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Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development **10-Jun-2010**

English - Or. English

DIRECTORATE FOR SCIENCE, TECHNOLOGY AND INDUSTRY
COMMITTEE FOR INFORMATION, COMPUTER AND COMMUNICATIONS POLICY

DSTI/ICCP/IE(2009)16/CHAP5/REV1
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Working Party on the Information Economy

OECD INFORMATION TECHNOLOGY OUTLOOK 2010

Chapter 5. Greener and Smarter: ICTs, the environment and climate change

The draft Chapter 5 of the Information Technology Outlook 2010 is circulated for comments and finalisation. The chapter builds on the draft synthesis report "ICTs, the environment and climate change" [DSTI/ICCP/IE(2009)12] discussed at the December WPIE meeting.

Comments should be provided within 2 weeks of the OLIS date. As for previous editions, the ITO 2010 will be declassified under the written procedure.

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JT03285327

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CHAPTER 5

GREENER AND SMARTER: ICTS, THE ENVIRONMENT AND CLIMATE CHANGE

Smart ICT and Internet applications have the potential to improve the environment and tackle climate change. Top application areas include manufacturing, energy, transport and buildings. Information and communication also foster sustainable consumption and greener lifestyles. At the same time, direct and systemic impacts related to the production, use and end of life of ICTs require careful study in order to comprehensively assess "net" environmental impacts. A better understanding of smart ICTs provides policy makers options for encouraging clean innovation for greener economic growth.

Introduction[1]

1. Boosting sustainable economic growth is a top priority for both OECD and non-OECD economies. Current patterns of growth will compromise and irreversibly damage the natural environment. At the same time, economies and populations continue to grow – especially in non-OECD countries – with accelerating global rates of production and consumption. Innovative modes of production, consumption and living are called for to deal with the challenges ahead. Technologies will play a key role in addressing these challenges.

2. Information and communication technologies (ICTs) are a key enabler of "green growth" in all sectors of the economy. The importance of understanding the links between ICTs and environmental issues is widely acknowledged in areas such as energy conservation, climate change and management of sustainable resources. "Green ICTs" is an umbrella term for ICTs with better environmental performance than previous generations (direct impacts) and ICTs that can be used to improve environmental performance throughout the economy (enabling and systemic impacts). Other terms used are "smart ICTs" and "sustainable IT".

3. This chapter provides an overview of ICTs, the environment and climate change.[2] It has two main parts, an analytical framework and impact assessment. The first part develops a framework for assessing the environmental benefits and impacts of ICTs. These include the direct impacts of technologies themselves as well the impacts of ICTs in improving environmental performance more widely. The second part describes empirical findings on environmental impacts for a range of ICT and Internet applications (see also Chapter 6, which focuses on sensor-based technologies to improve the environment).

Framework

What are "green ICTs"?

4. ICTs and their applications can have both positive and negative impacts on the environment.[3] An analysis of green ICTs covers both aspects in order to assess the "net" environmental impacts of ICTs. The

net environmental impact of an ICT product or application is the sum of all of its interactions with the environment. This means, for example, balancing greenhouse gas emissions resulting from the development, production and operation of ICT products against emissions reductions attributed to the application of these ICTs to improve energy efficiency elsewhere, *e.g.* in buildings, transport systems or electricity distribution. Besides these immediate impacts, ICTs and their application also affect the ways in which people live and work and in which goods and services are produced and delivered. The resulting environmental impacts are more difficult to trace but need to be part of a comprehensive analytical framework.

Box 5.1. OECD work on ICTs for green growth

Policies to promote diffusion and uptake of ICTs for environmental purposes are receiving increasing attention. Most governments have only recently (but faster and faster) begun to combine “green ICT” promotion initiatives with traditional ICT and environmental policies (OECD, 2009a). The separation between ICT and climate change research communities is sometimes reflected in government: ministries with competence for ICTs may have pilot projects, but these are rarely taken up at a national level in co-ordination with national environmental policy institutions.

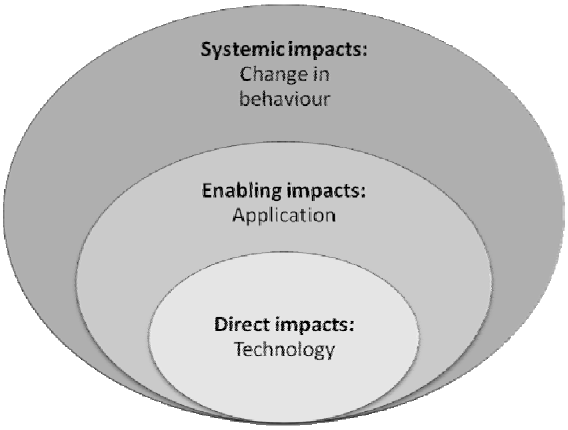
The OECD’s work programme on ICTs, the environment and climate change is part of the Organisation’s development of a wider *Green Growth Strategy* – interim results were presented at the OECD Council at Ministerial Level in May 2010 (OECD, 2010). A workshop on green ICTs was held in Copenhagen in 2008 and a high-level conference took place in 2009 in Helsingør, Denmark. During the conference, participants agreed that ICTs had a central role to play in tackling climate change and improving environmental performance overall. Later that year, the 2009 UN Climate Change Conference in Copenhagen (COP15) brought together global policy makers in an attempt to limit the impacts of climate change. The OECD, together with the UNFCCC, relied on ICTs to limit travel by using the latest video link technology to connect speakers from Copenhagen, Paris, Tokyo, Bangalore and Hong Kong (China), live and in high definition (a webcast is available).

In 2010, OECD member countries agreed to make better use of ICTs to tackle environmental challenges and accelerate green growth. The OECD Council Recommendation on ICTs and the environment gives a ten-point checklist for government policy, including provisions on improving the environmental impacts of ICTs. It encourages cross-sector co-operation and knowledge exchange on resource-efficient ICTs and “smart” applications, and highlights the importance of government support for R&D and innovation (see also Chapter 7).

Source: www.oecd.org/sti/ict/green-ict; www.oecd.org/greengrowth.

5. The interaction of ICTs and the natural environment described in this chapter can be categorised in a framework of three analytical levels: direct impacts (first order), enabling impacts (second order) and systemic impacts (third order) (Figure 5.1).[4] The following paragraphs describe the characteristics of environmental impacts of ICTs on each level.

Figure 5.1. Framework for green ICTs



Source: OECD.

6. Direct impacts of ICTs on the environment (or "first-order effects") refer to positive and negative impacts due to the physical existence of ICT products (goods and services) and related processes.[5] The sources of the direct environmental impacts of ICT products are ICT producers (ICT manufacturing and services firms, including intermediate goods production) and final consumers and users of ICTs. ICT producers affect the natural environment during both the production of ICT hardware, components and ICT services and through their operations (*e.g.* operating infrastructures, offices, vehicle fleets). In addition, the design of ICT products determines how they affect the environment beyond company boundaries. Energy-efficient components, for example, can reduce the energy used by ICT equipment. Modular ICT equipment and reduced use of chemicals in production can improve re-use and recyclability.

7. At the other end of the value chain, consumers and users influence the direct environmental footprint through their purchase, consumption, use and end-of-life treatment of ICT products. Consumers can choose energy-efficient and certified "green" ICT equipment over other products. The use of ICTs largely determines the amount of energy consumed by ICT equipment (widespread changes in use patterns, however, are part of systemic impacts). At the end of a product's useful life, consumers can choose to return equipment for re-use, recycling, etc. This lowers the burden on the natural environment compared to disposal in a landfill or incineration, the most common destinations for household waste.

8. Enabling impacts of ICTs (or "second-order effects") arise from ICT applications that reduce environmental impacts across economic and social activities. ICTs affect how other products are designed, produced, consumed, used and disposed of. This makes production and consumption more resource-efficient. Potential negative effects need to be factored in when assessing "net" environmental impacts, such as greater use of energy by ICT-enabled systems compared to conventional systems.

9. ICT products can affect the environmental footprint of other products and activities across the economy in four ways:

- *Optimisation*: ICTs can reduce another product's environmental impact. Examples include embedded systems in cars for fuel-efficient driving, "smart" electricity distribution networks to reduce transmission and distribution losses, and intelligent heating and lighting systems in buildings which increase their energy efficiency.

- *Dematerialisation and substitution*: Advances in ICTs and other technologies facilitate the replacement of physical products and processes by digital products and processes. For example digital music may replace physical music media and teleconferences may replace business travel.

- *Induction* effects can occur if ICT products help to increase demand for other products, *e.g.* efficient printers may stimulate demand for paper.

- *Degradation* can occur if ICT devices embedded in non-ICT products create difficulties for local waste management processes. Car tyres, bottles and cardboard equipped with "smart" tags, for example, often require specific recycling procedures (Wäger *et al.*, 2005).

10. Systemic impacts of ICTs and their application on the environment (or "third-order effects") are those involving behavioural change and other non-technological factors. Systemic impacts include the intended and unintended consequences of wide application of green ICTs. Positive environmental outcomes of green ICT applications largely depend on wide end-user acceptance.[6] Therefore, systemic impacts also include the adjustments to individual lifestyles that are necessary to make sensible use of ICTs for the environment. ICT applications can have systemic impacts on economies and societies in one or more of the following ways:

- *Providing and disclosing information*: ICTs and the Internet help bridge information gaps across industry sectors. They also facilitate monitoring, measuring and reporting changes to the natural environment. Access to and display of data inform decisions by households (*e.g.* "smart" meters), businesses (*e.g.* choice of suppliers, verifying "green" claims), and governments (*e.g.* allocation of emission allowances, territorial development policies).[7] Sensor-based networks that collect information and software-based interpretation of data can be used to adapt lifestyles, production and commerce in OECD and developing countries to the impacts of climate change (FAO, 2010; Kalas and Finlay, 2009). For example, ICT-enabled research and observation of desertification trends around the Sahara provide data for decisions that affect these countries' economic development.

- *Enabling dynamic pricing and fostering price sensitivity*: ICT applications form the basis of dynamic or adaptive pricing systems, *e.g.* for the provision of electricity or the trade of agricultural goods. Through the use of ICTs, producers can provide immediate price signals about supply levels to final consumers. In areas of high price elasticity, optimisation of demand can be expected. Electricity customers, for example, can choose to turn off non-critical devices when cheap (and renewable) energy is scarce and turn them on again when it is more plentiful. This is an important part of green growth strategies that aim to use market principles to encourage sustainable behaviour.

