to ICT even under best-case assumptions.

This is illustrated in Figure 1 below. A negative value indicates that the indicator level would be higher without ICT, a positive value indicates that ICT contributes to growth of the indicator. The length of the bars indicates the uncertainty of the results. Bars crossing the zero line therefore represent ambivalent impacts: the impact of ICT can be positive or negative depending on policies chosen and other external factors.

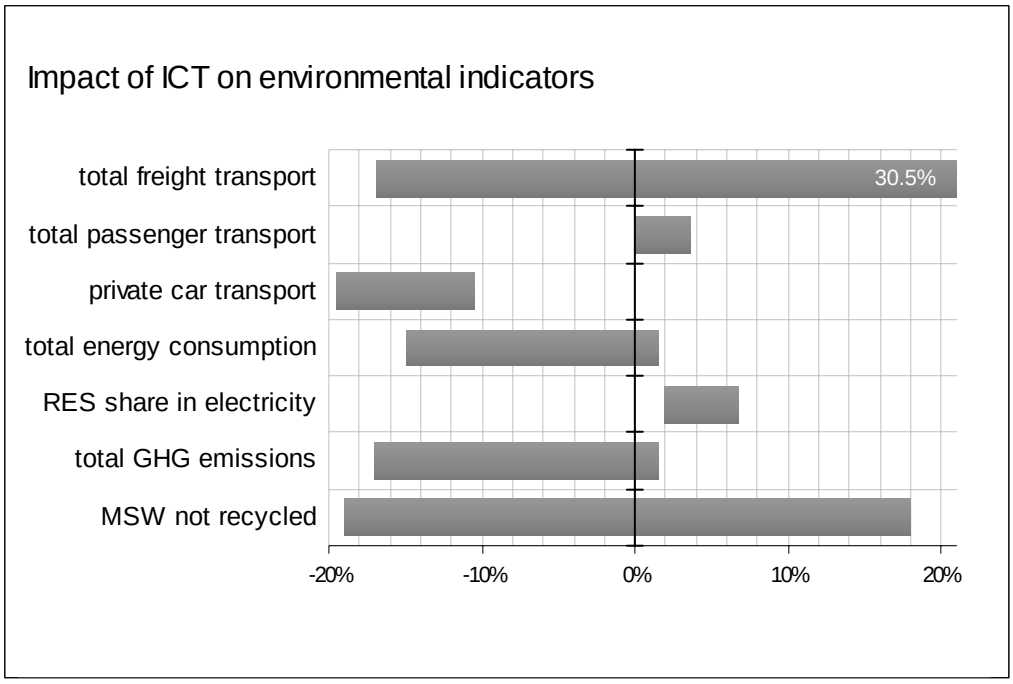

Figure 1: The future impact of ICT on seven environmental indicators, expressed in % increase or decrease of the projected (2020) indicator levels.

The impacts shown in Figure 1 are aggregated values over all ICT applications considered and all scenarios simulated. In order to understand in detail how ICT affects the environmental indicators, it is necessary to break this down and look at the effects of ICT applications. This is shown in Table 4 below.

Table 4: The future impact of ICT on environmental sustainability indicators in 2020

	Freight transport volume	**Passenger transport volume**	**Share of private car in passenger transport**	**Energy cons.**	**Share of renewables in electricity**	**Green-house gas emissions**	**Municipal solid waste not recycled**
Potential impact to:	reduce tkm	reduce pkm	reduce %	reduce TWh	increase %	reduce CO_2-eq. Mt	reduce Mt
First order effects of ICT	-	-	-	☹	-	☹	☹
ICT in supply chain mgmt.	☺	-	-	☺	-	☺	☺
Tele-shopping	☹	☺	😐	😐	-	☺	😐
Telework & virtual meetings	-	☺	☺	☺	-	☺	-
Virtual goods	☺		-	☺	-	☺	☺
ICT in waste mgmt.	-		-	-	-	-	☺
Intelligent transport systems	☹	☹	☺	☹	-	☹	-
ICT in energy supply	-	-	-	😐	☺	☺	-
ICT in facility mgmt.	-	-	-	☺	-	☺	-
ICT in production process mgmt.	☺	-	-	☺	-	☺	☺
Mobile ICT time utili-sation 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

Looking at the ICT applications in Table 4 we can see, for example, that according to our analysis, intelligent transport systems have an environmentally negative influence on total freight transport, total passenger transport, total energy consumption and greenhouse gas

emissions, but an environmentally positive influence on relative levels of private car transport in 2020.

