Measuring the Relationship between ICT and the Environment

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FOREWORD

This report was presented to the Working Party on the Information Economy (WPIE) in December 2008, and declassified by the Committee for Information, Computer and Communications Policy in March 2009. The report was updated to include comments received from WPIE delegates until March 2009.

More recently, the statistical offices of Denmark and Sweden have commenced survey work in the area of ICT and the environment. Denmark has added questions on environmentally friendly use of ICT to existing household and business ICT use surveys. Sweden has added a module on ICT and environment to its business ICT use survey.

The report was prepared by Sheridan Roberts, consultant, as part of the WPIE's work on ICT and the environment under the overall direction of Graham Vickery, OECD Secretariat. It will contribute to improved definition and collection of information on ICT and the environment. It also contributed to the OECD Conference on "ICTs, the environment and climate change", Helsingør, Denmark, 27-28 May 2009 (www.oecd.org/sti/ict/green-ict). This report was also issued under the OECD code DSTI/ICCP/IE(2008)4/FINAL.

TABLE OF CONTENTS

Summary

While the links between ICT and environmental outcomes are becoming clearer, there is no separate statistical field that links the two. Nevertheless, some data are available from official statistical sources, from analytical work and from product life cycle studies.

This report suggests a conceptual framework for the new statistical field "ICT and the environment" based on an existing OECD framework for information society statistics. Sources of official data to populate the framework are investigated and some relevant work has been identified.

Given the serious environmental problems facing the world, and the potential for ICT to both lessen and worsen those problems, it is suggested that this field should be of more interest to official statisticians. A number of actions are recommended and they include: conducting new or expanded household and business surveys, expanding statistical classifications to better reflect ICT and the environment, ensuring that sample sizes are sufficient to enable better identification of ICT and environment data, and producing time series data on the topic.

Further OECD work on this topic could include compilation of existing data that link ICT and the environment, development of model questions, and development of a core set of indicators. Some possible core indicators are described in Annex 1.

Introduction

The aim of this report is to scope out the statistical field *ICT and the environment*. This work is associated with broader Organisation for Economic Co-operation and Development (OECD) analytical and policy work on the relationship between information and communication technology (ICT) and the environment.[1]

With a host of environmental and energy challenges facing the world, attention has turned to the positive and negative relationships between ICT and the environment. A number of international organisations and partnerships are involved in examining these relationships and proposing industry and policy actions for mitigating adverse environmental outcomes. The organisations and their goals in relation to ICT and the environment may be summarised as follows:[2]

- The OECD is developing policy, undertaking analysis, and facilitating international debate, on the use of ICT to tackle environmental challenges. The OECD Ministerial Meeting on the Future of the Internet Economy, held in Seoul in June 2008, concluded that analysis of the environmental impact of ICT (including the Internet), coupled with appropriate policy action, is essential for tackling climate change and environmental issues. The OECD and other stakeholders were invited to explore the role of ICT and Internet-related technologies in tackling climate change and energy efficiency, and to develop policies that harness this potential across all sectors of the economy. The OECD's Committee for Information, Computer and Communications Policy is pursuing this work through its Working Party on the Information Economy. A multi-stakeholder approach has been adopted, with work including analytical work on statistics and policy action required, and the hosting of workshops and conferences (OECD, 2008a).[3]

- European Commission. Europe has a number of ambitious targets for reducing greenhouse gases (GHG) by 2020. Those relevant to this study are: more energy-efficient ICT products; ICT-enabled energy-efficient buildings, manufacturing, logistics and power-grids; and new ICT-enabled business-models, markets and life-styles (European Commission, 2008).

- Intergovernmental Panel on Climate Change (IPCC) refers to the capacity to mitigate and adapt to the effects of climate change, as being dependent on "… socio-economic and environmental circumstances and the availability of information and technology." Technology is defined as "… the practical application of knowledge to achieve particular tasks that employs both technical artefacts (hardware, equipment) and (social) information (software, know-how for production and use of artefacts)." (IPCC, 2007a).

- International Telecommunication Union (ITU) argues that "Methodologies for evaluating CO_2 reductions through the use of ICT should be standardized". ITU organised two symposia on ICT and climate change during 2008.[4]

- The World Economic Forum (WEF) states that "ICT solutions have the potential to be an enabler to reduce a significant part of the remaining 98%".[5]

- The Global Information Infrastructure Commission (GIIC) conference (Japan, April 2008) resulted in two declarations. Declaration 1 – "Lower the Environmental Impact OF ICT" and "Lower the Environmental Impact BY using ICT" and Declaration 2 – "To accelerate achieving the goal by: Exchange of Information, Development of a Roadmap, Market-based Approach and Early Action Needed".

- International Institute for Sustainable Development (IISD). IISD has worked on the relationship between ICTs and sustainable development since 2003. It contends that policy makers have underestimated the impact of ICT on sustainable development (and vice versa) (IISD, 2008).

- Global e-Sustainability Initiative (GeSI) to address sustainability (triple bottom line – social, environmental and economical). GeSI is industry-led and open to ICT industry participants; it is partnered with several international organisations, including the United Nations Environment Programme (UNEP) (GeSI, 2008).

- World Wide Fund for Nature (WWF). Its mission is "to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature…". It started work with ICT in 2000 and works with other organisations, including the WEF.

For the purposes of this study, the scope of statistics on ICT and the environment has been defined as follows:

- The environmental scope is limited to aspects where ICT may be a strong positive or negative factor, that is, climate change,[6] energy use and waste.[7] Even though this only represents three aspects of the environment, arguably climate change and energy use are the most important ones at this point in human history. In addition, climate change is multi-faceted, encompassing several other topics such as water resources, land use, and conservation of ecosystems and species in the face of changing climatic conditions.[8]

- The statistical scope of the report is official statistics, where available, otherwise reliable unofficial statistics.[9]

- The geographical scope is the world.

In respect of climate change, a further focus is on those areas where ICT is most likely to have an impact – in either a negative or positive sense – such as energy supply and use, transport, buildings and industry.[10]

Conceptual frameworks for *ICT* and for *environment* statistics

In a statistical sense, a conceptual framework provides an underlying set of standards applying to the statistics of a particular field. It will include elements and boundaries of the field, relationships between elements, links to other frameworks, concepts, definitions, units, classifications, and possibly sources, methods and model surveys.

While the relationship between ICT and the environment is not a recognised field of statistics, individually *ICT statistics* and *environment statistics* are recognised fields. A brief description of the conceptual frameworks for these fields is presented below.

Conceptual framework for ICT statistics

A supply/demand conceptual framework for ICT statistics has been promulgated by the OECD's Working Party on Indicators for the Information Society (WPIIS) (OECD, 2009a). The WPIIS has been developing statistical standards for measuring ICT since 1997, with some individual member countries active in this field since the 1980s. Statistical standards for ICT statistics include concepts (for example, the information economy and society), definitions (for example, e-commerce, ICT products[11] and the ICT industry), classifications (of ICT products and ICT industries) and model surveys (of ICT use by households and businesses). The OECD has prepared a diagrammatic representation of a conceptual model for measuring the information society (which is broader than ICT). The model explicitly includes the impacts of ICT production and ICT use upon the environment but does not distinguish positive from negative impacts.[12] More information on the standards applying to ICT statistics can be found in the OECD's *Guide to Measuring the Information Society* (OECD, 2005 and 2009a).

Conceptual frameworks for environment statistics

It appears that the most complete and current internationally agreed framework for environment statistics is the System of Integrated Economic and Environmental Accounts (SEEA) (UN *et al.*, 2003) – a satellite system of the 1993 System of National Accounts (SNA). It includes four categories of accounts, which together expand and augment the economic data available from national accounts. They include the valuation of environmental assets, environmental impacts (such as the economic impacts of depletion and degradation) and physical flow accounts (including GHG emission accounts). The system includes several environment classifications, including:

- A classification of environmental assets.
- A classification of natural resource flows.
- A classification of residuals (*e.g.* emissions and waste).
- A classification of environmental protection activities and expenditure.
- Sub-classifications based on existing international standards (for instance, covering industries and products).

Other international frameworks include the United Nations Statistics Division (UNSD) *Framework for the Development of Environment Statistics,* published in 1984. A set of indicators is based on the *Framework* and covers economic, social and environment issues (UNSD, 2008a). The UN Commission on Sustainable Development list of *CSD*[13] *indicators* (UNDESA, 2007) includes economic, social and environmental themes, in the context of sustainable development. CSD environment indicators include climate change, air quality, land use and degradation, forest cover, freshwater availability and quality and biodiversity. Included amongst the economic indicators are three on ICT (number of Internet users, fixed telephone lines and mobile phone subscribers – all per 100 population). The CSD indicator framework is linked to the SEEA via common definitions and classifications (UNDESA, 2007). None of these frameworks explicitly recognises ICT's role in environmental change. Note also that it is difficult to fit ICTs, or any specific technology, into the SEEA.