- *Fostering technology adoption*: Technological progress provokes behavioural changes. The "evolution" from desktop PCs to laptops to netbooks is one example of changing consumer preferences. Digital music, e-mail communications and teleconferencing technologies are affecting the ways in which their physical counterparts are produced and consumed, *i.e.* recorded music, written letters and physical business travel. As new consumption patterns emerge, *e.g.* in the consumption of music on digital media, these trends result in direct impacts (energy use of servers to store and provide digital music) and enabling impacts (reduction in the use of physical music media).

- *Triggering rebound effects*: Rebound effects refer to the phenomenon that higher efficiencies at the micro level (*e.g.* a product) do not necessarily translate into equivalent savings at the macro level (*e.g.* economy-wide). This means, for example, that the nationwide application of a 30%

more efficient technology does not necessarily translate into energy savings of 30% in the application area. Analysis, mostly in the area of consumer products, shows that "rebound effects" at the macro level partly offset efficiency gains at the micro level, but the exact causes, magnitudes and long-term trends are not yet clear (Turner, 2009). In areas such as personal car transport or household heating, higher efficiency (or lower price) of a product can increase demand in ways that offset up to one-third of the energy savings (Sorrell, Dimitropoulos and Sommerville, 2009). Relatively little empirical analysis has focused on ICT-enabled rebound effects. As an example of the interaction between the direct and rebound impacts of ICTs, higher energy efficiencies of semiconductor products must be weighed against the overall growth of the use of ICT products.

Assessing the overall environmental impacts of ICTs

11. The use and application of ICTs can affect the environment in different ways. Impacts of ICTs on climate change, energy use and energy conservation are the aspects typically analysed. It is evident that climate change is severely affecting ecosystems, business and human activities, and human health (OECD, 2008a; IPCC, 2007). Nevertheless, environmental policies and consequently green ICTs also target other challenges, such as protection of biodiversity and management of water resources, water supply and sanitation.

12. There are different approaches to categorising environmental impacts (Bare and Gloria, 2008). The International Organization for Standardization (ISO) has issued a non-hierarchical categorisation of impacts in its standard ISO 14042:2000 (life-cycle impact assessment), which serves as the basis of OECD work on key environmental indicators (OECD, 2004). Table 5.1 provides an overview of environmental impact categories defined under ISO 14042 (left-hand column) along with their causes and examples.

Table 5.1. Categories of environmental impacts

Impact category	Causes	Examples of environmental impacts
Global warming	• Carbon dioxide (CO_2) • Nitrogen dioxide (NO_2) • Methane (CH) • Chlorofluorocarbons (CFCs) • Hydro-chlorofluorocarbons (HCFCs) • Methyl bromide (CH_3Br)	• Polar melt, change in wind and ocean patterns
Primary energy use	• Fossil fuels used	• Loss of fossil fuel resources
Toxicity	• Photochemical smog: Non-methane hydrocarbon (NMHC) • Terrestrial and aquatic toxicity: Toxic chemicals • Acidification: Sulphur oxides (SOx), nitrogen oxides (NOx), hydrochloric acid (HCL), hydrofluoric Acid (HF), ammonia (NH_4), mercury (Hg) • Eutrophication: Phosphate (PO_4), nitrogen oxide (NO), nitrogen dioxide (NO_2), nitrates, ammonia (NH_4)	• "Smog," decreased visibility, eye irritation, respiratory tract and lung irritation, vegetation damage • Decreased biodiversity and wildlife • Decreased aquatic plant and biodiversity; decreased fishing • Acid rain • Building corrosion, water acidification, vegetation and soil effects • Excessive plant growth and oxygen depletion through nutrients entering lakes, estuaries and streams
Non-energy resource depletion	• Minerals used, scarce resources such as lead, tin, copper	• Loss of mineral resources
Land use	• Landfill disposal, plant construction and other land modifications	• Loss of terrestrial habitat for humans and wildlife; decreased landfill space
Water use	• Water used or consumed	• Loss of available water from water sources
Ozone layer depletion	• Cholorofluorocarbons (CFCs) • Hydro-chlorofluorocarbons (HCFCs) • Halons • Methyl bromide (CH_3Br)	• Increased ultraviolet radiation
Impacts on biodiversity	• Toxicity • Land use	• Decreased biodiversity and wildlife • Loss of terrestrial habitat for humans and wildlife

Source: Adapted from U.S. EPA 2006 and ISO 14042).

13. ICTs can affect the environment in each of the categories listed in Table 5.1. However, most "green ICT" policies and initiatives focus on two categories: global warming and primary energy use (OECD, 2009a). Cutting greenhouse gas emissions and increasing energy efficiency are critical components of strategies to improve environmental performance. But a focus solely on energy use falls short of tackling potentially harmful environmental impacts in other categories, *e.g.* pollution or resource depletion.

14. A product life-cycle assessment (LCA) can be used to comprehensively examine the environmental impacts of ICTs. LCA approaches are effective at this level since they offer a standardised approach to measuring material and energy flows in and out of individual products. Recent LCA approaches have been expanded to cover socioeconomic impacts of products throughout their life cycle, *e.g.* on employment conditions (Moberg *et al*., 2009). Traditional LCAs have been applied to a wide range of tangible and intangible products from various industries and even to entire systems such as mobile communications networks (Box 5.2). This represents a bottom-up approach that captures the impacts of the different phases in a product's "life cycle" for individual ICT products (direct impacts) and their contributions to reducing environmental impacts during the life cycle of other goods and services (enabling impacts).

Box 5.2. Life-cycle assessment (LCA) of environmental impacts

A product's life-cycle assessment covers its value chain, but extends further to follow a product all the way "from cradle to grave" or "from cradle to cradle". The latter metaphor implies that products and their components can be re-used and recycled and that these considerations can be part of the initial product design (McDonough and Braungart, 2002; also, "The Story of Stuff" at www.storyofstuff.com).

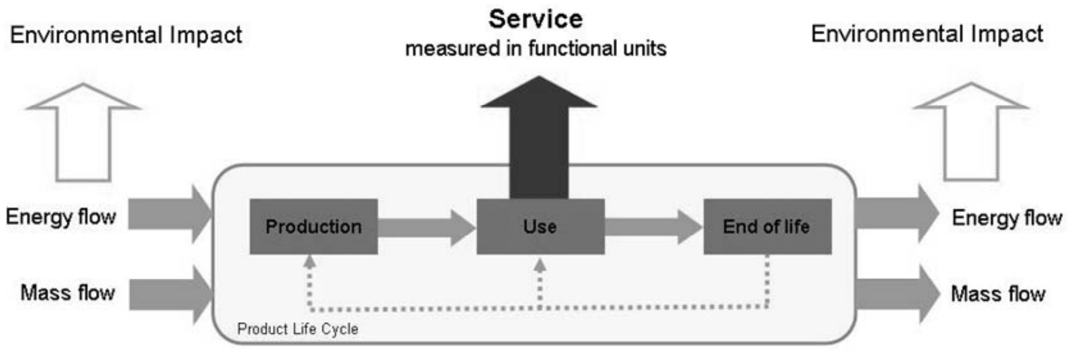
Life-cycle assessment is an internationally standardised means of assessing the environmental impact of a product, comparing it with other products, and guiding policies to lower environmental impacts (ISO 14042). An LCA is typically time- and resource-intensive, but so-called "screening" LCAs are widely used to indicate environmental "hot spots" based on a less detailed analysis. Results of these screening studies can then be used to select products and product categories for more detailed analysis.

LCAs can provide information for raising awareness among purchasers and consumers, *e.g.* through eco-labelling and rankings of products' environmental performance. They are part of a larger group of material flow approaches (MFAs) that enable sophisticated environmental accounting at the level of national economies and down to economic activities and sectors, products and product groups (OECD, 2008b). In combination with economy-wide analytical tools such as input-output analysis, LCAs can contribute to a better understanding of the environmental impacts of all economic activities.

LCAs can be used to assess the environmental impacts of individual products. They also allow for a comprehensive environmental impact assessment of systems of interdependent products. For instance, LCAs of electric or plug-in hybrid vehicles take into account CO_2 emissions and other environmental impacts that are not at the "end of the pipe", *e.g.* as a result of electricity generation needed to charge the car or resulting from manufacturing and disposal of batteries (Samaras and Meisterling, 2008). Life-cycle assessments of mobile telecommunications systems highlight the energy used to operate system components, *e.g.* radio base stations, but also assess manufacturing and end-of-life aspects (Scharnhorst, Hilty and Jolliet, 2006). In the case of bio-based ethanol production for fuel for motor vehicles, LCAs are important for capturing all related environmental impacts, *e.g.* nitrogen use in fertilisers, GHG emissions due to land use for growing the biomass (von Blottnitz and Curran, 2007).

15. An LCA for ICTs aims to identify ICT products with significant environmental impacts in any of the categories listed in Table 5.1. Figure 5.2 shows a generic life-cycle model with an ICT product at the centre. The product's main purpose is to provide a service (plain arrow). Provision of the service requires production, use and disposal of materials throughout the life cycle. The LCA measures and assesses the direct environmental impacts of all material and energy flows related to the ICT product.

Figure 5.2. ICT product life cycle (direct impacts)



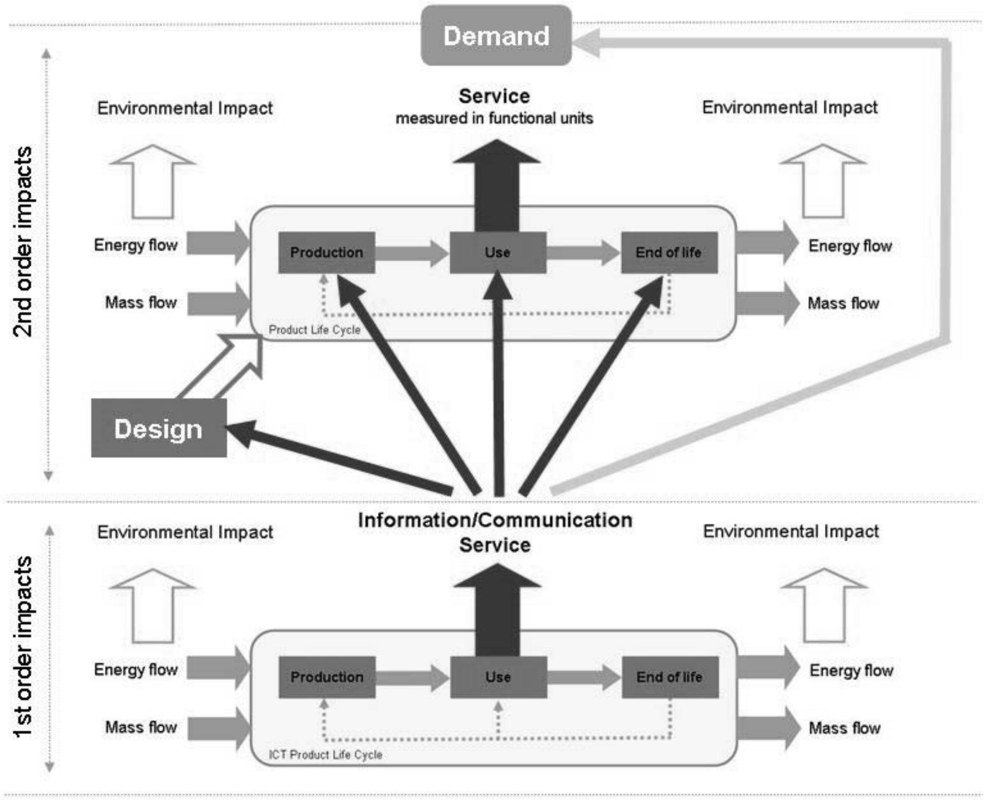
Source: Hilty, 2008.