Based on our conclusions regarding the relationship between the environmental indicators and projected developments in ICT to 2020, we were able to highlight eleven critical areas where ICT applications have a significant effect, and rank them in order of significance. These eleven areas formed a reference point for the recommendations. We 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. The eleven areas are:

1. ICT applications for heating management. ICT has a high potential impact on the rational use of heating energy. Heating accounts for roughly 30% of total energy consumption, and the most effective conservation measures using physical materials tend only to be applied to the small annual share of buildings that is renovated or newly built. 'Soft measures' using ICT (such as intelligent heating systems) have the advantage of being applicable in all buildings, and could therefore have a significant effect. The use of ICT applications for heat management should therefore be a priority for future research and development.
2. ICT applications for product-to-service shift. Although there are widely diverging opinions concerning an ICT-supported product-to-service shift and its possible energy saving and dematerialization effects until 2020, 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, first of all freight transport performance, but also waste and the energy used by the industrial sector.
3. ICT applications for passenger transport efficiency. All ICT applications that make passenger transport more time efficient (such as intelligent transport systems) will create more traffic and possibly more energy consumption. The efficiency gains also apply to public transport, but it is unlikely that this will compensate for increases in private transport. Induced passenger transport demand has severe environmental consequences in energy use and greenhouse gas emissions, although ICT contributes to lowering the energy and GHG intensity of passenger transport.
4. ICT applications for mobile work. Mobile work enabled or supported by pervasive computing and other new forms of ICT application can have a significant effect on passenger transport, because it increases the share of time spent in traffic that people 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 currently underestimated indirect impacts of ICT on the environment.
5. ICT applications for freight transport efficiency. 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, with severe environmental effects, unless measures are taken to limit demand of transport.
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 contributes to e-waste, which can create problems in 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 miniaturization of ICT works for less waste; even if this is counterbalanced by a higher number of devices being used in the future, the e-waste stream could be stabilized if there were no trend towards shorter use phases.
8. Although it is uncertain how much ICT can contribute to decentralized 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 mention 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 can save passenger transport, which pays off for long distances and is much more effective than telework in environmental terms. However, it is not the virtual mobility that reduces physical mobility, but physical mobility coming into conflict with time and infrastructure constraints that calls 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.

IV. POLICY RECOMMENDATIONS

Based on the analysis of the project outputs, analyses of existing and discussed European policies, as well as on expert consultations, a number of recommendations were presented with the aim to optimise the contribution of ICT to environmental sustainability. The main recommendations, listed according to the relevant audience groups, are summarised as follows:

Industry should promote an environmentally sound and economically viable shift from products to services – product service systems (PSS), extending producers responsibility, and promoting life-cycle chain thinking in product and service design. The existing and developing policy frameworks (e.g. IPP and EuP) should be apt to address these issues and support implementation.

Transport. The use of intelligent transport systems (ITS) in support of public transport should be supported by directing research focus and allocating resources to multi-modal, seamless travel and public transport supported by ITS. In addition prerequisites for ICT supported work during train travel and in public transportation should be provided, and attractiveness of public transport increased by developing and implementing systems for individually tailor-made information. ICT's efficiency improvements in transport must be combined with demand side management in order to result in an overall reduction of environmental impact.

Energy - supply side. Promote the deployment of ICT support systems for decentralized electricity production from renewable sources and small CHP devices, by R & D on coordinating demand for heat and electricity, and supply of electricity by CHP engines, and by supporting virtual utility.

Energy - demand side. Promote ICT supported energy saving measures in buildings, and energy efficient products and services, particularly a shift towards mobile ICT devices and ac hoc infrastructures with as few stationary devices connected to the mains as possible. 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 for.

a) Facility management. Cost-effective energy saving measures in buildings should be promoted by demonstration projects showing best available technology (BAT) and economic feasibility, as well as actively communicating these to the relevant stakeholders. Moreover, we recommend that economic incentives are established for producers of new houses and buildings to install energy saving measures (e.g. such as facilitating pay-per-use of heating and cooling), that funds for R & D are provided to develop efficient and cost-effective energy-saving measures, and that the results of cost-benefit analyses for different energy efficiency investments are distributed.

Waste. Counteract the high churn rates of ICT products in order to reduce material and energy consumption as well as reducing waste of electric and electronic equipment (WEEE), by promoting PSS in industry. Stimulate product designers and producers to minimise the waste stream, by increasingly making producers more responsible for managing the waste of their own products.