Conceptual framework for statistics on *ICT and the environment*

Several frameworks for considering the relationship between ICT and the environment exist. Although they are not conceptual frameworks in a statistical sense, they provide useful information on the elements of such a framework and the relationships between elements. The following works are of interest for this scoping study:

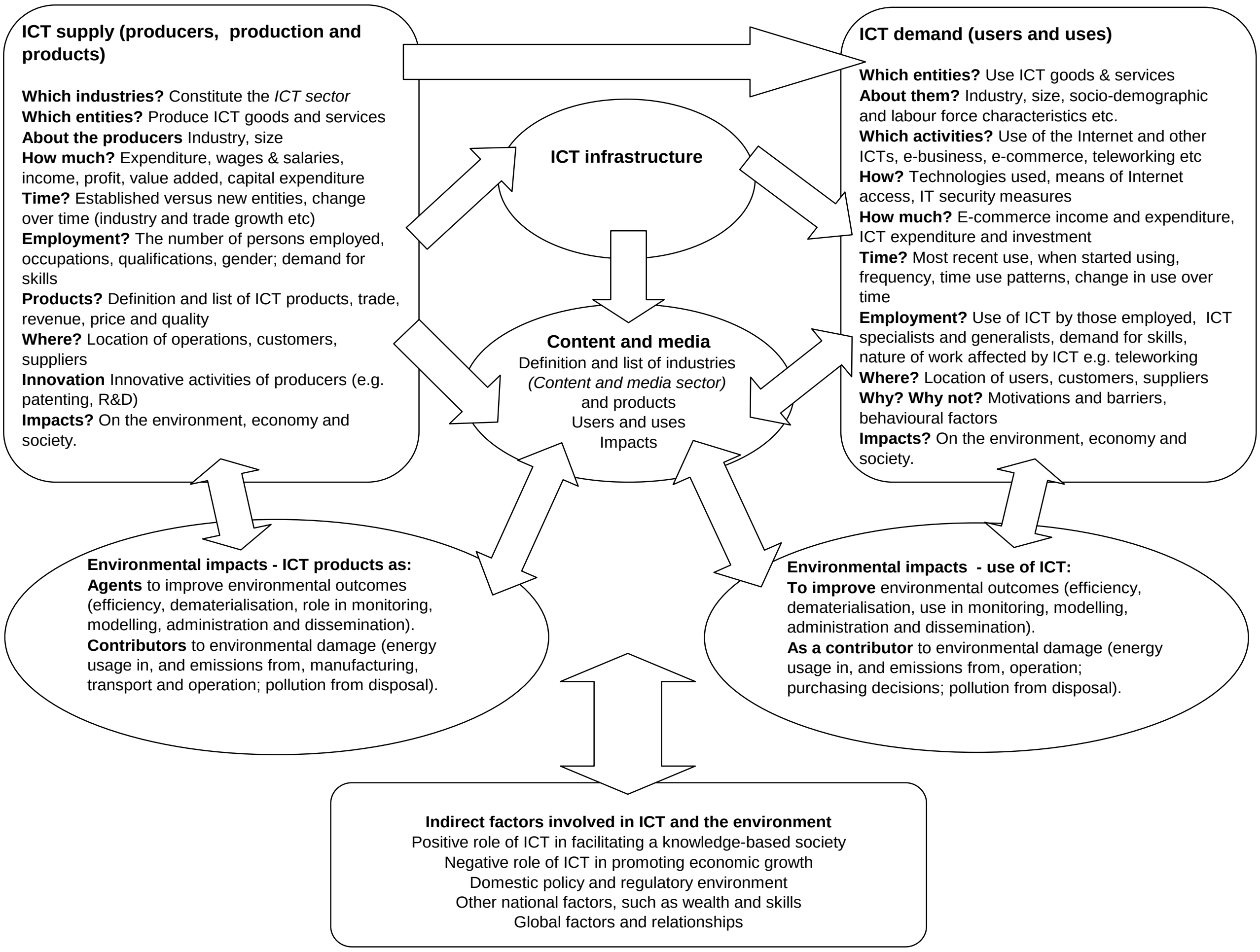
- The Global e-Sustainability Initiative considers both the positive role of ICT in climate change – ICT's role in a low carbon economy (enabling new business opportunities and improving efficiency in all sectors) and the negative role – the GHG emissions of ICT products (GeSI, 2008).

- The International Institute for Sustainable Development. Sustainable development has three pillars – economic, environmental and social. Climate change is cross-cutting and can be seen as a driver of economic and social change. Elements of the framework are ICT's role in dematerialisation and improving efficiency, the role of ICT-enabled networks, the ICT sector, confidence and e-waste (IISD, 2008). [14]

- EMPA (Swiss Federal Laboratories for Materials Testing and Research). The relationship between ICT and the environment is seen in terms of "ICT as part of the solution" and "ICT as part of the problem". Elements include technology, application and societal change (EMPA, 2008).

A model for *ICT and the environment* statistics, outlining the elements of a conceptual framework is proposed and is shown in Figure 1. It is an elaboration of the OECD's conceptual model for the information society (OECD, 2009a)[15] and incorporates elements of the frameworks outlined above.

Figure 1. *ICT and the environment* statistics conceptual model



Source: Adapted from OECD *Guide to Measuring the Information Society* (OECD, 2009a).

The identified ICT and environment elements of the conceptual model in Figure 1 need to be expanded to be useful. Proposed components are described more fully as follows:

ICT industries and products (ICT supply)

This covers ICT products (see Box 1) as agents to improve environmental outcomes (improved efficiency of existing products and processes, dematerialisation, essential role of ICT in monitoring, modelling, administration and dissemination) and as contributors to environmental damage (energy use and emissions in manufacturing, transport and operation, pollution from disposal). The positive role of ICT includes both mitigation and adaptation.[16] Whilst the IPCC reports do not detail particular technologies, nor attempt to analyse their impact, it is clear that information and communication technologies are expected to play an important role in both mitigation and adaptation. The IPCC makes the important point that the net impact of ICT on GHG emissions could be positive or negative depending on whether or not efficiency gains are offset by increases in production (IPCC, 2007b).

Positive and negative framework elements are:

- Improved efficiency of existing products and processes, including improved engine management systems, improved transport logistics, smart motors, building and home energy management systems, manufacturing and inventory processes (such as RFID), more efficient electricity grids and ICT systems used for early warning of disasters associated with climate change (such as hurricanes). R&D and other innovation relating to new and improved processes facilitated by ICT products are of interest.[17] In summarising mitigation options that are currently available and those expected to be available by 2030, the IPCC (2007b) refers to technologies that increase efficiency of energy supply and distribution, of motor vehicles, of domestic and commercial buildings, and industrial equipment and processes.[18] (See also the forthcoming work on measuring eco-innovation.[19])

- There are a large number of existing technologies enabling dematerialisation. However, enhancements and new products will arise through R&D and other innovation undertaken by the ICT and other sectors (for instance, the higher education sector).[18]

- The essential role of ICT in monitoring, modelling, administration and dissemination. It is clear that ICTs, as both general purpose and specific technologies, are necessary in order to carry out these processes effectively. Products include those used for environmental monitoring[20] (*e.g.* for monitoring weather and climate change and deforestation using satellite imagery), environmental modelling (*e.g.* computer simulations of climate change),[21] administrative processes (such as emissions/carbon trading schemes), and dissemination (including information sharing and environmental advocacy).

- ICT products as contributors to environmental damage. Obvious questions to ask are which ICT industries and products, what kinds of environmental damage, and the extent of damage? An important aspect of this component is R&D and other innovation directed towards producing more "environmentally friendly" ICT products to reduce the harmful effects. These would include more energy-efficient products and those that are less environmentally damaging when disposed of (for instance, with lower toxicity). It is clear that the negative impact of ICT on the environment is a problem that must be addressed by international organisations, governments, the ICT industry and consumers. In respect of the ICT sector, there are problems that are within the control of industry, including reducing energy use of ICT goods (for instance, reducing standby power requirements) and facilities (such as data centres), reducing the embodied energy of manufacture (for instance, by miniaturisation), reducing the extent of built-in obsolescence and reducing the toxic content of ICT goods. Both Gartner (2007) and The Climate Group and GeSI (2008) estimate that the ICT sector and ICT products are currently responsible for about 2% of global GHG emissions.[22] Unfortunately, the high rate of growth in ICT penetration and increases in processing power mean that, without mitigation, the harmful contributions of ICT are likely to grow quickly (ITU, 2008; The Climate Group and GeSI, 2008).[23]

ICT use (ICT demand)

This covers use of ICT to improve environmental outcomes (efficiency, dematerialisation, monitoring, modelling, administration and dissemination) and uses of ICT that result in environmental damage (energy usage in operation, purchasing decisions and pollution from disposal). Framework elements include:

- Questions on use of ICT to improve efficiency such as: which products and processes can be made more efficient by the use of ICT and by how much?

- Questions on dematerialisation include: what activities can be "dematerialised", which entities undertake these activities, and what is the current and potential impact of such activities? There are numerous examples of the use of ICT by organisations and individuals in dematerialisation. Impacts include reduced transport and other energy use, through consumption of virtual rather than tangible products – such as using online news media and magazines instead of newspapers; and using online movies and music instead of their physical analogues. Other examples include reducing physical mail and paper use; online purchasing; use of e-government services; video-conferencing; telemedicine; and teleworking and other remote working arrangements.

- As we saw above, there is an essential role for ICT through its use for environmental monitoring, modelling, administrative processes and dissemination. This is likely to be linked more generally to use of ICT by businesses, government organisations and individuals.