16. Standardised LCA approaches can be adapted in order to capture the enabling impacts of ICTs. An ICT product (good or service) is the element linking LCAs of ICT products and non-ICT products

(Hilty, 2008; Ericsson 2009). Linking the two separate life cycles makes it possible to assess ICTs as an enabling technology, *e.g.* for improving energy efficiency and resource productivity. As application areas of ICTs are virtually unlimited, product life cycles from diverse economic sectors can be linked to that of an ICT product, *e.g.* embedded systems in car engines, central heating and lighting management systems in buildings.

17. Figure 5.3 provides a schematic illustration of how an ICT good or service (bottom) can modify the life cycle of another product (top). The enabling environmental impacts refer to *i)* modifying the design, production, use or end-of-life phase of that product (optimisation or degrading; dark arrows); and *ii)* influencing demand for a given service (dematerialisation, substitution or induction; shaded arrow). Changes in the demand for a non-ICT product can occur, for example, as digital music purchases replace the purchase of physical music media; another example is the increased use of paper due to more efficient and affordable printers.

Figure 5.3. ICT and non-ICT product life cycles (enabling impacts)



Source: Hilty, 2008.

18. LCAs can be used to assess the economy-wide environmental impacts of a product. For this purpose, individual product results are scaled up using various data, *e.g.* production, consumption and trade statistics as well as qualitative data on product use patterns.

19. Systemic impacts of ICTs and their environmental repercussions are relatively unexplored, mainly because of the complexity of assessing future directions of production and consumption. The project on the “Future Impact of ICT on Environmental Sustainability” (Erdmann *et al*., 2004), for example, uses elasticity of demand, time-use models and assumptions about the subjective cost of time to

determine environmental impacts of technologies such as intelligent transport systems (ITS) in 2020 (see the section "Systemic impacts"). Uncertainties in the analysis result from incomplete data, the difficulty of covering income effects and changing general framework conditions (*e.g.* taxation). Nevertheless, studies on the "net" long-term environmental impacts of ICTs need to take into account changes in user behaviour. Qualitative data sources can help to understand the specific contexts in which ICT products are applied and the ways in which they are used. For example, surveys and interviews can indicate whether teleworkers really reduce commuting distances travelled by car; or whether total travelled road miles are reoriented, and maybe increased, through driving for other purposes, *e.g.* leisure, children and elderly care, shopping. The development of such future scenarios needs inputs from different scientific disciplines, *e.g.* ICT engineering, energy and environmental sciences, and social sciences.

Assessments

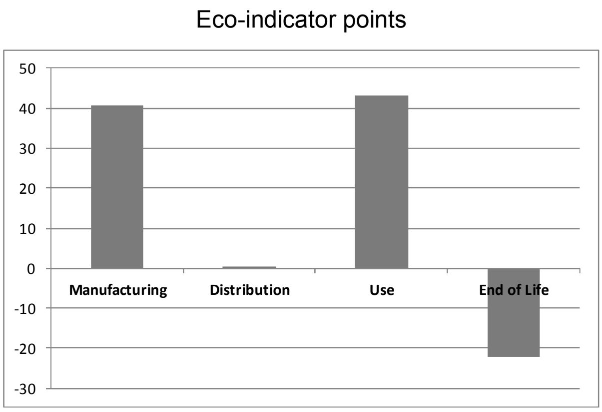
20. This section discusses estimates of and scenarios on the impacts of ICTs on the environment. It starts by assessing direct environmental impacts. The data quality and coverage is higher than for enabling and especially systemic impacts. Most internationally comparable data available cover direct impacts such as energy use of computers and amounts of electronic waste. The overview of assessments of enabling and systemic impacts in this section covers individual case studies, broad estimates and future scenarios.

Direct environmental impacts

PC life cycle

21. Manufacture and use account for the bulk of the environmental impacts of a desktop personal computer (PC) with peripheral devices. Figure 5.4 shows the aggregate environmental impacts of a PC manufactured in China, used over a period of six years and disposed of using mandatory procedures for treating waste from electric and electronic equipment (WEEE) in the European Union. During production, most impacts result from energy use, manufacturing-related extraction of raw materials and use of other natural resources. Environmental impacts during the use phase result solely from the use of electricity by the PC and peripheral devices. Assembly of components into final products and distribution are relatively insignificant. Under optimal conditions (*i.e.* following WEEE-mandated shares of recycling), the end-of-life phase has positive environmental impacts owing to the recovery of materials and adequate treatment of hazardous substances (*i.e.* negative eco-indicator points shown in Figure 5.4).[8]

Figure 5.4. Life-cycle environmental impacts of a PC with peripherals



Note: The figure shows a composite indicator which aggregates the individual environmental impacts shown in Table 5.1. It uses the "Eco-Indicator 99" method, developed by PRé Consultants. The vertical axis displays eco-indicator points: positive numbers represent aggregate negative environmental impact during the life-cycle phase; negative numbers represent positive environmental impacts.

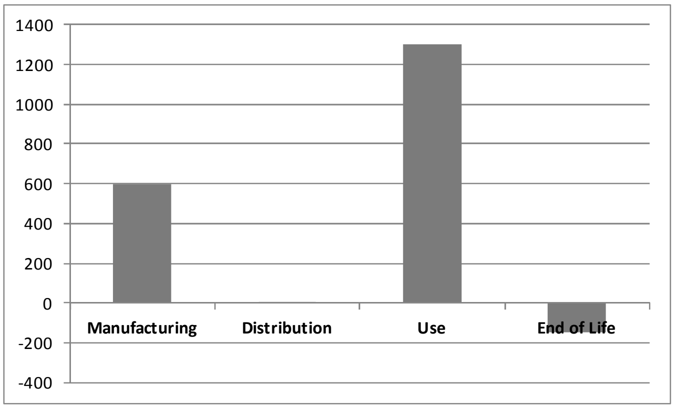
Source: Eugster, Hischier, and Duan 2007.

22. Producing a PC affects the environment in all impact categories shown in Table 5.1. Overall, the desktop PC and screen are the major sources of environmental impacts, with differences depending on the screen technology (Figure 5.4). Large amounts of energy are required to produce the electronic circuits and semiconductors that are used in computer motherboards and screens (EPIC-ICT, 2006; Eugster, Hischier and Duan, 2007). Moreover, the production of ICT components requires large amounts of materials, especially compared to the mass of the final product. A memory semiconductor with a mass of 2 grams requires processing over 1 kg of fossil fuels, *i.e.* a factor of 500 (Williams, 2003). ICT producers are major consumers of minerals, notably the rare metals used in conductors, optical electronics and energy storage. Extraction and mining of these commodities, largely in developing countries, is known to involve poor working conditions and to create serious health and environmental concerns (Steinweg and de Haan, 2007). The use of water in the production of memory chips and processors can also be significant. Water is used for cooling, heating and filtering, but also as "ultra-pure water" for rinsing semiconductor wafers, chemical preparation, etc. This purification process is very energy-intensive.

23. Using a PC contributes more to energy use and consequently to global warming than any other activity in the PC life cycle (Figure 5.5) because of greenhouse gas emissions from the generation of the electricity required to power a computer. In fact, the energy consumed during use (assuming a typical service life of six years) represents over 70% of all energy used during the life cycle (EPIC-ICT, 2006; Eugster, Hischier and Duan, 2007). Only a few years ago the situation was the reverse, with production the main contributor to energy use during the PC life cycle (Williams, 2003). ICT producers have since switched to more efficient production technologies (Hilty, 2008).

Figure 5.5. Life-cycle global warming potential of a PC with peripherals

Global warming potential (GWP) over 100 years



Note: Global warming potential (GWP) is an indicator for estimating the aggregate impact of greenhouse gases on global warming. The aggregate number represents the GWP of all greenhouse gases emitted during a life-cycle phase.
Source: Eugster, Hischier, and Duan 2007.

24. The shift towards the use phase as the main contributor to global warming points to the importance of energy-efficient ICT products and consumer-oriented policies. ICT producers have greatly increased the energy efficiency of their products. Semiconductor manufacturers, for example, highlight large efficiency increases through improved architectures and miniaturisation (Koomey *et al.*, 2009). An example from Intel cites two different generations of processors running at the speed of 1.6 GHz: one consumed 22 W in 2003 ("Centrino") and the other consumed only 2 W in 2009 ("Atom") (RTC Group, 2009).

25. Packaging and distributing a PC generally have relatively small impacts on the environment. Even when international distribution, *e.g.* between China and Europe, is taken into account, this does not

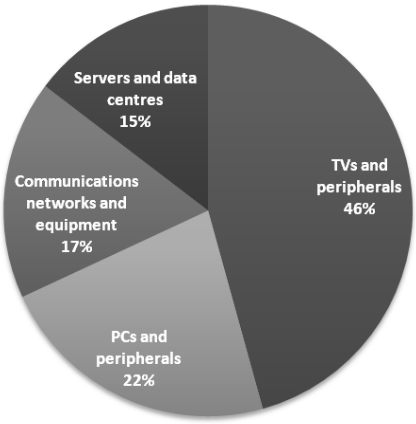
significantly affect the environment (Bio Intelligence Service, 2003; Choi *et al.*, 2006; Eugster, Hischier and Duan, 2007). Small aggregate environmental impacts are largely due to efficient transport and distribution channels that minimise the environmental contribution of an individual product unit.

26. Disposing of a PC has positive environmental impacts when mandated recovery and recycling rates of the EU WEEE Directive are enforced. In that case, significant environmental benefits in this life-cycle phase result from the recovery of precious metals (*e.g.* copper, steel, aluminium), the energy saved by recycling instead of producing, and the components available for re-use (Eugster, Hischier and Duan, 2007; Hischier, Wäger and Gauglhofer, 2005). Preliminary analysis shows, however, that mandated rates are not necessarily attained. Reports outline deficiencies in the electronics take-back and reporting schemes in EU countries, leaving large quantities of "electronic waste" uncollected and untreated (Greenpeace, 2008). As a result, large negative environmental impacts result from a potentially very high share of "electronic waste" being deposited in landfills or incinerated (see the section "Electronic waste").