Limit business models making ICT products of little or no value in a short period of time, and adapt policy for limiting environmental impacts from the trends of pervasive computing and electronics embedded in non-traditional ICT products, that are not covered by the scope of the current policy framework (e.g. Directives for WEEE and RoHS). Develop incentive systems for teleshopping retailers to reduce packaging waste, and adapt current systems for packaging waste to including transboundary packaging. Support intelligent waste management systems for recycling and other forms of recovery, thereby decreasing the waste fraction that goes to final disposal and incineration.

b) Virtual meetings. Promote the use of these meetings in business by establishing policies and routines for virtual meetings in public administration and private businesses. This should be combined with establishing routines for reporting of business travel and of its environmental impact, and preferably a taxation of fuel for aviation. Promote development of affordable and reliable broadband access.

e-work (or telework). Promote eco-efficient e-work in organisational policies and agreements and allow employees in public administrations to telework if suitable. Set up e-work arrangements in ways that teleworkers reduce commuting travel and office space, not duplicate equipment, and handle all working documents digitally. Make employers increasingly take on environmental and economic responsibility for their employees' commuting travel, and reduce or remove subsidies for commuting travel by car. Facilitate ICT-based mobile e-work in trains and long-distance public transport, and promote development of affordable and reliable broadband access.

Cross relevant issues:

c) Greenhouse gas emissions: promote R & D on ICT supported measures for GHG emission reductions, monitoring and reporting schemes that enable transport to be included in emissions trading schemes, and demand-side management measures to adjust consumption of energy and transport to a sustainable level using economic instruments.

Acceding countries: accelerate adaptation of national policies to the WEEE and RoHS Directives and the implementation of end-of-life systems for electronics, to manage the expected fast growth of ICT equipment in these countries. Direct ITS investments towards improving the public transport system by making it more effective, attractive and beneficial for mobile work, thereby maintaining the relatively high share of public transport use compared to private car use.

Research and development: pay special attention to research and development in the following areas:

- e-materialisation: the shift from products to services, dematerialisation and rematerialisation;
- ITS's impact on increasing transport performance and on promoting a shift from passenger car to public transport;
- ICT equipment's electricity consumption in the domestic and tertiary sector; efficiency in electricity production and supply;
- ICT supported facility management energy savings;
- The use of virtual utility promoting RES and CHP;
- ICT supported systems for recovery and recycling of MSW in general and WEEE in particular;
- and on understanding the mechanisms of rebound effects.

V. COMMENTS ON THE METHODOLOGY USED

The principle challenge of the project was to produce quantitative estimates of how environmental indicators might be influenced by ICT in 2020 and form policy recommendations on that basis. This timeframe involved a great degree of uncertainty, not just with regard to the type of ICT in use and the scale of penetration of ICT into everyday life in Europe, but also with regard to a wide range of other factors not directly related to the production and use of the technology.

Much of the uncertainty was addressed through the use of qualitative estimation and validation from experts. Specifically, the development of scenarios is a qualitative means of accommodating uncertainty, and in this case formed the basis for the construction of the evaluative simulation model. Furthermore, at a number of stages throughout the project experts were asked to validate decisions made by the project team on a qualitative basis. This section of the paper examines these two areas of qualitative input in turn.

1. The link between scenario building and evaluative model building

Scenarios were an ideal basis for the evaluative model in this case, for the following reasons:

Scenarios suggest a range of possibilities rather than focusing on a narrow range of probability. This mirrored the aims of the project, which were to describe quantitatively plausible impacts that could be influenced by future policy, rather than firm predictions.
Scenario methodology is focused on identifying and reconciling contradictions that would not be tenable in a quantitative modelling process.
Scenario methodology is able to accommodate a diverse range of views about past, present and future developments, find the common themes and assumptions that may be underlying those views and make them explicit. This latter point is particularly relevant as the construction of a model must be transparent and the many assumptions that are made in the construction must be stated openly.

The scenario building process resulted in three scenarios, named “Technocracy”, “Government First” and “Stakeholder Democracy”. However, unlike conventional scenario building, the aim of this process was not just to provide convincing standalone narratives, but also to feed into the next stage of the project, i.e. the evaluative modelling process. Thus the end results of the project do not refer to the scenarios, but rely on and are significantly influenced by the scenario development process.

There are three ways in which the qualitative scenario building process fed into the quantitative modelling:

- the “base matrix”, a matrix of the causal relationship between variables;
- the scenario narratives themselves;
- estimates of key environmental trends.