- Use of ICT as a direct contributor to environmental damage (energy usage in operation, purchasing decisions, pollution from disposal). The interest here is in how use of ICT has negative environmental impacts, which entities are responsible for such use, and the magnitude of damage. It is clear that ICT users have an important role in solving these problems, for instance, by using ICT more efficiently, carefully disposing of, or recycling, ICT goods and matching ICT equipment turnover to environment outcomes (which could mean either retaining equipment for longer or replacing it with more efficient equipment). In respect of disposal, the European Union has introduced a community waste strategy, which includes provision for disposal of electrical and electronic equipment waste (WEEE) and separation of hazardous substances, including those in ICT equipment The WEEE directive[24] of the EU is broader in scope than ICT (*e.g.* it includes large household appliances). Note that the term "WEEE" is also used beyond the EU.

- Behavioural factors and attitudes towards the environment and use of ICT are an important element of use. The provision of ICT-enabled solutions to mitigating, and adapting to, environmental damage will only result in better outcomes if those solutions are used – and users are aware of their options (and obligations). Therefore an important element of the conceptual model is the behavioural aspect of ICT use, for instance, how can people and businesses be encouraged to use ICT to improve environmental outcomes? What are the barriers to greater use of ICT for good environmental outcomes and to reduced use in the case of damaging environmental outcomes?

Indirect factors affecting ICT and the environment

- Indirect positive impacts of ICT on the environment no doubt exist, though these are likely to be impossible to measure. They could include the important role of ICT in promoting a knowledge-based society and subsequent link between education/knowledge and actions that have a positive effect on the environment (such as reduction in birth-rates and other acts of individuals that promote sustainable development).

- Arguably, ICT also has an indirect negative impact on the environment, for instance, through its role in increasing general *per capita* wealth through productivity and GDP growth (see OECD 2007a for a review of work in this area).

- National level factors. This will include the policy and regulatory environment for each country, level of education and skills, and wealth. Government policies and actions are very important and are likely to affect ICT production and use nationally. This level is not so relevant for this study (except for illustrative purposes).

- Global factors and relationships, including the influences of international organisations and partnerships. These will be vitally important in bringing understanding of, and action by, countries and industry to solve environmental problems. Production and use of ICT may be affected by outcomes of global agreements and treaties. The interest of a number of international organisations and consortia in the relationship between ICT and the environment was outlined in the introduction to this report.

Box 1. OECD definitions of ICT products (2009)

OECD defines ICT products in the following broad groups as follows:

- Computers and peripheral equipment
- Communication equipment
- Consumer electronic equipment
- Miscellaneous ICT components and goods
- Manufacturing services for ICT equipment
- Business and productivity software and licensing services
- Information technology consultancy and services
- Telecommunications services
- Leasing or rental services for ICT equipment
- Other ICT services

This list was finalised in 2009 and is based on the United Nations Central Product Classification (CPC Ver. 2). In respect of ICT goods, the main difference between this version and that of 2002 (see OECD, 2005) is the exclusion of "other ICT goods". Importantly, these include measuring, checking, testing and navigating equipment, many of which are relevant to ICT's role in monitoring environmental factors.[25] Note however that this new list has not yet been implemented in *e.g.* the *OECD Information Technology Outlook 2008* (OECD, 2008b).

Source: OECD (2009b).

Statistical indicators on *ICT* and on *the environment*

Given the likely importance of the relationship of ICT and the environment, it is useful to show global statistical data on time series trends in both fields.

A range of time series data are available for ICT, showing trends in trade in ICT goods, value added and employment of the ICT sector, growth in subscribers to ICT equipment, changes in prices charged, and changes in the level (and nature) of use of ICT by households and businesses.

In respect of the environment, international time series data are compiled by the OECD and UN agencies including UNSD, UNEP and UNFCCC. The OECD focuses on OECD countries (OECD, 2008c), while UN data cover all countries for which data are available (UNSD, 2008a). The UNEP has a repository of data series relating to the environment (UNEP, 2006).

Annex 1 shows a set of suggested statistical indicators on *ICT* and on *the environment*. They have been chosen for their availability (including across a number of countries and time periods), relevance and data quality.

Statistical data on ICT

There is a wide range of statistical data on ICT available at international level. Sources include:

- OECD publications: the biennial releases: *Science, Technology and Industry Scoreboard*, *Information Technology Outlook* and *Communications Outlook*.
- OECD *Key ICT Indicators* (web-based).
- Partnership on Measuring ICT for Development: *The Global Information Society: a Statistical View, 2008*.
- International Telecommunication Union: *World Telecommunication/ICT Indicators Database*.

These sources present information on a number of aspects of ICT, including:

- ICT infrastructure and access, including subscribers, prices, investment and revenues for ICT services.
- The ICT sector,[26] including value added, employment, R&D and other innovation.
- Trade in ICT goods[27] and services.[28]
- ICT patents.[29]
- ICT-related occupations and skills.
- Access to, and use of, ICT by households and businesses, including e-commerce, various Internet activities; IT security and broadband access.
- ICT productivity impacts.[30]

Statistical data on the environment

The OECD has produced a compendium of environment statistics (OECD, 2008c) and the UNSD presents a range of indicators on its website (UNSD, 2008a). Other UN bodies and international organisations are also active in data compilation, especially on greenhouse gases. The United Nations Framework Convention on Climate Change (UNFCCC) provides an inventory of sources on the latter.[31] The UNFCCC itself has a comprehensive database on GHG emissions data. While it does not compile global data (because of different reporting requirements for Annex 1[32] and non-Annex 1 countries), UNFCCC has more recent data than UNSD for Annex 1 countries, see UNFCCC (2007). UNFCCC compiled data for non-Annex 1 countries in 2005 (UNFCCC, 2005). Data are less current than for Annex 1 countries, with most countries reporting in respect of 1994 or earlier. About 40% of non-Annex 1 countries reported data limitations in relation to the IPCC methodologies employed and about half the countries reported uncertainties in reported data. There were also a number of variations in reporting by non-Annex 1 countries.

A number of data series on the environment are available from UNEP, via the GEO Data Portal (UNEP, 2006).[33] Series most relevant to this report are:

- Emissions of CO_2 – from All Anthropogenic[34] Sources; from Cement Production; from Fossil Fuels – Total; from Gas Flaring; from Gas Fuel Consumption; from Liquid Fuel Consumption; from Manufacturing Industries and Construction; from Power Generation; from Public Electricity and Heat Production; from Residentials, Commercials and Other Sector; from Solid Fuel Consumption; from Transport; and from Transport Road.

- Emissions of CO_2, Total, Excluding* and Including Land Use, Land-Use Change and Forestry.

- Emissions of GHGs – from Agriculture; from Industrial Processes; from Transport; and from Waste.

- Emissions of GHG (CO_2, CH_4, N_2O, HFCs,[35] PFCs[36] and SF_6[37]), Total, Excluding and Including, Land Use, Land-Use Change and Forestry.

- Energy Consumption for Road Transport Sector; Total Transport Sector.

- Motor Vehicles in Use – Commercial Vehicles per Thousand People; Number of Commercial Vehicles; Number of Passenger Cars; and Passenger Cars per Thousand People.

- Energy Production – Combustible Renewables and Waste; Crude Oil; Hydro; Natural gas; Nuclear; and Total.

- Proportion of Land Area Covered by Forest.*

- Change in Glacier Mass – Mean Cumulative Net Balance.*

- Renewable Energy Supply Index – Biofuels; Geothermal; Hydro; Solar; Tide, Wave, Ocean; and Wind.*

- Primary Energy Supply – Coal and Coal Products; Combustible Renewables and Waste; Crude Oil; Geothermal; Hydro; Natural Gas; Nuclear; Petroleum Products; and Solar, Wind, Tide and Wave; Total.

- Energy Supply per $1000 Gross Domestic Product (PPP).*

The IPCC, in its 2007 reports, presents a number of time series – some very long. For instance, in its 2007 *Synthesis Report* (IPCC, 2007a), IPCC presents time series data on surface temperature, sea level and Northern hemisphere snow cover ranging from 1850 to about 2005. The report of Working Group I presents very long time series data on concentrations of GHG (IPCC, 2007c). The *Synthesis Report* presents several scenarios for future concentrations of GHG and surface temperature.

The OECD publication *OECD Key Environmental Indicators, 2008* (OECD, 2008c) presents a set of selected "core indicators". According to the publication, the selection took into account:

- Policy relevance ("with respect to major challenges for the first decade of the 21st century").

- Analytical soundness.

- Measurability.

Statistics are presented according to the following broad headings:

- Climate change – CO_2 emission intensities and index of greenhouse gas emissions.[38,39]
- Ozone layer – ozone depleting substances.
- Air quality – SO_x and NO_x emission intensities.
- Waste generation – municipal waste generation intensities.
- Freshwater quality – waste water treatment connection rates.
- Freshwater resources – intensity of use of water resources.
- Forest resources – intensity of use of forest resources.
- Fish resources – intensity of use of fish resources.
- Energy resources – intensity of energy use.[40]
- Biodiversity – threatened species.