ICT product categories

27. Based on the analysis of individual products, this section highlights environmental impacts of the ICT industry by main product categories. At this stage, the only comprehensive empirical findings relate to national shares of energy use and greenhouse gas emissions aggregated by selected product categories. Four categories of ICT goods and related services constitute the bulk of the sector's global GHG emissions. In descending order of their contribution to global GHGs, they are TVs and peripherals, PCs and peripherals, communications networks and equipment, and servers and data centres (Figure 5.6). Printers and copiers are not included in the figure, but they have lower aggregate energy and carbon footprints (Gartner, 2007; GeSI/The Climate Group, 2008).

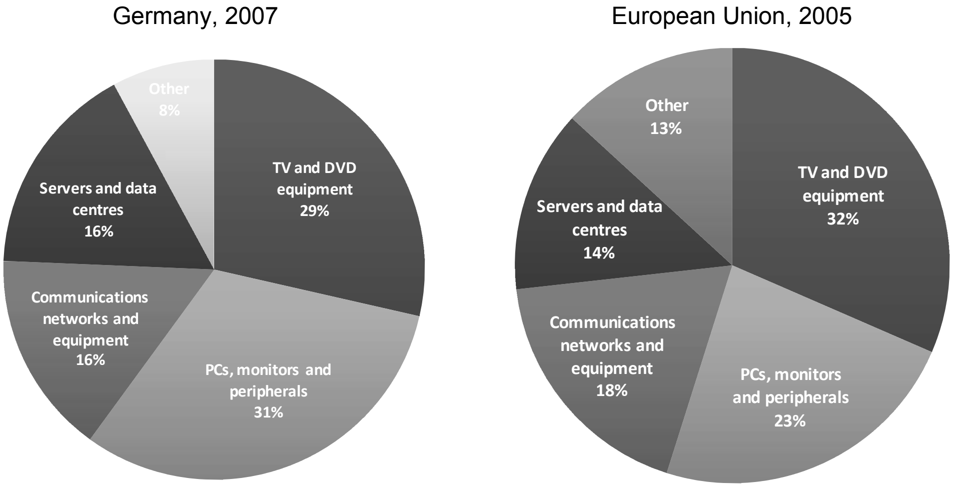
Figure 5.6. Global greenhouse gas emissions by ICT product categories, share of ICT overall, 2007



Note: Shares cover greenhouse gas emissions during production and use phases of the ICT product life cycle.
Source: : Malmodin et al., forthcoming.

28. National studies largely confirm the findings outlined above. Methodological differences make direct comparisons difficult, but global trends are largely reflected in national studies (see Figure 5.7 for Germany and the European Union). Analysis for Denmark (Gram-Hanssen, Larsen and Christensen, 2009) and the United Kingdom (UK Defra, Market Transformation Programme) covers a more limited set of data, which makes disaggregation less illustrative. Studies for Australia and the United States examine only environmental impacts of ICT use in their business sectors (see notes to Table 5.4).

Figure 5.7. Electricity used by ICT product categories, share of ICT overall



Note: Shares of electricity consumption per product category during use phase of the ICT product life cycle.
Source: (Fraunhofer IZM/ISI 2009; Bio Intelligence Service 2008).

29. Electricity use is commonly used to measure environmental impacts in national studies. Measuring electricity use during operation is not the primary goal of an environmental impact assessment, but it is a good proxy for environmental impacts during the use phase – LCAs show that it is the only significant impact category during this phase. Electricity use can be converted to CO_2 and GHG emissions using fixed conversion factors that depend on a country's "energy mix", *i.e.* the different energy sources used for generated and imported electricity. Consequently, the shares of electricity consumed roughly correspond to the shares of emissions generated.[9]

30. The Internet infrastructure (approximated by "servers and data centres" and "communications networks and equipment") creates around one-third of the ICT sector's carbon and energy footprints. Although Internet technologies steadily increase their energy efficiency (Taylor and Koomey, 2008), absolute electricity consumption is rising owing to the integration of ICTs and the Internet into most aspects of economies and individual lifestyles (a systemic impact). At the same time, Internet-based technologies enable important environmental savings, which makes them part of the equation when tackling environmental challenges (Box 5.3 and the sections "Enabling impacts" and "Systemic impacts").

Box 5.3. How green is the Internet?

The balance of direct, enabling and systemic impacts determines how green the Internet is. There has been discussion about the carbon footprint of various Internet activities, *e.g.* using a search engine to look for information. Apart from narrowly-focussed accounts about the electricity use and related CO_2 emissions of individual companies, more systematic studies have estimated the electricity footprint of servers and data centres to be around 1% of global electricity consumption (153 TWh in 2005) (Koomey, 2008). Operators of servers and data centres doubled their electricity consumption between 2000 and 2005; the trend is expected to continue into 2010 (Fichter, 2008). Global data for electricity use by communications networks and equipment are not available, but in the European Union they are estimated to consume around 1.4% of total electricity use (or 39 TWh) (Bio Intelligence Service, 2008).

Organisations that want to reduce electricity use by data centres can do so in various ways, *e.g.* by allowing higher temperatures in data centres or by virtualising and consolidating servers (Fichter, 2008). Further reductions in electricity use, related costs and emissions are possible through cloud computing. Cloud computing helps rationalise servers and networks by consolidating computing and storage on a system-wide level, *e.g.* across the federal government. The United States General Accountability Office (GAO), for example, has launched a central cloud computing service, Apps.gov, which helps government agencies to reduce the need for dedicated data centres. Cost savings across the US government are estimated to be as high as 50% with the bulk coming from lower electricity bills (Brookings Institution, 2010).

In order to calculate net environmental impacts, enabling and systemic impacts of the Internet and cloud computing must be accounted for. Using the framework presented in this chapter, studies need to account for the environmental benefits of Internet-based applications, *e.g.* telework that replaces physical commuting or digital music that replaces consumption of physical media products (enabling impacts). The Internet also brings about changes in lifestyles and acts as a source of information and knowledge. Information can be used to orient individuals towards more sustainable behaviour or to inform policy decisions, *e.g.* about mitigation and adaptation to climate change (systemic impacts).

31. The example of the Internet highlights the importance of life-cycle assessments which go beyond individual devices to assess entire ICT-based systems. Some firms have assessed the environmental impacts of entire mobile communications systems. This covers not only the operation of mobile phones, but also LCAs of base stations, mobile devices and business operations, such as operating the company's offices and vehicle fleets.[10]

Global carbon footprint and electricity use of ICTs

32. So far, three major studies have attempted to assess the global carbon footprint of the ICT sector and ICT products. Although methodologies and coverage differ significantly, results point to a similar direction: the ICT sector accounts for around 2-3% of global CO_2 emissions (and slightly less in terms of GHG emissions) (Table 5.2). This share is expected to rise as a result of the increasing diffusion of ICTs and the Internet across economies (IEA, 2009a).

Table 5.2. Global CO_2 and GHG emissions of ICTs

Year	ICT CO_2 (GHG) emissions million tonnes		ICT share of overall CO_2 (GHG) emissions		Source
2002		(530)		(1.1%)	(GeSI/The Climate Group 2008)
2007	661		2.3%		(Gartner 2007)
2007		(830)		(1.8%)	(GeSI/The Climate Group 2008)
2007		(1 160)		(2.5%)	Malmodin *et al.*, forthcoming

Notes: Global CO_2 and GHG emissions are based on the following sources: 2002 GHG emissions: OECD calculations based on (IPCC 2007); global GHG emissions estimates available for 2000 and 2004 only, so 2002 values are estimated using the average of GHG emissions in 2000 and 2004; 2007 CO_2 emissions: IEA, 2009b, 2009c; *2007* GHG emissions: Herzog (2009), cited in Malmodin *et al*, forthcoming.
Source : Compiled by OECD, based on the sources indicated.

33. The three studies differ significantly in their scope and methodology, and none of the studies uses an internationally agreed definition of ICT products, such as that adopted by the OECD (2009b). This makes comparisons difficult (see also Chapter 6, Annex Table 6.A1.1). Individual characteristics and shortcomings of each study include:

- *The "2% / 98%" study*: The life-cycle approach is not used consistently. Life-cycle emissions are used for some ICT-sector activities, *e.g.* including business travel within the ICT industry. But "embodied" or "upstream" CO_2 emissions are not included for the largest category, PCs and monitors. This means that impacts during manufacturing and materials extraction are not accounted for. Main assumptions and important intermediate calculation steps, *e.g.* electricity use, are not available for public scrutiny. Therefore the scope and validity of the study cannot be evaluated (Gartner, 2007).

- *Smart 2020 study:* The study includes emissions generated during the production phase for most categories of ICT products ("embodied emissions"). However, it does not cover emissions related to ICT-sector activities, *e.g.* office construction and operation, vehicle fleets, business travel and other non-manufacturing activities. Major telecommunications companies, for example, employ hundreds of thousands of employees, operate tens of thousands of vehicles and maintain thousands of premises. Important intermediate calculation steps, *e.g.* electricity use, are not available for public scrutiny (GeSI/The Climate Group, 2008).

- *ICT, entertainment and media sectors study*: The study is the most comprehensive so far in terms of coverage of ICT products and geographical scope. Developed by researchers from Ericsson, TeliaSonera and the Swedish Royal Institute of Technology, it overcomes many of the problems relating to life-cycle emissions. Intermediate results are available for public scrutiny, *e.g.* electricity use by ICT product categories. However, emissions during end-of-life treatment are not covered (Malmodin *et al.*, forthcoming).

34. ICT manufacturing, *i.e.* the production phase of the life cycle, accounts for less than 1% of global GHG emissions (Table 5.3). There is, however, a risk of double-counting: iron and steel used in the production of ICTs is likely to appear in footprints of the ICT sector as well as the iron and steel sector. Nevertheless, Table 5.3 provides an idea of how ICT manufacturing emissions compare to those of other major industry sectors.

Table 5.3. Shares of ICT and selected industry sectors in global GHG emissions

2007 or latest available year

Industry sector	Share
Electricity generation	25%
Vehicle manufacturing	10%
Oil and gas production	6%
Iron and steel manufacturing	5%
Chemicals manufacturing	5%
Cement manufacturing	4%
Aluminium manufacturing	0.8%
ICT manufacturing	**0.6%**

Note: Different methodologies are used to estimate the ICT manufacturing and the other industry sectors. The share of ICT manufacturing is based on Herzog (2009), cited in Malmodin *et al.* (forthcoming). The remaining sectors are based on UNEP (2009).
Source: Malmodin, forthcoming; UNEP, 2009.