The "base matrix"

In task two of the project, an extensive literature review located the critical areas in the relationship between ICT and the environmental indicators. 212 variables (defined as a "named quantity that may change over time") were identified, such as "the percentage of companies using virtual conferencing technology" or "the percentage of roads covered by intelligent transport systems", judged to be quantifiable, relevant to the relationship between ICT and the environment, and relevant to the timeframe 2020.

Known or estimated values of the variables formed the data basis for the entire project. A selection of the most relevant variables describing the development of ICT-related issues ("internal variables") was combined with a small number of "external variables" that related to the socio-economic context for ICT development and use, and a small number of "output variables" that related to the environmental indicators.

In total 27 variables were combined in a matrix (the "base matrix") and the causal relationships between each of them were estimated. This was a qualitative process, based on the expertise and knowledge of the project team and the literature review. There was a significant subjective element to this task and therefore critically, these causal relationships were validated by external experts in a workshop and a number of adjustments were made.

Since the relationships set out in the base matrix also influenced the structural basis for the simulation model, the process of validating the base matrix also served to establish the validity of the model's basic structure.

In sum, the base matrix was a series of qualitatively estimated causal relationships between socio-economic, ICT-related and environment-related variables, that formed the basis for the scenarios and many of the key relationships featured in the quantitative modelling process.

The scenario narratives

The network of causal relationships represented in the base matrix contributed significantly to the process of putting the flesh on the bones of the scenarios to develop the scenario narratives. The three scenario narratives were then used to estimate the likely values in 2020 of the internal ICT-related variables, for each scenario. This was then validated by a panel of experts in a workshop and the data was used in the running of the model.

The three sets of data corresponding to the three scenarios provided the range of variability in environmental impacts of ICT in 2020 seen in the results of the project.

Estimates of key environmental trends

Based on the scenario narratives, a panel of experts was asked to estimate the general trend in the environmental indicators represented by the output variables, for each scenario to 2020. These estimates were later used to validate the outputs of the evaluative model. Table 5 below shows how these qualitative estimates were used in the case of scenario A ("Technocracy") to check for consistency.

Table 5: Consistency check for Scenario A

Environmental indicator	**Qualitative estimate**	**Simulation Result**	**Comment**
Share of renewables and CHP in total energy mix	Doubled	RES: 3.0 % → 6.6 % CHP: 4.3 % → 9.7 %	Consistent
Total energy consumption	Increase	+ 27 %	Consistent
Total volume of passenger transport	Increase	+ 66 %	Consistent
Total volume of freight transport	Increase	+ 122 %	Consistent
Total volume of waste generated	Stable	+ 46 %	to be discussed

2. Further expert validation

The qualitative process of scenario building requires validation at regular stages. When attempting to refine and quantify outputs from a qualitative methodology, the need for validation is even greater.

Two workshops were held specifically for validation of methodology and outputs. One was held to aid with the scenario building process, and one was held to aid with the construction of the model. In both cases, a large number of comments were made and accommodated in the approach taken by the project team.

This is also true for the development of policy recommendations. The task of translating the outputs of the evaluative model so that they were understandable to a policy audience was significant. The subsequent generation and validation of policy recommendations based on the model outputs required in-depth interviews with over twenty experts in the area of ICT and /or environmental policy.

VI. CONCLUSION

The methodology adopted to provide quantitative estimates of the impact of ICT on environmental indicators in 2020 was a combination of qualitative and quantitative techniques.

The foundations for the project were laid down using secondary desk-based research, followed by a process of careful selection of areas of impact and narrowing of the project scope, drawing boundaries for the pragmatic delivery of results.

There followed a qualitative process of establishing causal relationships between three different types of variables: external variables, i.e. socio-economic variables; internal variables, relating to the take up and use of ICT up to 2020; and output variables, relating to the environmental indicators.

Scenarios featuring the same variables were developed and on that basis qualitative estimates of the value of the external and internal variables were made.

An evaluative model was then constructed using the causal relationships and the estimated values of the variables. The model was able to add the complexity and sophistication of relationships that a qualitative approach could not and produce estimates of the value of output variables.

Every practical step of the methodology was validated using external experts in order to confirm methodological rigour. The result was an evaluative model that was able to produce quantitative estimates of the impact of ICT on the environment, providing a sound basis for the development of a suite of policy recommendations designed to optimise the contribution of ICT to environmental sustainability.