UNSD environment indicators cover the following areas (UNSD, 2008a):

- Water (water resources, water supply industry, waste water).
- Air Pollution (SO_2 emissions, NO_x emissions).
- Climate Change[41] (Greenhouse gas emissions[42] (GHG) per capita, GHG emissions by sector,[43] CO_2 emissions,[44] CH_4 and N_2O emissions[45]).
- Waste (Municipal waste collection, Municipal waste treatment, Hazardous waste).
- Land Use (Total surface area, Forest area, Agricultural land).

Statistical indicators linking ICT and the environment

The field *ICT and the environment* is a new one. Consequently, statistics directed to the policy questions related to the field are scarce. In respect of official statistics, it is necessary to look for data that throw light on relevant aspects of the field, though were not necessarily collected with a view to answering policy questions about the relationship between ICT and the environment.

Several useful studies, which are not based on official statistics, have been carried out on the relationship between ICT and the environment. A recent and comprehensive study of the potential impact of ICT products has been carried out by The Climate Group and GeSI (2008), *SMART[46] 2020 – Enabling the low carbon economy in the information age*. It found that the greatest potential for a positive impact of ICT to 2020 is to increase the energy efficiency of a number of industrial processes that are high GHG emitters – specifically, power transmission and distribution, buildings, manufacturing industry and transport. Reductions would also be enabled by dematerialisation but these are relatively small. In respect of the negative impact of the ICT sector, the report makes the point that massive efficiency gains are required to offset expected increases in penetration of ICT goods and services[47] by 2020. The report found that better use of ICT to improve efficiency of other industries and to enable different ways of doing things (dematerialisation) could potentially reduce total GHG emissions by as much as five times the emissions of the ICT sector. It identifies the major opportunities as being: dematerialisation, smart motor systems, smart logistics, smart buildings and smart grids.

A 2004 report commissioned by the European Commission's Institute for Prospective Technological Studies (IPTS) looked at a similar set of ICT impacts by 2020, including energy use of ICT products, several dematerialisation options, intelligent transport, role of ICT in energy supply, and ICT's role in facility and production process management (IPTS, 2004). The report found a much greater potential for GHG reduction associated with virtual products than the GeSI report.

Similar studies have been undertaken for individual countries, for instance, a study by the Japanese Ministry of Internal Affairs and Communications (MIC) on the contributions of ICT to reduction in GHG emissions (cited by Fujitsu, 2008).

Selection of statistical indicators on ICT and the environment

An important issue to consider with all statistics is the extent to which they are reliable according to a range of criteria, including policy relevance, accuracy, timeliness and currency, accessibility and clarity, and international comparability.

In respect of ICT statistics, OECD (2007b) and the Partnership on Measuring ICT for Development (2008) refer to several aspects of data reliability. The latter highlights poor data availability for some indicators, especially for developing economies, and a general lack of international comparability for many survey based indicators.

In respect of environment statistics, UNSD presents information on the policy relevance and data quality of the indicators it presents. UNEP provides metadata on sources and concepts, and identifies a set of core indicators that are stated to be relatively reliable. The UNFCCC focuses on both the currency and quality of emissions data it collects; in particular, it is clear that there is a statistical gap for the indicators on GHG between those countries that are Annex 1 parties to the Climate Change Convention and the remaining (non-Annex 1) parties.[42] The OECD has selected the more reliable indicators and provides comments on measurability, including data quality, availability and gaps.

The information of interest is broadly described in the conceptual model presented earlier. Statistical data can be described in terms of the same conceptual model as follows:

ICT industries and products

- ICT products as *agents* to improve environmental outcomes (improved efficiency of existing products and processes, dematerialisation, essential role in monitoring, modelling, administration and dissemination). Statistical indicators could include data on patenting activity for new and improved ICT products (see also OECD work on measuring eco-innovation using patent data, OECD, 2008e) and data on R&D undertaken by the ICT sector that has an environment objective and/or is in an environment field of science. In a statistical sense, both the ICT sector (industry) and ICT products have been defined by the OECD.

- ICT products as direct *contributors* to environmental damage (energy use and emissions in manufacturing, transport and operation, pollution from disposal[48]). Statistical indicators could include data on patenting activity for ICT products that are more "environmentally friendly" and data on R&D in this area. Other important data sources include analytical and life cycle studies on ICT goods. The former include studies that measure the emissions attributable to ICT (for instance, Gartner (2007)). The latter are described by EMPA (2008) as calculating "… the relevant environmental impacts of the life cycle per functional unit." Life cycle studies include impacts in all phases – design, production, use and disposal – but are difficult to aggregate. EMPA presents some findings of such studies, including the environmental impact of recovery of e-waste components compared with disposal by incineration.

ICT use

- Use of ICT to improve environmental outcomes (efficiency, dematerialisation, monitoring, modelling, administration and dissemination). There appear to be little official statistical data on use of ICT to improve efficiency. One example is data from Statistics Canada showing growth between 1994 and 2006 in use of programmable thermostats by households (Statistics Canada, 2006a). There are some official statistics on dematerialisation, this being an important area of ICT policy interest (in large part, because of its potential for improving productivity). Data are available on teleworking by individuals and use of teleworking by businesses, use of business processes such as video-conferencing, e-commerce (by businesses and individuals), and trends in paper use and changes in the volume of physical mail. Importantly, most of these statistics derive from surveys and data can therefore be tabulated by characteristics such as individual age and business size. Official data on use of ICT for monitoring, modelling, administration and dissemination are unlikely to be available. However, given the essential role of ICT in those processes, it could be argued even without statistical evidence, that they would be vastly less efficient in the absence of ICT.

- Use of ICT as a contributor to environmental damage (energy usage in operation, purchasing decisions, pollution from disposal). Life cycle studies are of some relevance, along with data on ICT use and numbers of subscribers. Comparable statistics on the amount of electrical and electronic equipment waste (WEEE) are not widely available, although data are available for individual countries, for example, data for the Nordic countries, Netherlands and Switzerland (TemaNord, 2003). The Households and the Environment Survey run by Statistics Canada in 2006 examined household disposal of ICT equipment, although other countries do not appear to have collected similar data. More generally, OECD (2008c) reports that data on waste generation and disposal are weak in many countries. It would also be useful to know the existing stock of ICT equipment that may be disposed of in the future so that the extent of the future problem can be quantified.[49]

- Behavioural factors. Individuals' positive and negative attitudes to the environment would be of interest, especially when compared with ICT use by the same groups (for instance, the same age groups).

Other factors affecting ICT and the environment

- Domestic policy and regulatory environment, global factors and relationships, and influence of other factors such as level of education and skills, wealth. Some activities of government may be measurable for some countries (for instance, R&D in an ICT field directed towards an environmental objective). Regarding factors such as level of education, for some countries, it is possible to tabulate data on teleworking, and Internet activities by level of education and income. In general, there is a strong positive correlation between the level of education and income, and use of ICT.

Annex 1 shows available statistical indicators on *ICT and the environment*. While they address some of the above elements of the conceptual model, they clearly represent only a small fraction of the data required to throw light on this important topic.

Information on much of the available data is presented below, representing statistics from international organisations and individual countries.

Availability of official statistics[9] linking ICT and the environment

Environmental drivers for innovation by ICT sector businesses

A number of countries collect data on the innovative activities of businesses. The *Oslo Manual* for measuring scientific and technological activities (OECD and Eurostat, 2005) suggests that countries collect data on objectives for innovation, including "develop environment-friendly products", "reduce environmental damage" and "cutting energy consumption" (as a means of lowering costs).

Several countries, including European countries that undertook the Community Innovation Survey, 2002-2004 (CIS4), have collected some data on these and similar drivers. Of particular interest for this project would be data on the environment-driven innovation activities of ICT sector businesses. The CIS4 questionnaire (Eurostat, 2004) asks about the importance of the effects of product and process innovations during 2002-2004 and includes the response items, "Reduced environmental impacts or improved health and safety" and "Reduced materials and energy per unit output". Data are available on the proportion of businesses, including ICT sector businesses, which reported that these effects were highly important. As at May 2008, the draft CIS 2008 questionnaire included a module on environmental benefits (Eurostat, 2008a). Questions included one on the environmental effects of innovations, with a number of response categories, covering the environmental benefit to the enterprise and to the ultimate product user. There were also questions on innovative activity undertaken for regulatory requirements and whether the firm had introduced systems to regularly identify and reduce environmental impacts.

The Australian Business Characteristics Survey of 2006-07 asked all innovating businesses the main reasons for developing or introducing new goods, services, processes or methods (ABS, 2007a). The reasons included "Reduce environmental impacts". The survey also asked about barriers to innovation, including environmental factors. Unfortunately, the sample sizes used do not allow data on reasons and barriers to be tabulated for the ICT sector.

Statistics New Zealand, in its 2005 innovation survey, collected information on reasons for innovating including "Reduce energy consumption" and "Reduce environmental impact" (Statistics NZ, 2007).

The Canadian Innovation Survey of 2005 asked about the importance of success factors, including “Ability to comply with environmental standards and regulations”. The survey also asked about the importance of various impacts of innovation, including “Reduced environmental impacts” and “Reduced materials or energy per unit output” (Statistics Canada, 2005).