35. In individual countries, ICTs consume at least 10% of national electricity during the use phase and contribute some 2% to 5% of domestic CO_2/GHG emissions (Table 5.4).[11] Some studies (*e.g.* Australia in 2005, the United States in 2000) display lower shares because estimates are limited to ICT use by business. Estimates for the European Union are lower because they cover major OECD economies but also countries with lower ICT diffusion rates. Finally, the disparities between the share of electricity use and GHG emissions are due to different energy sources for electricity generation and import in individual countries.

Table 5.4. National electricity and carbon footprints of ICTs

Country	Year	ICT electricity consumption (GWh)	National electricity consumption (GWh)	ICT share in national electricity consumption	ICT CO_2 emissions (mn tonnes)	National CO_2 emissions (mn tonnes)	ICT share in national CO_2 emissions	
Australia	2005	..	..	**..**	7.9*	525*	**1.5%**	1
European Union	2005	214 500	2 691 000	**8.0%**	98.3*	3 921*	**2.5%**	2
France	2008	58 500	425 882	**13.7%**	4.9 (30.2)	401	**1.2% (7.5%)**	3
Germany	2007	55 400	527 352	**10.5%**	22.6*	956*	**2.4%**	4
Japan	..	..	..	**..**	..	..	**2.2%**	5
Portugal	2007	..	..	**..**	1.0*	82*	**1.3%**	6
United Kingdom	2006	47 769	344 690	**13.9%**	25.9	555	**4.7%**	7
United States	2000	97 000	3 499 285	**2.8%**	..	..	**..**	8
United States	2007	..	..	**..**	150.0	6 094	**2.5%**	9

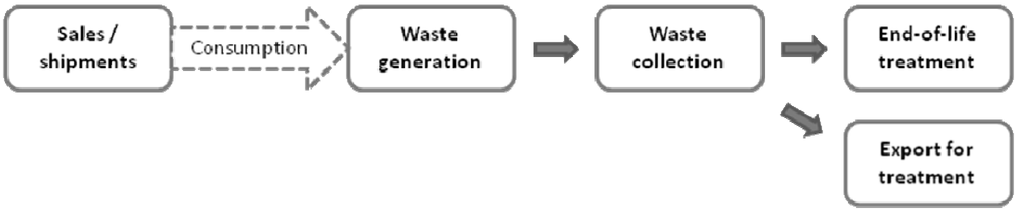
Notes and sources:
CO_2 and GHG emissions based on UNFCCC Greenhouse Gas Inventory Data for the respective year (excluding removals and emissions from land use, land-use change and forestry (LULUCF)). National electricity consumption based on IEA (2009d). ICT electricity consumption and CO_2/GHG emissions based on sources as indicated below. With the exception of France, all country studies assess impacts during the use phase only.
* GHG emissions in million tonnes CO_2 equivalent (CO_2eq).
.. Data not available.
Australia: Industry and business use of ICT only, (ACS 2007).
European Union: EU27 without Bulgaria and Romania, (Bio Intelligence Service 2008).
France: Values in brackets refer to CO_2 emissions from the production and use phases. (Breuil et al. 2008).
Germany: (GeSI/BCG 2009; Fraunhofer IZM/ISI 2009).
Japan: Report commissioned by MIC, no detailed methodology or scope available, (MIC 2008).
Portugal: (GeSI/APDC, forthcoming).
United Kingdom: (UK DEFRA, *Market Transformation Programme, What-If tool*).
United States: (Roth, Goldstein, and Kleinman 2002) and (GeSI/BCG 2008).

Electronic waste

36. Waste from ICT goods (often referred to as “electronic waste”) is a growing global challenge, with two principal sources: the rapidly increasing volumes of ICT equipment disposed of worldwide create inefficiencies when simply landfilled or incinerated and the hazardous character of components and substances in ICT equipment can have severe environmental as well as human health and safety impacts. While the challenge of growing volumes is mainly driven by production and consumption, the environmental impacts of ICT equipment after their useful life – as well as during previous stages in the product life – have a lot to do with their design and production.

37. Data on volumes of electronic waste can be collected at different stages in the product’s “end-of-life” phase: generation, collection and treatment/export for treatment. Some sources add data on sales and shipments in order to arrive at estimates of waste generated when this information is not readily available (Figure 5.8). Collection data is typically more reliable and provided by national statistical offices, especially under WEEE legislation in the EU. However, it does not account for the very high share of waste generated, but illegally disposed of or exported, recycled and re-used outside of the formal waste management system. Estimates of the shares of ICT equipment waste unaccounted for reach 75% in EU countries and 80% in the United States (Greenpeace, 2008).

Figure 5.8. Data collection points for waste and ICT equipment waste



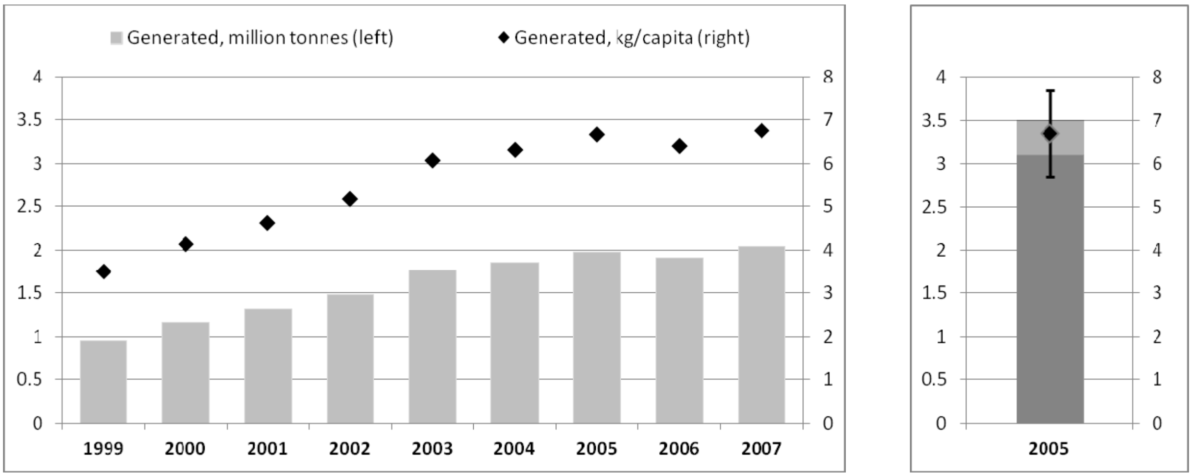
Source: OECD.

38. Worldwide generation of “electronic waste” is around 20 to 50 million tonnes a year, according to the *OECD Environmental Outlook to 2030* (OECD, 2008a). More specific data on the share of ICT equipment in municipal waste are available for the United States and a number of European countries. In the United States, the amount of ICT equipment waste generated stood at 2 million tonnes in 2007, up from under 1 million tonnes in 1999 (Figure 5.9a). In 2005, this represented 1% of total municipal waste. Per capita generation is close to 7 kg and almost double the amount in 1999. In the EU27, the amount of electronic waste generated in 2005 is estimated at 3.1 to 3.5 million tonnes (UNU, 2008). European per capita generation stands at around 6.3 to 7.1 kg of ICT-related waste a year (Figure 5.9b). The variations are due to uncertainties in the data quality as outlined in UNU (2008).

Figure 5.9. ICT equipment waste generated

5.9a. United States, 1999-2007

5.9b. European Union, 2005



Note: Estimates for the European Union display a variation due to uncertainty in the data quality.
Source: UNU, 2008; US EPA 2008.

39. Domestic electronic waste is becoming a major challenge in emerging and developing economies. Although few comparable data are available, recent trends are a cause for concern, given the low domestic absorption capacity for electronic waste and its sustainable treatment in non-OECD countries. Greenpeace and the United Nations StEP Initiative have reviewed available estimates for domestic waste generated from PCs, TVs, printers and mobile phones (Greenpeace, 2008):

- Argentina, 2007: 47 000 tonnes.
- Brazil, 2005: Over 250 000 tonnes.
- China: From 1.2 million tonnes in 2005 to over 1.7 million tonnes in 2007, including PCs, TVs, mobile phones.
- Kenya, 2007: 6 000 tonnes
- India, 2007: 330 000 tonnes, of which 19 000 tonnes recycled.
- South Africa, 2007: up to 50 000 tonnes.

40. Exports of ICT equipment waste pose another major challenge for non-OECD countries. Exports of "electronic waste" to developing countries are strictly limited by national legislation (*e.g.* Australia's Hazardous Waste [Regulation of Exports and Imports] Act, 1989) and international instruments (*e.g. OECD Council Resolution on the Control of Transfrontier Movements of Hazardous Wastes* (C(89)112/Final) and the *Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal*).

41. Reliable data on electronic waste exports are scarce, but individual reports highlight the problematic nature of these activities, many of which are illegal. Countries such as Nigeria and India are estimated to receive over 50 000 tonnes of illegal "e-waste" imports a year (MAIT, 2010; CNN, 2010). The European Environment Agency (EEA) has used EU export data to show that average prices of ICT goods declared as functioning and exported to Ghana, Nigeria or Egypt are of significantly lower value than exports to other countries (EEA, 2009). The study concludes that at such a low value, many are likely to be defunct and destined for informal recycling and/or dismantling. Despite the uncertainties, these analyses point to the existence of business practices in OECD countries whereby recyclers or other entities label defunct ICT goods as used but functioning and export them to developing countries where their treatment threatens human health and the environment (Hilty, 2008). Individual cases have been uncovered and publicised (US GAO, 2008; Greenpeace, 2008; Nordbrand, 2009).

Enabling environmental impacts

42. This section reviews enabling impact assessments of ICTs in four application areas: transport, energy, goods consumption and waste management. Enabling impacts in other areas are discussed in Chapter 6, which complements the following section by analysing in more detail the enabling impacts of sensors and sensor-based networks.

Transport

43. ICT applications can help to mitigate the around 13% of global man-made GHG emissions resulting from transport, including air travel (IPCC, 2007).[12] A wide range of ICT applications can be used for this purpose. A report by the UK's Sustainable Development Commission highlights six potential levers: reducing travel needs, influencing travel choices, changing driver behaviour, changing vehicle behaviour, increasing vehicle load factor, and increasing network efficiency (SDC, 2010). Two applications are illustrated here: embedded automotive systems to change vehicle behaviour and telework to reduce travel needs.