Use of patent data to examine inventions that link ICT and the environment

There are several patents databases that might be used to find patents for ICT products that, if commercialised, would result in benefits for the environment. The most relevant patents would be for ICT products that:

- Have improved energy efficiency in manufacture or usage (PCs, monitors and data servers are particularly high-energy users, though any ICT equipment, including consumer electronics, which uses power is of interest).

- Improve functionality of processes that would ultimately lead to reduced energy use, such as systems for video-conferencing/tele-meeting, engine management and new engine technologies, intelligent transport (including traffic control to reduce congestion), building management (for instance to control temperature and lighting) and public lighting.

- Assist/optimise power generation by alternative and traditional sources; and/or

- Assist in reducing emissions from traditional power generation (for instance, an ICT role in carbon sequestration).

Additionally, there will be many inventions that are not for ICT products and/or the environment specifically, but will reduce the environmental impact of ICT (such as different types of batteries and materials). In both cases, it is suggested that technical expertise is needed to identify relevant keywords for searching. Some work has already been done in this area by the OECD (for instance, on motor vehicle pollution control technologies) though not to the extent of ICT components (OECD, 2008 e,f). There are limits to this work due to the lack of comprehensiveness of patent data (some firms do not patent and the degree of patenting varies by technology, sector and country).

R&D performed by the ICT sector and R&D in an ICT field with an environment objective

From a policy viewpoint, funding of ICT R&D with an environmental and/or energy objective is becoming increasingly evident. OECD has summarised a number of ICT R&D funding programmes, many of which have environmental or energy objectives (OECD, 2008b). OECD and European Union member countries (as well as some non-member economies) compile R&D statistics according to the *Frascati Manual* (OECD, 2002). Data are classified by industry (including the ICT sector), field of science and socio-economic objective.[50] The relevant categories are as follows:

- Field of science (FOS) categories, “Earth and related environmental sciences”,[51] “Mathematics and computer sciences and Electrical engineering, electronics”.

- Socio-economic objectives (SEO), “Control and care of the environment”[52] and “Production, distribution and rational utilisation of energy”.[53]

- ICT and environment industry and product fields (both applying to business sector R&D).[54]

For the purposes of this study, the main interest would be in data that link ICT and the environment, for example:

- To show R&D performed by the ICT sector for the FOS category “Earth and related environmental sciences” and/or the SEO categories “Control and care of the environment” and “Production, distribution and rational utilisation of energy”; and

- Cross-classified data between ICT and environment categories, for example, by the “Control and care of the environment” SEO for all sectors.

Unfortunately, the OECD is unable to produce such cross-classifications. However, it is able to provide simple time series data at country level on:

- Intramural R&D expenditure performed by the ICT sector in current and constant prices, by country (OECD and some non-OECD), and

- Expenditure on intramural R&D directed towards the objective “Control and care of the environment” (by country and institutional sector).

Some individual countries may be able to produce R&D data for the ICT sector with an environmental objective or field, or R&D in an ICT field with an environment objective.[55] Australia collects data according to industry, a detailed *Research fields, courses and disciplines* (RFCD) classification (equivalent to the OECD’s Field of science) and a detailed *Socio-economic objective* (SEO) classification.

The 1998 version of the RFCD classification (in use until 2007) includes a number of detailed classifications on the environment,[56] ICT[57] and other relevant categories, including *Automotive engineering, Environmental engineering, Architecture and Urban Environment* and *Building*.

The 1998 version of the SEO classification has detailed categories, including *Environment*, with detailed sub-categories (such as climate change and climate variability). It also includes the categories *Energy resources* and *Energy supply (*each with a number of detailed categories including renewable energy)*,* as well as *Prevention and treatment of pollution* (by industry sector, including mining, energy supply, manufacturing, construction, transport, ICT services, and commercial services and tourism). There are several ICT categories, including a number of ICT manufacturing and services categories (ABS, 1998).

Detailed data on ICT and the environment, based on the 1998 classifications, are available as follows:

- ICT sector R&D expenditure in environment fields, including environmental engineering (RFCDs); and

- ICT sector R&D expenditure directed towards environment, atmospheric sciences, energy and prevention/treatment of pollution objectives.

However, data are not available showing R&D in an ICT field classified by an environment or energy objective.

The 2008 version of the classifications (ABS, 2008a) also includes detailed *Field of research* (equivalent to the OECD’s Field of science) and *Socio-economic objective* categories in respect of the environment and ICT. The first outputs using the new classification will be available for the 2007-08 Business R&D release and the 2008-09 releases for other sectors. Note that the 2008 version is a joint classification that will also be used by Statistics New Zealand.

Similar tabulations could possibly also be produced from Statistics Canada's R&D data.

Sweden (through the International Institute for Industrial Environmental Economics) is carrying out a survey of R&D in the area of ICT and environment, with a focus on indirect and systemic effects.

Individuals' teleworking trends

For the purposes of this study, the word "teleworking" is used to describe home-based work that is enabled by ICT. Other terminology includes "e-working" and "telecommuting". There is no internationally agreed definition, nor recommended method of collection. As a result, statistics on teleworking can be difficult to interpret and compare. For instance, some statistical organisations distinguish work at home that is in addition to work undertaken at the workplace, from work at home that substitutes for working at the workplace. However, most do not. Other concepts and definitions may differ even for a given country (for instance, Canada) and collection methodologies vary. Nevertheless, it is useful to look at teleworking trends for several countries for which time series data are available.

Between 1997 and 2007, the United Kingdom's Office for National Statistics collected teleworking data as part of its Labour Force survey. The surveys asked respondents whether they worked from home and whether such work is enabled by the use of ICT (a telephone and a computer) (ONS, 2005; eironline, 2008).

Statistics Denmark collected similar data through the Danish Labour Force Survey between 2000 and 2006. The relevant questions were: "Have you worked from home in the past 4 weeks?" If yes, "Do you have a home-office with connection to the network of your workplace?" From 2007, only the first question is included in the survey (personal communication, National IT and Telecom Agency, Denmark).

Statistics Canada has collected data on teleworking from several surveys but the data are generally not very comparable. However, data from the 2000 and 2005 General Social Surveys can be compared reasonably well and show changes over the period in teleworking trends (Statistics Canada, 2007).

Data on the incidence of working away from the place of work are collected in the Quality of Work Life Surveys conducted by Statistics Finland. Data were collected in 1977, 1984, 1990, 1997, 2003 and 2008 (Statistics Finland, 2007, 2008).

The Australian Bureau of Statistics has, from time to time, collected data on teleworking. The most recent example is a small module on the 2006 Time Use Survey. A filter question asks whether the respondent has an agreement with his/her employer to work from home on an ongoing basis (in his/her main job). A follow up question asks whether the work from home is enabled by ICTs, including access to the employer's computer system via a modem, a portable PC and/or a mobile phone (ABS, 2008b).

The Australian population censuses of 2001 and 2006 collected information on whether people worked from home on census day (but not whether such work was enabled by ICT) (ABS, 2002, 2007b).

Motor vehicle use and potential savings from teleworking

Australia is one of the few OECD countries where the national statistical office (the Australian Bureau of Statistics) has current surveys that collect official statistics on personal transport use.[58] They include an annual survey of motor vehicle use that collects a range of data about motor vehicle use including distance travelled and fuel used split by type of vehicle and purpose of travel (ABS, 1999, 2003, 2007c, d and 2008c). In addition, the five-yearly Census of Population and Housing collects information on method of travel to work on census day and the number of people who worked from home on that day (ABS, 2002, 2007b). These surveys can show changes in patterns of transport use over time and enable CO_2 emission reduction scenarios to be constructed, assuming an increasing level of dematerialisation activities, including teleworking and some personal use activities, such as shopping, banking and dealing with government.

Estimates of potential emissions savings through teleworking have also been constructed for France (Ministry of Economy, Industry, and Employment, 2008).

Teleworking also offers potential savings of emissions attributable to employers' premises. However, these savings are less certain than those from transport because of offsetting emissions from home-based work and because business premises are unlikely to become smaller until a relatively large proportion of worker days are spent away from the premises.

A series of Australian household surveys from 1996 to 2006 have collected information on people's usual method of travelling to work or study, and their reasons for choosing each method (ABS, 2008d). Such data throw light on the behavioural barriers to greater use of public transport and may suggest ways to reduce those barriers by greater use of ICT (for instance, improving attractiveness by having Internet access on trains, use of ICT to better manage transport and therefore improve reliability, better use of websites and SMS technology to provide information on timetables and trips). The ABS surveys also show the reasons why people use public transport, including concern for the environment.

European business incidence of remote employment

Eurostat co-ordinates, and compiles data from, the European Community Surveys on ICT Usage and e-Commerce in Enterprises. For 2006, data are available for the proportion of enterprises that have employed persons who connect to IT systems through networks (including locations: home, customer or business premises, other locations of enterprise group and during business travel). Data can be classified by country, industry and business size.