Embedded automotive systems

44. Embedded systems are integrated semiconductor devices that enable control, measurement and management in a wide range of application areas. In fact, the bulk of semiconductors produced today are embedded in non-ICT products, such as motor vehicles, defence, aviation and health care.

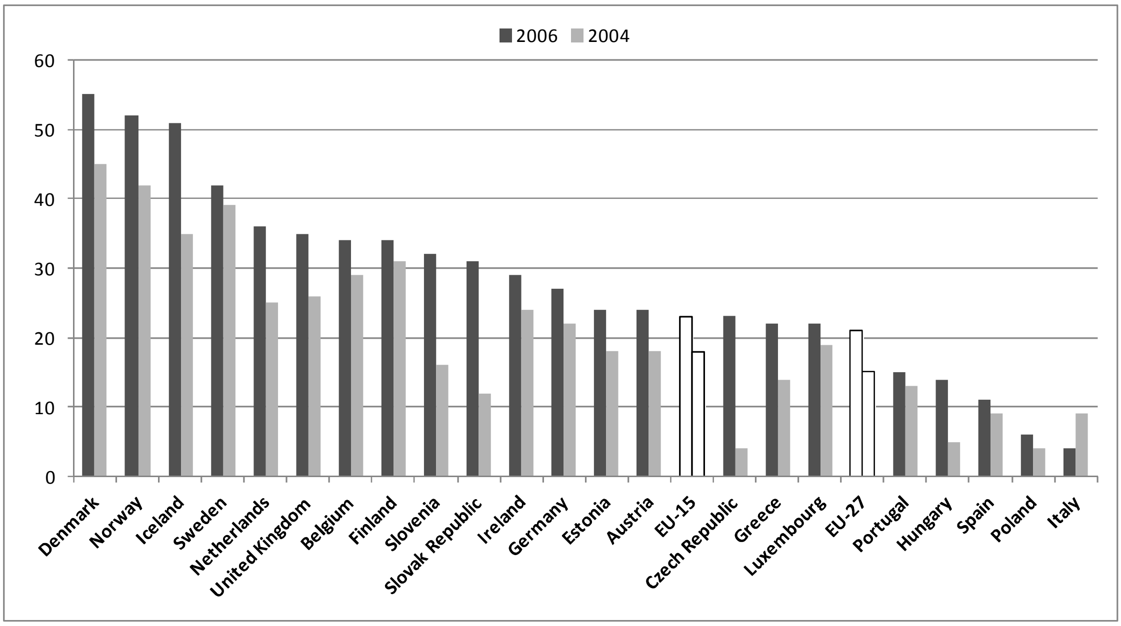
45. Embedded automotive systems have the potential to increase fuel efficiency and to reduce CO_2 from individual vehicles by around 20%, according to industry estimates. Measures such as electric power steering, improved power supply systems and others have been estimated to increase the fuel efficiency of an average US automobile by 16% (Heinrichs, Graf and Koeppl, 2008). The potential reduction of CO_2 emissions amounts to around 10% of an average US automobile's CO_2 emissions in 2007 (or around 14% of an average EU automobile's emissions). Similar rates have already been achieved in existing models owing to embedded systems (Hönes, 2009). Existing hybrid vehicles have even surpassed these efficiency increases and emissions reductions, *e.g.* by re-using the energy generated while driving and braking. Embedded systems and software are indispensable to achieve these savings, which is why the number of semiconductors is two to three times higher than in conventional fuel combustion cars.[13]

Telework

46. Telework is an ICT application which can help reduce work-related commuting and travel. Allusions to the potential replacement of travel by communications infrastructures has been discussed since the 1960s; the phrase "telecommuting" was coined in the 1970s (Nilles, 2007; Owen, 1962). The 1980s and 1990s saw enthusiasm about the topic from businesses and governments, *e.g.* through pilot projects (*e.g.* in California, Kitamura *et al.*, 1991). In 2002, the European Commission's statistical service Eurostat started collecting data on telework through surveys in EU member states and compiled results in a series of publications. However, both data collection and publications were discontinued in 2006.

47. The supply of telework has increased overall over the period for which data are available. In 2006, around 23% of enterprises in the EU15 employed teleworkers, compared to only 18% in 2004 (Figure 5.10).[14] The data show that three variables determine a company's likeliness to offer its employees the possibility to telework: location (country), size, and industry sector.

Figure 5.10. Share of enterprises employing teleworkers, EU15



Note: Telework is defined to include any remote location. However, the majority of teleworkers access company IT systems from home.

Source: Eurostat survey on computers and the Internet in households and enterprises.

There are clear differences between northern European countries – Denmark, Norway, Iceland, Sweden – which have the highest shares of companies offering telework, and southern and eastern European countries – Italy, Poland, Spain, Hungary, Portugal – which are below the average. This distribution largely reflects national broadband diffusion rates.

In terms of size, large firms offer telework arrangements more often than small- and medium-sized enterprises (SMEs). In Denmark, for example, the share of large companies offering telework is double that of small enterprises. In Italy, the share is multiplied by a factor of 10.

Not all industry sectors accommodate telework easily. The highest rates of teleworking employees can be found in the audiovisual and content production sectors, real estate businesses, utilities (gas, water, electricity). The utilities sector has the highest share of companies with telework arrangements in Hungary, the Netherlands, Spain and the United Kingdom. Firms in other manufacturing sectors are less likely to offer telework opportunities.[15]

48. Reliable figures for telework uptake are available for very few countries. In the United States, around 12% of employees were estimated to have teleworked in 1998, a sign of the country's early leadership in this area (Choo, Mokhtarian and Salomon, 2005). In Finland, around 5% of the working population in 2001 was reported to telework (Helminen and Ristimaki, 2007). Determinants of telework uptake include commuting distances, education and other socioeconomic factors. In Finland, proportions were higher when employees lived over 80 km from their workplace. In the European Union, around 13% of employees were estimated to have teleworked in 2002, based on private data sources (SUSTEL, 2004).

49. The environmental impacts of telework have been analysed but have limitations. As for embedded systems, individual telework applications have lower environmental burdens than physical transport. Small-scale empirical studies assess the benefits positively at the local level (*e.g.* Kitamura *et al.*, 1991; Hamer, Kroes and Ooststroom, 1991). Consequently, personal transport distances "are substantially reduced for those who telecommute, on days that they telecommute, for as long as they telecommute" (Choo, Mokhtarian and Salomon, 2005). However, there is still uncertainty as to whether the benefits and other potential factors scale up to "net" environmental benefits at the system level, *e.g.* nationally (see the section "Systemic impacts").

Electricity

50. ICTs can help to limit greenhouse gas emissions from the energy supply industry, which is responsible for one-quarter of global GHG emissions (Table 5.3; IPCC, 2007). Electricity production is a major driver of the industry's carbon footprint: over two-thirds of worldwide electricity is generated by plants using fossil fuels (IEA, 2009d). Rising electricity consumption in households, businesses and industry continues to pose challenges to OECD countries, but even more to emerging economies: growth in final electricity consumption between 2006 and 2007 was 2.2% in the OECD area, compared to 8.7% in non-OECD countries (IEA, 2009d).

Smart meters

51. Utilities around the world have started projects to replace traditional residential customer electricity meters with "smart" electricity meters (or "advanced metering infrastructures" (AMI); see Chapter 6 for the diffusion of other types of metering). According to Meterpedia.com, a privately compiled database of smart metering projects, a total of 60 million smart meters were in operation worldwide in mid-2009, but another 800 million have been announced (the total population of OECD countries is around 1.2 billion). Italy and Sweden were the first to roll out smart electricity meters to over 90% of residential electricity customers (ESMA, 2010). Over 4 million smart meters are in operation in Canada, the bulk in

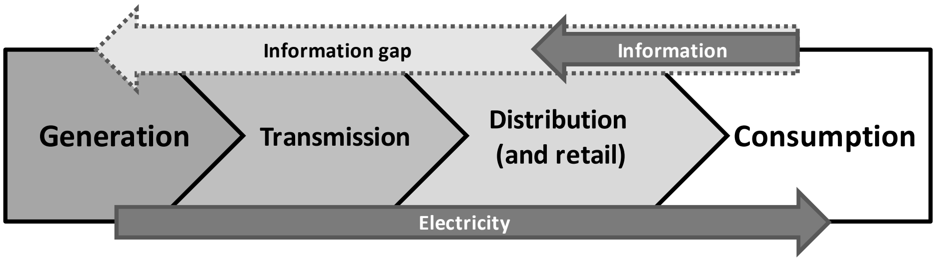
the province of Ontario; in the United States, close to 3 million smart electricity meters are operational in 2010, including over 1 million in the state of Pennsylvania.[16] Pilot projects are under way in most other OECD countries, partly spurred by legislation: in the EU the 2006 EC Directive on energy end-use efficiency and energy services (2006/32/EC) mandates member countries to improve information provision to final electricity customers.

52. Studies have found that residential end users can lower their electricity bills by up to 20%, but savings depend on a variety of factors (see the section "Systemic impacts"): the environmental benefits of smart meters include automation and remote control of domestic electrical appliances (enabling impacts) and provision of real-time and disaggregated information about energy use and prices (systemic impacts). Smart meters provide the necessary link between "smart" household appliances and the electricity provider. They enable utilities to balance loads across different times of the day, for example by sending signals to non-critical devices such as dishwashers which turn on or off depending on electricity prices, real-time availability of renewable energy sources and customer preferences. Information provision can lead customers to adapt their energy use patterns.

Smart grid

53. The "smart" grid is a key component of strategies to limit GHG emissions across the entire energy sector value chain (Figure 5.11). The concept is sometimes reduced to the installation of smart meters in individual households. It is true that smart electricity meters are a key means of overcoming classical information gaps between suppliers and final consumers. They can enable changes in individual energy consumption as well as grid-wide improvements such as automated peak load reduction (see the section "Smart meters"). But smart grids also include a wide range of other, mostly ICT-based components (see also Chapter 6) that offer environmental opportunities that go beyond micro-level energy savings.[17]

Figure 5.11. Stylised electricity sector value chain



Source: OECD.

54. In the traditional energy sector value chain, electricity flows are typically unidirectional and information flows are limited. Smart grid technologies such as smart meters, intelligent storage devices, sensors and communications networks transform unidirectional flows of electricity and information into networked grids. Electricity and information circulate between the different elements in the network and these flows can be centrally managed to optimise energy supply, demand and storage. Networked elements in a smart grid can be added and removed in response to real-time requirements, *e.g.* turning wind turbines on or off, adding or removing energy storage as needed.

55. Smarter electricity grids are in fact needed to meet future grid requirements, which will considerably increase the amount of data generated and required for managing electricity grids. Energy sector actors deal regularly with challenges such as load balancing and peak load management. These challenges are increasing as new sources of energy generation, consumption and storage are added to existing grids, *e.g.* decentralised energy generation, micro-grids, energy storage solutions, plug-in electric

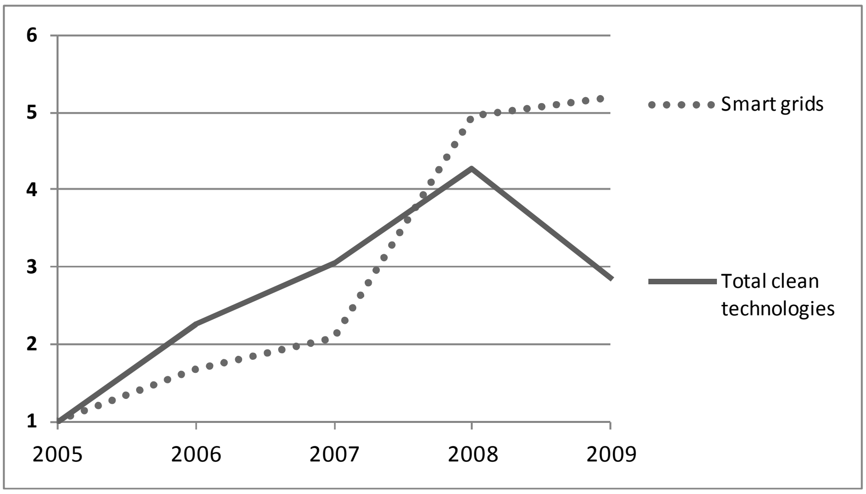
cars. These challenges and the respective "smart" grid applications are similar worldwide, but it is important to keep context-specific challenges in mind.[18]

56. Smart grid pilot projects are being conducted by industry consortia around the world, often with government support. In the United States, Xcel Energy is conducting a large-scale pilot project in the state of Colorado, which is entirely run by the private sector. Examples in which governments co-fund high initial investments include Jeju Island (Korea) with a view to rolling out smart grids in the cities of Seoul; the e-energy pilot regions (Germany) with cross-industry consortia and accompanying research by universities and research institutes such as Fraunhofer; Spain's "smart city" pilot in Malaga, co-funded by the private sector and local, national and European funds; Australia's "Smart Grid, Smart City" programme which will designate a pilot city for a cross-sector partnership; China's city of Yangzhou (Jiangsu region), where General Electric and the local government have announced a smart grid demonstration project. Governments have also made smart grids a priority investment in national stimulus plans for economic recovery (OECD, 2009c; ZPryme, 2010). The United States and China have planned investments of several billion USD in smart grid R&D and deployment projects.

57. Policy signals stimulate private-sector activity around "smart" grid technologies. In the United States, legislation such as the *Energy Independence and Security Act* (2007) and the *American Recovery and Reinvestment Act* (2009) provide government support and funding for nationwide modernisation of the electrical grid and stable mid-term prospects for private investors. This contributed to continued growth of commercial investments in innovative smart grid ventures during 2009, even though overall clean technology investments tumbled by 33% (see Figure 5.12). Three of the top five VC investments in 2009 (each over USD 100 million) targeted companies working on smart metering, smart energy storage and smart grid communications (Cleantech Group, 2010). These investments are also expected to generate high value-added jobs in OECD countries and emerging economies.

Figure 5.12. Growth of global venture capital: smart grids and overall clean technologies, 2005-09

Index (2005 = 1.0)



Source: OECD calculations, based on data by Cleantech Group.

58. However, there are challenges, of which high up-front investment costs are possibly the greatest. As a consequence, industry surveys indicate that most global utilities still hesitate to deploy smart grid technologies.[19] Utilities focus on automation of transmission and distribution (T&D), smart metering and dynamic pricing projects.[20] System-wide roll-outs of the smart grid are currently not the primary concern of utilities, despite government commitments to advance in this area. Financing modes and effective public-private partnerships will in many cases be critical to success.

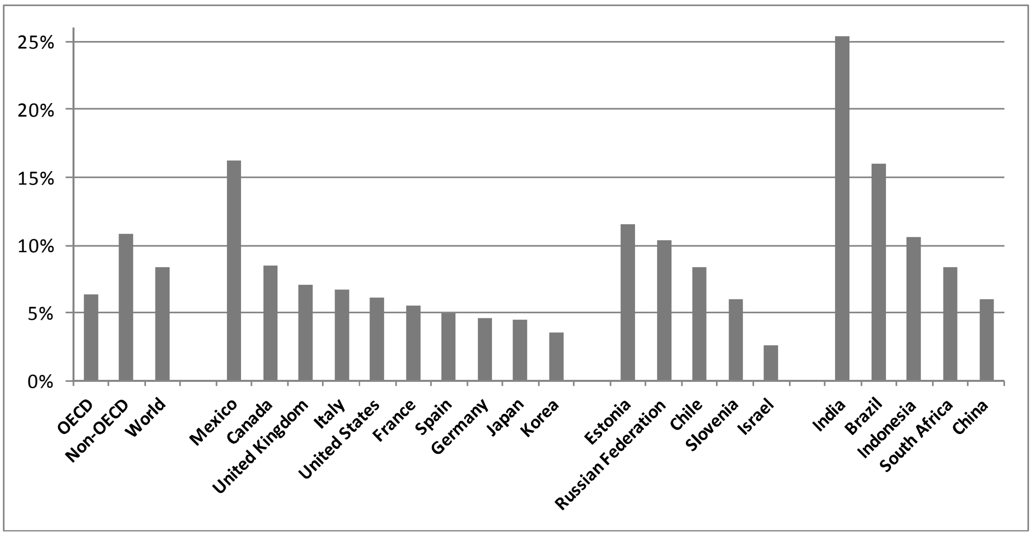
59. Quantification of the environmental impacts of the smart grid depends on the levers taken into account (see Chapter 6 for a critical review of existing estimates). Smart grid technologies can improve environmental footprints across the entire energy sector value chain: energy generation, *e.g.* through integration of renewable energy sources and the creation of "virtual power plants"; energy transmission and distribution, *e.g.* measuring and verifying the state of the grid (Box 5.4); integrating energy storage solutions such as vehicle-to-grid (V2G) applications; final energy consumption, *e.g.* through information provision, dynamic pricing and remote demand-side management. Most smart grid projects are still in pilot phases so that few quantitative data are available on enabling impacts. Future GHG emissions reductions depend on systemic impacts that are still relatively unexplored (see the section "Systemic impacts").

Box 1. Lost in transmission – smart ICTs to avoid electricity losses across the grid

Globally, around 8% of the electricity generated in 2007 was lost before it reached final consumers (Figure 5.13). The causes may be simple leaks and inefficiencies, but they also involve fraud and electricity theft. It is estimated that these power losses are responsible for over 600 million tonnes of CO_2 emissions across major global economies (MEF, 2009). In OECD countries, 6% of generated electricity on average is lost between the producer and the final consumer. Shares are higher in non-OECD countries, at around 11%, and can reach over 25%, as in India. Smart grid technologies can help operators reduce the amount of electricity lost during T&D, *e.g.* by using sensor-based networks to identify and locate leaks. Applications are not standardised, but must be tailored to suit the country-specific infrastructure conditions and causes of losses.

Figure 5.13. Electricity lost during transmission and distribution, selected countries, 2007

Share of domestic electricity production, percentage



Note: OECD countries selected based on gross domestic electricity production (ten largest); plus five OECD accession and five OECD enhanced engagement countries.

Source: OECD calculations based on IEA, 2009d.

Digital content

60. Consumption of digital goods can help reduce the 19% of global GHG emissions resulting from manufacturing industries (IPCC, 2007). Digital content can lower consumption of resources in many areas. Digital music and digital document delivery services, for example, can help to reduce global paper production for packaging, printing and writing purposes, which stood at 22 kg per capita globally in 2008

(and four times higher in OECD countries with 88 kg on average, based on data from FAO ForesSTAT). While environmental benefits are evident at the level of individual products, the net environmental impacts of digital content vary. In particular, impact assessments change when direct impacts of the required Internet infrastructures and access devices are included. The behaviour of users determines systemic environmental impacts (see the section "Systemic impacts").

61. Digital music delivery offers environmental benefits as compared to physical CD purchases. The main sources of CO_2 emissions for physical CD purchases are CD manufacturing, packaging and transport. Production of CD cases alone accounts for around one-third of the music industry's overall carbon footprint (Greater London Authority, 2009). Water use for CD and DVD production has a major environmental impact (Türk *et al.*, 2003). Consequently, digital and online music have a large enabling potential. Depending on the scenario, digital music downloads lower CO_2 emissions by at least 60% compared to physical CD consumption (Koomey, Weber and Matthews, 2009).

62. Compared to traditional document delivery, E-Boks, a digital document delivery service in Denmark, has been found to reduce global warming potential by up to 60%, energy consumption by up to 70%, and wood use by over 90% (Schmidt and Kløverpris, 2009). The impact assessment includes the energy use of the servers needed to store and distribute digital documents; it excludes the wider Internet infrastructure, arguing that this exists independently of the document delivery system. Scaled up to the entire user base of E-Boks in Denmark, the study found that 1 600 tonnes of CO_2eq emissions were avoided, *i.e.* around 6.5% of a Danish person's annual GHG footprint in 2007.[21] It avoided the processing of over 90% of the pulp that would have otherwise been used in delivering the documents on paper via the postal service. The study indicates two behavioural factors that can alter these results: longer viewing times of documents on the computer and higher frequencies of domestic printing. Consequently, the environmental impact of the E-Boks application depends to a large degree on how it is used (systemic impacts).

63. Studies on the enabling impacts of electronic newspapers reach similar results, *i.e.* lower energy use of production and delivery compared to printed publications (Kamburow, 2004; Toffel and Horvath, 2004; Moberg *et al.*, 2010). However, the life-cycle environmental impacts depend on the scope of the analysis, *e.g.* on whether Internet infrastructures and access devices (tablet PCs, e-readers) are included. Moreover, delivery formats play a role as consulting entire newspapers in PDF format typically increases environmental impacts compared to online viewing of selected articles.

Waste management

64. Embedded systems can be used in waste management, for example for weight- or volume-based pricing or for dispatching and routing of collection vehicles. Pilot projects indicate significant environmental benefits, *e.g.* up to 40% reduction of total driven collection routes, in Granada, Spain (Zamorano *et al.*, 2009), Shanghai, China (Rovetta *et al.*, 2009) and Malmö, Sweden (Johansson, 2006). Waste bins in these projects are equipped with RFID-based sensors that capture weight, volume and sometimes the specific type of waste contained. Sensors are connected via wireless communications networks (*e.g.* GSM, GPRS) in order to transfer data to software management systems that integrate databases and geographic information systems for routing and scheduling purposes.