Comparison of the characteristics of ICT users and those showing concern for the environment

An interesting study that could increase understanding of the more general social dynamics, would be to compare the socio-demographic characteristics of high ICT users with those whose views or attitudes indicate a concern or awareness for environmental issues. Such studies could help us understand the propensity of heavy ICT users to use ICT for purposes that are beneficial to the environment (such as becoming teleworkers or facilitating teleworking by others) or to use ICT in ways that add to or limit environmental damage (for instance, using ICT inefficiently/efficiently). Ideally, such a study would be carried out via a single survey, so that information on each individual's use of ICT and their views on the environment could be directly compared, and data tabulated by all characteristics likely to affect individuals' views and actions (these include age, gender, level of education, occupation, income, whether they are parents and home ownership). However, no such survey is known. Instead, we could examine ICT use datasets disaggregated by characteristics such as age, gender and occupation and separate datasets, similarly disaggregated, for environmental views. Whilst surveys of ICT use by individuals are carried out by many countries (especially developed economies), few countries conduct surveys of views or attitudes towards the environment.

A notable exception is the United Kingdom, which conducted a survey of attitudes and behaviour in relation to the environment in 2007 (DEFRA, 2007).[59] The scope of the survey was adults (aged 16 or over) living in England and it was conducted in mid-2007. Much of the individual level data are available classified by age and gender. Some data are available classified by the characteristics, "tenure", "household income" and "social grade" (a simplified occupation characteristic). Of interest is information on awareness and attitudes to the environment, and how this is reflected in current behaviour. Examples of the former include understanding of biodiversity and attitudes to carbon offsetting. Examples of the latter include use of motor vehicles, energy saving behaviours and recycling. Data are also available on grocery shopping via the Internet, split by a number of individual and household characteristics.

A more limited example comes from Australia, which conducts regular surveys of ICT use and, in 2006, also conducted a survey on environmental views. Most of the data collected in the latter were for households, though a small number of questions were directed towards individuals. Information is available, broken down by age, on reasons for taking public transport to work or study, and on reasons for cycling or walking to work or study (both including environmental concerns).

There are complications with this form of analysis, including the presence of other factors that might be related to the characteristics of interest. For example, young people could be less inclined to insulate their homes because they are renters or have a relatively low income. Likewise, they may be less likely to use a motor vehicle to travel to work or study because of income constraints, rather than environmental concerns.

Trends in Internet activities as a substitution for material activities (dematerialisation)

Eurostat, through its Community survey on ICT Usage in Households and by Individuals, has good time series data on use of the Internet by individuals for a range of "dematerialisation" activities (Eurostat, 2008b). They include use of the Internet:

- For finding information about goods and services.
- For reading/downloading online newspapers/news magazines.
- For Internet banking.
- For selling goods and services (*e.g.* via auctions).
- For formalised educational activities (school, university, etc.).
- For doing an online course (of any subject).

- For dealing with government.
- For ordering/buying goods or services, over the Internet, for private use, in the last 3/12 months, including the type of goods and services ordered;[60] and
- Goods and services ordered over the Internet that were delivered or upgraded on line, including films or music; books, magazines, newspapers or e-learning material; and computer software (including video games).

With the exception of Internet use for formalised educational activities, these items are included on the Eurostat surveys for 2008 and 2009. For 2006 and earlier years, Eurostat has data on barriers to Internet purchasing. Data on barriers to e-commerce will be collected in the 2009 surveys.

A number of other countries collect similar information on Internet activities. These have been recently compiled by the Partnership on Measuring ICT for Development (2008) based on data collections by Eurostat and ITU. OECD also collects such data from its member countries that are not covered by the Eurostat collections and these are published (along with Eurostat data) in the biennial *Scoreboard* publication (OECD, 2007b).

As these data are survey-based, they include classificatory detail that can be quite illuminating. For instance, if younger people are more likely to use the Internet for dematerialisation activities, that could indicate a generational change in favour of the environment (whether or not those young people are motivated by environmental goals).

Changes in use of paper and physical mail

In 2006, Eurostat collected information on the extent of individuals' substitution of traditional postal mail by mobile phone or e-mail messages. Data are available by country and by individual characteristics.

The Statistics Canada publication *Our Lives in Digital Times* (Statistics Canada, 2006b) used official and non-official statistics to examine whether some of the predictions about the impacts of ICT had eventuated. Of relevance to this study are data on changes in the extent of physical mail as the incidence of e-mail increases and changes in the use of printing and writing paper – the so-called "paperless office" prediction.

In respect of the volume of physical mail, data were presented for Canada. In respect of production and consumption of paper, data were presented for Canada and the United States, with the world total for paper production. Note that data on paper production are available for other countries as well, through FAOSTAT (FAO, 2008).

ICT equipment as a contributor to waste

Unfortunately, official statistics on ICT waste (or 'e-waste') appear to be scarce. An exception is data from the Households and the Environment Survey run by Statistics Canada in 2006. The survey examined household disposal of ICT ("Unwanted computers or communications devices") with response categories, "Put into the garbage", "Still had them in 2005 and did not know what to do with them", "Returned to depot or drop-off centre", "Returned to supplier" and "Donated or gave away" (Statistics Canada, 2006a).

The Australian Bureau of Statistics cited data on e-waste in Australia in a feature article on solid waste (ABS, 2006) and confirmed a growing stockpile of domestic ICT equipment and growth in e-waste. The data came from several sources including a market research survey[61] conducted in 2005 for Australian governments by Ipsos (cited in ABS, 2006).

Recommendations

This report proposes a conceptual framework for the statistical field "ICT and the environment" based on an existing OECD framework for information society statistics. Sources of official data that could be used to populate the framework have been investigated and some relevant work found.

Given the potential for ICT to both lessen and worsen environmental outcomes, it is recommended that national statistical offices respond to the findings of the report and increase their measurement efforts in this area. Responses by the statistical community could include:

- Undertaking targeted household surveys (or expanding existing ICT use *or* environment surveys) to collect information that links individual ICT use with environmental behaviours and concerns.

- Expanding household surveys to collect information about unused ICT equipment and disposal of ICT equipment.

- Adding questions to existing business ICT use surveys on the uses of ICT that can have a positive or negative effect on environmental outcomes. Examples include details of remote working facilities offered to employees; the number of worker days not spent on business premises; dematerialisation of energy-intensive activities such as business travel; questions on barriers to such activities; disposal of ICT equipment; and adoption of environmentally friendly building, transport, or energy systems.

- Expanding classifications (such as those for field of science and socio-economic objective used in R&D surveys) to better reflect ICT and the environment.

- Ensuring that sample sizes are sufficient to enable better tabulation of the ICT sector (for instance, in innovation surveys) and cross-tabulation of data by characteristics of interest (for example, Internet activities by age and gender).

- Emulating some of the relevant data collection work outlined in the report, for instance, the teleworking data collections of the United Kingdom, collected in labour force surveys.

- Focussing on time series data, which are of particular importance in this field as most of the achievement targets are expressed in terms of time.[62]

Further OECD work on this topic could include:

- Compilation and presentation of data from the sources described in this report.

- Development of model questions for collection of data linking ICT and the environment.

- Development of a core set of indicators of the relationships between ICT and the environment. Some possible core indicators are described in Annex 1.

ANNEX 1. SELECTED INDICATORS ON ICT AND THE ENVIRONMENT

INDICATOR	SOURCE[63] AND AVAILABILITY	COMMENTS (those marked ** are likely to be problematic)
Background (context) indicators on ICT		
Fixed broadband Internet subscribers per 100 inhabitants, time series, by level of development.[64]	ITU, widely available (about 180 economies).	Selected because of their wide availability, relatively long time series and established methodology and collection procedures.
Mobile cellular telephone subscribers per 100 inhabitants, time series, by level of development.	ITU, widely available (about 220 economies).	
Trade in ICT goods as a proportion of total trade, time series, by imports and exports, by level of development.	UN COMTRADE, widely available (about 165 economies).	
Proportion of households with ICT – computer and the Internet – by individual country and EU27, limited time series.	Various sources (ITU, OECD, Eurostat, UNECLAC, NSOs), available for most developed economies and for a reasonable number of other economies.	Selected because of the importance of showing demand for ICT by households.
Proportion of individuals who used ICT – computer and the Internet – in the last 12 months by age, by individual country and EU27, limited time series.	As above, but available for fewer less developed economies.	Selected because of the importance of showing demand for ICT by individuals; there are some differences in age scope across countries. Data can be classified by various individual characteristics, such as age and gender.
Proportion of businesses that use ICT – computer, the Internet and web presence – by size, by individual country and EU27, limited time series.	Various sources (UNCTAD, OECD, Eurostat, NSOs), available for most developed economies and a small number of other economies.	Selected because of the importance of showing demand for ICT by businesses; there are some differences in industry and size scope across countries.
ICT sector value added as a proportion of total business sector value added, time series, individual countries.	UNCTAD, OECD, UNIDO, available for most OECD countries and a small number of other economies.	**Selected to show growth in the ICT industry over time; there are a number of differences in the way the ICT sector is defined across countries.
R&D expenditure in selected ICT industries, time series, individual OECD countries.	OECD, available for OECD countries and possibly a small number of non-OECD countries.	Selected to show the size and growth of R&D by the ICT sector.

INDICATOR	SOURCE AND AVAILABILITY	COMMENTS (those marked ** are likely to be problematic)
Background (context) indicators on the environment		
Atmospheric concentrations of GHG, long time series and future scenarios (to 2100).	IPCC, Fourth Assessment Report, total world.	Key indicators of climate change.
Anthropogenic GHG emissions by main source, 1970 to 2004.		
Global average surface temperature, changes over time.		
Global average sea level, changes over time.		
Northern hemisphere snow cover, changes over time.		
Emissions of CO_2, total, excluding and including, land use, land-use change and forestry, long time series.	UNEP, regions and world.	Key indicators of contribution to climate change by regions. *Total excluding land use* etc is a core UNEP indicator and therefore considered to be reliable.
Proportion of land area covered by forest, 1990, 2000 and 2005.	UNEP, regions and world.	Key indicator of contribution to climate change, a core indicator and therefore considered to be reliable.
Renewable freshwater resources per capita, time series from 1990.	UNSD (compiled from several sources), available for a large number of economies.	Of environmental significance, in part, because of the likely effect on rainfall of climate change.
Primary energy supply – main traditional sources and aggregated alternative energy (solar, wind, tide and wave), long time series	UNEP, regions and world.	Indicates growth in energy supply and change in share of alternative energy sources.
Renewable energy supply index – biofuels; geothermal; hydro; solar; tide, wave, ocean; and wind.	UNEP, world.	Indicates growth in use of classes of renewable energy sources, a core indicator and therefore considered to be reliable.
Passenger cars per 1000 population	UNEP, available for some countries, regions and world.	**Indicates growth in a commodity that is a major contributor to emissions, data not very recent (individual series end at 2003 or earlier). Data do not distinguish fuel-efficient passenger cars from those that are not.
Expenditure on intramural R&D directed towards the objective "Control and care of the environment", by country and institutional sector.	OECD, available for OECD countries and possibly a small number of non-OECD countries.	Measure of R&D effort directed towards the environment.

INDICATOR	SOURCE AND AVAILABILITY	COMMENTS (those marked ** are likely to be problematic)
Indicators on *ICT and the environment*		
Innovation by the ICT sector directed to environmental objectives.	Eurostat, NSOs. Such data are feasible in terms of international standards (promulgated by the OECD and Eurostat) and the data collections of a number of (mostly developed) economies.	It is possible that sample sizes are currently insufficient to identify such innovative activities (with the possible exception of European countries that conduct the CIS surveys).
Patenting activity linking ICT and the environment (including for products that improve the performance of ICT products, such as better batteries), time series should be possible.	OECD patents database, data cover most patenting activity.	The extraction of these data is not straightforward and may require technical expertise to select relevant keywords.
R&D expenditure by the ICT sector, in an environment field, or directed towards an environment objective; limited time series may be possible.	Australia is the only country known to produce such data; further investigation of sources would be useful.	**R&D is a key component of innovative activity. Data should be of reasonable quality but appear to be of very limited availability.
Teleworking incidence (time series) by individuals (UK, Canada, Finland), scenarios based on travel data (Australia).	UK, Canada, Finland, Australia; further investigation of sources would be useful.	An example of dematerialisation, considered by many to be an important mechanism for ICT to mitigate damage to the environment; data are reliable but not necessarily comparable between countries.
Proportion of enterprises that have employed persons who connect to IT systems through networks (including locations: home, customer or business premises, other locations of enterprise group and during business travel). Data are available for 2006 only.	Eurostat, EU member countries and several other participating countries	Considers teleworking, and other forms of remote access, from the perspective of the employer. Data are considered reliable and comparable; they can be disaggregated by size and industry.
Comparison of the characteristics of ICT users and those showing concern for the environment.	Such an analysis appears to be feasible only for the United Kingdom, with very limited information available for Australia.	The complications with this form of analysis are explored in the body of the report.
Individual Internet activities such as using the Internet for finding information about products, reading/downloading online newspapers/news magazines, Internet banking, selling products, educational purposes and dealing with government.	OECD, Eurostat, ITU, UNECLAC, data are available for most developed economies and a number of other economies.	Various examples of dematerialisation.
Incidence of Internet commerce (buying and selling over the Internet), individuals and businesses, some time series data are available. For individuals, some information from Eurostat is available on products ordered over the Internet that were delivered or upgraded on line (films or music; books, magazines, newspapers or e-learning material; and computer software (including video games)).	OECD, Eurostat, ITU, UNCTAD, data are available for most developed economies and some other economies.	Another potentially important example of dematerialisation. Data are reasonably widely available, and, for OECD and Eurostat countries at least, fairly comparable. Comparability issues arise mainly through age scope differences. Data on downloading of digital products from Eurostat are particularly relevant.

INDICATOR	SOURCE AND AVAILABILITY	COMMENTS (those marked ** are likely to be problematic)
Indicators on *ICT and the environment* (continued)		
Change in paper production and physical mail.	Data are available from FAO, Canada and Eurostat. Time series data on paper production are available for a number of countries from FAO. Data on change in volume of physical mail are available for the US and Canada. Data on individuals' substitution of traditional mail by electronic means are available in respect of EU countries.	These indicators are of interest because of the potential of ICT to reduce the need for paper. Such a reduction could be expected to lead to a reduction in emissions by reducing destruction of forests, and lowering emissions from paper manufacturing, transport and recycling.

Note: Further work could be undertaken to develop a core set of indicators of the main ICT impacts on the environment.

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NOTES

1. See analysis, conferences, and other relevant work at: www.oecd.org/sti/ict/green-ict.

2. Unless otherwise indicated, as cited by Fujitsu (2008).

3. The Workshop on ICTs and Environmental Challenges was held in May 2008 in Copenhagen, hosted by the National IT and Telecom Agency of the Danish Ministry of Science, Technology and Innovation. An OECD Conference on ICTs, the Environment and Climate Change, is planned for 27-28 May 2009 in Denmark. It will bring together policymakers and major stakeholders and will contribute to the United Nations Climate Change Conference in 2009 (OECD, 2008a). See www.oecd.org/sti/ict/green-ict.

4. In Tokyo and London, see www.itu.int/ITU-T/worksem/climatechange/index.html.

5. This refers to the often-cited statistic that ICT products are responsible for 2% of emissions.

6. Climate change as defined by the Intergovernmental Panel on Climate Change (IPCC) is "… a change in the state of the climate that can be identified (*e.g.* using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity." The IPCC notes that this definition differs from that of the United Nations Framework Convention on Climate Change (UNFCCC), where "climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods." (IPCC, 2007c).

7. A broad concept of environment is assumed to include: climate change, energy, water, sustainable development, pollution, waste, land use and degradation, and conservation of species and ecosystems. These elements are not mutually exclusive.

8. IPCC (2007a) presents a useful summary of the impacts of global warming, including impacts on water, ecosystems, food, coasts and health.

9. Official statistics are those produced by government statistical agencies according to the UN's fundamental principles of official statistics, as adopted by the United Nations Statistical Commission in 1994: http://unstats.un.org/unsd/statcom/doc94/e1994.htm. Note that government statistical agencies are not limited to national statistical offices. A recent presentation by Dennis Trewin (to the 2008 UN Conference on Climate Change and Official Statistics) expanded the scope of official statistics, for the purposes of the conference, to include output of international statistical organisations. This study adopts that principle and includes national official statistical data (often compiled by international organisations, such as the OECD, ITU, UNSD and UNFCCC) as well as data collected directly by international organisations (including data on telecommunications, patents and the environment).

10. The Intergovernmental Panel on Climate Change (IPCC) in its *Synthesis Report* (IPCC, 2007a) presents a breakdown of anthropogenic GHG emissions by sector for 2004. Together, energy supply,

transport, buildings and industry accounted for two-thirds of total emissions in 2004. The *Synthesis Report* also presents potential gains from mitigation, at three different carbon prices, by sector, using technologies and practices expected to be available by 2030. Highest potential gains are likely to come from buildings, followed by agriculture, industry and energy supply (based on end-use allocations of emissions, therefore, emissions from electricity, for example, are not counted towards the energy supply sector) (IPCC, 2007a-d). In respect of individual industries, pulp and paper manufacture is a moderate producer of GHG (emissions from energy use and processes) – with estimates ranging from 2% to 7% of emissions of CO_2 equivalents in 2030 (IPCC, 2007b). The ICT sector is not separately identified in the report but its emissions will be a function of its own activities as well as inputs from other industries (for example, metal and plastics).

11. Products include both goods and services.

12. Distinguishing and measuring positive and negative impacts is very difficult in practice.

13. CSD stands for the Commission on Sustainable Development.

14. See also the work of Digital Futures: the UK Digital Futures project (Forum for the Future) http://www.amazon.co.uk/Digital-Futures-Living-Networked-World/dp/1853838985 http://www.forumforthefuture.org/greenfutures/articles/60279; EU Digital Europe project (Forum for the Future & other partners) http://www.forumforthefuture.org/files/DigitaleuropeSocialresponsibilityintheinformationsociety.pdf .

15. The OECD conceptual model refers to the "information society", which includes information 'content'. That element has been included in the ICT and environment model, particularly because of the links between electronic content, such as on-line information, and the environment.

16. These are concepts used by the IPCC, which defines mitigation as "A human intervention to reduce the sources or enhance the sinks of greenhouse gases." The IPCC does not defined adaptation, though applies its usual meaning.

17. As a general purpose technology, ICT will also facilitate innovation into technologies and processes that will have positive environmental outcomes.

18. An important consideration, when replacing ICT equipment or introducing dematerialisation activities, is the net environmental cost. For instance, how does the environmental cost of changing to more efficient ICT equipment compare with the cost of continuing to use old equipment, when the costs of manufacture, transport and disposal are taken into account? The same sort of question can be asked of introducing dematerialisation activities such as teleconferencing. For instance, at what point does the environment start to benefit, when the facility costs of manufacture and transport are taken into account?

19. See OECD (2009, forthcoming), "Sustainable manufacturing and eco-innovation. Chapter 4, Measuring eco-innovation", Working paper.

20. The importance of ICT in weather monitoring is well described in ITU (2008).

21. The IPCC states that "Climate scenarios rely upon the use of numerical models. The continuous evolution of these models over recent decades has been enabled by a considerable increase in computational capacity, with supercomputer speeds increasing by roughly a factor of a million in the three decades from the 1970s to the present. This computational progress has permitted a corresponding increase in model complexity …… in the length of the simulations, and in spatial

resolution…" The report also notes that climate modelling is limited by the current state of computing power. (IPCC, 2007a).

22. The Gartner reference is to CO_2 emissions but it is likely that the difference is insignificant.

23. The Climate Group and GeSI report (2008) estimates that, even taking into account improvements in efficiency of ICT products, the whole-of-life emissions of ICT products, compared with 2002 levels, are estimated to nearly treble by 2020. The report presents splits by type of product and by geographical region.

24. Directive 2002/96/EC came into effect on 27 January, 2003.

25. For the purposes of examining ICT's role in environmental outcomes, it is reasonable to include equipment that is heavily reliant on ICT components for its performance.

26. As defined by the OECD in 2003, based on ISIC Rev. 3.1. A definition based on ISIC Rev. 4 is available but appears not yet to be in widespread use (see OECD, 2009a).

27. As defined by the OECD in 2002, based on the World Customs Organization's 2002 Harmonized System for trade statistics. See OECD 2005 for details.

28. ICT services data are currently quite limited compared to ICT goods data. A revised *Manual on Statistics of International Trade in Services* is expected to be released in 2010 and is expected to include a slightly more detailed classification of ICT services. The current services classification used by UNSD in its UN Service Trade Database is the Extended Balance of Payments Services classification (EBOPS) which includes *Computer services* and *Telecommunications services*. Data availability is limited at that level of aggregation (to 44 and 55 countries respectively). More countries are able to report data at the next level (*Computer and information services* – which is broader in scope than ICT – and *Communication services*).

29. OECD definition, see OECD (2009a).

30. See OECD 2007a.

31. See http://unfccc.int/ghg_data/ghg_data_non_unfccc/items/3170.php.

32. There are 41 Annex 1 parties to the Climate Change Convention (consisting mainly of OECD and European Union member countries plus some transition economies, including the Russian Federation).

33. Country level coverage varies between indicators. Some are "core indicators" (indicated by *) and these are considered by UNEP to "… reflect headline trends for the major global and regional environmental issues addressed under the Global Environment Outlook (GEO) assessment and reporting process. They aim to give a consistent, up-to-date overview of the major environmental trends at global and regional levels on an annual basis, making it easy to track major environmental issues over the years. For each issue, the single most important, suitable and reliable indicators currently available are presented."

34. Emissions of greenhouse gases, greenhouse-gas precursors, and aerosols associated with human activities. These include the burning of fossil fuels, deforestation, land-use changes, livestock, fertilisation, etc. that result in a net increase in emissions (IPCC, 2007b).

35. Hydrofluorocarbons.

36. Perfluorocarbons.

37. Sulphur hexafluoride.

38. According to the publication: "Environmental performance can be assessed against domestic objectives and international commitments: The main international agreement is the United Nations Framework Convention on Climate Change (1992). Its 1997 Kyoto Protocol establishes differentiated national or regional emission reduction or limitation targets for six GHG for 2008-12 with 1990 as the reference year."

39. The OECD presents emissions as: "gross direct emissions, emitted within the national territory and excluding sinks and indirect effects." Greenhouse gas emissions refer to the sum of the six gases of the Kyoto Protocol (CO_2, CH_4, N_2O, PFCs, HFCs and SF_6) expressed in CO_2 equivalents (note the difference with UNSD, which presents data in respect of three greenhouse gases). Regarding data source and quality, OECD notes that data on GHG emissions are reported annually to the Secretariat of the UNFCCC. Although significant progress has been made with national GHG inventories, data availability remains best for CO_2 emissions from energy use.

40. According to the OECD, data on energy supply and consumption are available from international sources for all OECD countries. It notes that more work needs to be done on the development of appropriate measures of energy efficiency.

41. The source of climate change statistics is the UN Framework Convention on Climate Change (UNFCCC) except for CO_2 emissions data, which come from the UN's Millennium Development Goals (MDG) Indicators Database.

42. Greenhouse gases (GHG) refer to carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Data are shown in absolute and per capita values. In respect of data quality of GHG data, UNSD notes that countries are expected to report GHG to UNFCCC according to IPCC Guidelines. They note that the quality of data is regularly checked by UNFCCC for the 41 Annex 1 parties to the Climate Change Convention that report annually (consisting mainly of OECD and European Union member countries plus some transition economies, including the Russian Federation); non-Annex 1 countries do not report regularly and their data are not subject to the same degree of checking. Data quality is usually best for energy-related emissions and, for other sources, the data should be used with caution when comparing countries. In respect of data currency, much of the GHG data are out of date, with data for many countries dating from the mid 1990s.

43. Shown in absolute and percentage distribution terms. Sectors are: energy, industrial processes, agriculture and waste.

44. Absolute value, per capita and per surface area (in km^2). In a note on data quality, UNSD comments that data for Annex 1 countries comes from UNFCCC and conforms with Intergovernmental Panel on Climate Change guidelines. Such data covers all sources of anthropogenic carbon dioxide emissions as well as carbon sinks (such as forests). For non-Annex 1 countries, data are estimated by the Carbon Dioxide Information Analysis Center (CDIAC) (see: http://cdiac.ornl.gov/) and include emissions from consumption of solid, liquid and gas fuels; cement production; and gas flaring. Data for CO_2 emissions are relatively recent, mainly dating from 2004.

45. Absolute and per capita value, separately for CH_4 and N_2O.

46. SMART is an acronym for Standardise, Monitor, Accountability, Rethink, Transformation.

47. The report has a narrower definition of ICT products than that used by the OECD – it does not include consumer electronics.

48. A readable discussion of the environmental damage caused by ICT products can be found here: www.environment.gov.au/settlements/publications/chemicals/hazardous-waste/pubs/electronic-scrap-fs.pdf.

49. An example of a survey collecting data from consumers on the stock of unused ICT equipment and disposal of ICT equipment is the 2006 Ewaste Survey of the US Consumer Reports National Research Center, see: www.greenerchoices.org/electronicsrecycling/Ewaste_survey_2006.pdf.

50. Positive impacts on the environment will also come from general product development and improvement.

51. Includes geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences.

52. This SEO covers research into the control of pollution, aimed at the identification and analysis of the sources of pollution and their causes, and all pollutants, including their dispersal in the environment and the effects on man, species (fauna, flora, micro-organisms) and the biosphere. Development of monitoring facilities for the measurement of all kinds of pollution is included. The same is valid for the elimination and prevention of all forms of pollution in all types of environment.

53. This SEO covers research into the production, storage, transportation, distribution and rational use of all forms of energy. It also includes research on processes designed to increase the efficiency of energy production and distribution, and the study of energy conservation. It does not include research into vehicle and engine propulsion.

54. Includes Radio, television and communication equipment and apparatus; Instruments and appliances for measuring, checking, testing, navigating and other purposes; Industrial process control equipment; Recycling; Electricity, gas and water supply; Wholesale of computers, computer peripheral equipment and software; and Telecommunications services.

55. Data could come from existing statistical systems for R&D data or through additional analysis of R&D statistics or other national data.

56. They include Environmental chemistry, Atmospheric sciences, Ecology and evolution, Environmental engineering, Environmental sciences, Environment and resource economics, and Environmental and natural resources law.

57. Categories on ICT include the broad level Information, computing and communication sciences, with a number of detailed sub-categories, and the engineering categories, Computer hardware and Communications technologies.

58. The United States has non-current data (2002) and they only refer to trucks. Statistics Canada collected data on distance travelled by household vehicles in 2006 but they were not split by purpose (Statistics Canada, 2006a).

59. The survey was conducted as part of the national statistical system and the results are considered to be “national statistics” per the National Statistics Code of Practice.

60. The impact of transport of goods ordered over the Internet should be taken into account. There are mixed views on whether the net impact of purchasing goods over the Internet is positive or negative.

61. Household Electrical and Electronic Waste Benchmark Survey 2005.

62. For instance, while it is interesting to know that a particular country had 5% of its workforce involved in teleworking in 2007, that statistic is far more powerful if one also knows the observations that precede and follow it. Such time series information would help analysts to estimate the future mitigation potential of teleworking on global emissions.

63. Not necessarily the original source.

64. The "Level of development" classification is based on the UN Statistics Division's *Standard country or area codes for statistical use*, see http://unstats.un.org/unsd/methods/m49/m49.htm. The categories are "developed", "transition", "developing" and "least developed".