65. Embedded sensors and sensor networks can also be used to track hazardous waste transport domestically and across international borders. Simple "dumping" of hazardous waste, *e.g.* medical and toxic waste, can result in severe environmental and health impacts. Disposal, treatment and international flows of these waste types are therefore regulated in OECD countries. The US Environmental Protection Agency (EPA) has tested integrated systems of radio frequency identification (RFID) transmitters and readers, global positioning system (GPS) tracking devices and central management software to track

hazardous waste transport across the US-Mexican border. The problem is serious because of re-imports of hazardous resources and waste from around 4 000 foreign-owned manufacturing plants in Mexico (*maquilas*). Two commercial RFID applications have proved sufficiently accurate, precise and useable to track and monitor these cross-border flows of hazardous waste.[22]

66. Potential negative impacts of ICTs on waste management must be noted. Challenges to municipal waste streams arise when semiconductors are embedded in goods for tracking and monitoring purposes, *e.g.* in cardboard, glass bottles, car tyres, tin cans and product packaging. This can be particularly problematic if the tags are tightly integrated, *e.g.* in wearable electronics, “smart” tickets and credit cards. In Germany, the total amount of passive RFID-based embedded systems was estimated to be over 90 million units in 2007, *i.e.* more than one per inhabitant (Erdmann and Hilty, 2009). This amount is projected to increase ten-fold by 2012 (see also Wäger *et al*., 2005).

Systemic impacts

67. Few analytical studies of the environmental impacts of ICTs consider the systemic impacts described in the first section of this chapter. A relatively comprehensive assessment of direct, enabling and systemic impacts of selected ICT applications was developed in a study for the European Commission Institute for Prospective Technological Studies (IPTS) (Erdmann *et al.*, 2004). This section complements some of the study’s main results with findings on mediated environmental impacts in three ICT application areas discussed in the section on enabling impacts: transport, electricity and consumption of digital content (see also Chapter 6). Finally, information provision and facilitation of research can lead to better understanding of the natural environment and thus facilitate strategies that go beyond mitigating environmental impacts of human activities to adaptation to inevitable environmental changes (*e.g.* climate change).

68. The IPTS study concludes that ICTs are very important for achieving environmental policy goals. Depending on the scenario, ICT applications can help to alter a range of seven environmental indicators by up to 30% in 2020: GHG emissions, energy consumption, freight transport, passenger transport, private car transport, renewable share of electricity generation, and share of municipal solid waste not recycled. The study projects that the ICT applications considered will help lower the share of private cars in total passenger transport and increase the share of renewable energy sources in electricity generation. Impacts on other indicators are uncertain: considerable benefits can be obtained from ICT applications in areas such as GHG emissions and energy consumption, but outcomes vary by scenario and depend on future policies. The study projects that, regardless of the scenario used, total passenger transport (any traffic mode) will not grow more slowly as a result of ICT applications.

69. The IPTS study provides guidance for the future analysis of ICT applications. Potential areas in which studies can expand the existing template to examine systemic impacts of enabling technologies include: *i)* selection of ICT application areas, *e.g.* including smart vehicle technologies, smart meters, smart grids and automated demand-side management, and precision farming; *ii)* selection of environmental indicators, *e.g.* using the environmental impact categories outlined in Table 5.1; *iii)* scenario development, *e.g.* projecting future energy and electricity prices, GDP growth; and *iv)* modelling of environmental impacts, *e.g.* data validation, causal relationships, ICT-sector impacts (based on communication with Lorenz Erdmann, co-author of the IPTS study).

Transport

70. In the area of personal transport (all transport modes) the IPTS study concludes that ICT applications will have a neutral impact or contribute to increases of overall transport of up to 4% in 2020. Applications such as e-commerce, telework and teleconferencing can limit this growth by up to 3% each.

These values are lower than those found in other impact assessments because rebound effects are considered. The study's authors assume that only a limited share of business travel can be replaced with teleconferences and that not all jobs are compatible with telework. Intelligent transport systems (ITS) are estimated to increase future passenger transport volume because they improve traffic fluidity and thus provide incentives to travel. Rebound effects are highly relevant in this area so that other demand-side measures (*e.g.* pricing) are necessary to transform efficiency gains into environmental benefits. Finally, ICTs enable passengers to work while using public transport, *e.g.* using Internet-connected smartphones, which in turn provides incentives to travel. It is important to note that this favours public transport over individual cars.

71. Various behavioural factors can mediate the systemic relationship between telework and road travel, thereby altering net environmental impacts. It has been suggested, for example, that teleworking employees increasingly use their car for non-commuting trips, *e.g.* for shopping, leisure, children's activities, elderly care (Mokhtarian, 1991). Telework potentially facilitates settlement of employees further from main office locations in urban centres, which can in turn contribute to "urban sprawl" (Kamal-Chaoui and Robert, 2009). Systemic environmental impacts can include longer commuting distances and changed land use as more individual homes and new transport infrastructures are built. Few studies have assessed systemic impacts on overall road travel, including assessments of commuting frequencies and distances. Reliable, if dated, baselines of the impact of telework on road transport volumes have been found only for Finland and the United States: in Finland, telework is estimated to have reduced road travel by up to 0.7% in 2001 (Helminen and Ristimaki, 2007); in the United States, telework is estimated to have reduced vehicle road travel by up to 0.8% in 1998 (or by over 19 billion miles/31 billion kilometres) (Choo, Mokhtarian and Salomon, 2005).

Electricity

72. The IPTS study projects that ICT applications in the energy sector will unambiguously contribute to reducing GHG emissions. This finding is based on the assumption that ICTs will help to increase the share of sources of renewable energy in electricity generation by up to 7% in 2020. As outlined above, "smart" ICTs in the electricity sector can enable a much wider range of environmental benefits. Other smart grid technologies, however, are not examined in the IPTS study.

73. Smart meters can reduce household energy consumption, but their success largely depends on behavioural changes by individuals. Research findings suggest that better (access to) information about the use and price of electricity can help reduce energy consumption by up to 20%.[23] These include data from pilot projects on the Portuguese Azores islands and in Denmark;[24] in Canada's Ontario province (Mountain, 2006); and the PowerCentsDC programme in the United States (Wolak, 2010). Savings achieved depend on a variety of factors, including how users receive feedback on their energy use (direct, *e.g.* via in-house displays or Internet applications; indirect, *e.g.* via monthly bills). Aggregate data can be used to evaluate the performance of entities larger than individual households, *e.g.* at the scale of city neighbourhoods as in the "Urban EcoMaps" of Amsterdam and San Francisco. Further energy savings can be achieved when smart meters are integrated with home automation systems and connected to the Internet. This allows users to control electrical devices over the Internet, *e.g.* using applications such as Google's PowerMeter, Microsoft's Hohm or the Danish Electricity Savings Trust's My E-Home. Through a combination of these ICT applications, smart meters can lead to a systemic change in the electricity consumption of individuals and households.

Digital content

74. The IPTS study points to the strong dematerialisation potential of virtual goods. Under best-case assumptions, virtual goods help reduce material flows in the economy by over 20% in 2020. This relates

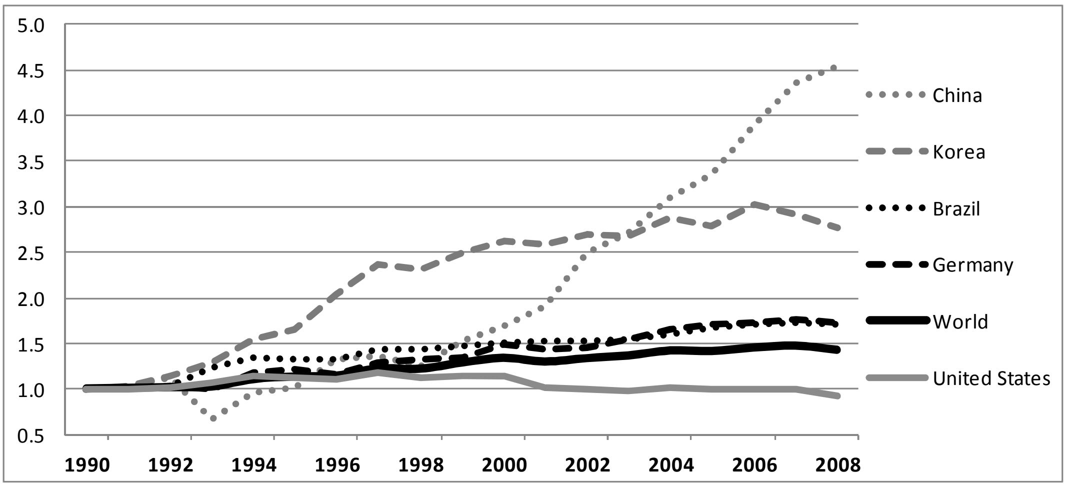
mainly to reduced freight transport and municipal solid waste generation. Virtual goods can limit future energy consumption and GHG emissions by over 10% each. Using worst-case assumptions, the impacts become negligible. The wide range of potential impacts is due to the high level of uncertainty about the future use of virtual goods.

75. For digital music, behavioural aspects play a major role in determining net environmental impacts. The best-case scenario (Koomey, Weber and Matthews, 2009) assumes that music downloads stay on the computer, in which case CO_2 emissions result mainly from server operation for the hosting of digital music. The worst-case scenario assumes that users create physical back-ups of their digital music collections, *i.e.* “burning” to CDs. However, studies highlight that the life-cycle environmental impacts of physical music media cannot be directly compared to those of digital music. This is because consumers of digital music have different use patterns: Internet users tend to prefer individual songs to entire albums (Julie's Bicycle, 2009). More recently, online music streaming services such as Spotify, Deezer and Pandora have gained in popularity with Internet and mobile phone users. The resulting environmental impacts of streaming music services can differ from those of “buy-to-download” platforms such as the Apple iTunes store and Amazon MP3.

76. The global impacts of ICT applications aimed at replacing the consumption of paper – *e.g.* e-mail, digital document delivery, online news – are difficult to assess. It has been argued that digital technologies are slowly contributing to an overall levelling of paper consumption (The Economist, 2008). However, global production of paper for writing and printing (including newsprint) increased by 44% between 1990 and 2008 (Figure 5.14). A levelling on a global scale and in some individual countries is apparent since 2007, but it is too early to attribute this to enabling impacts of ICTs. Further analysis is needed to assess the systemic impacts of ICT applications such as digital document delivery on global paper production and consumption.

Figure 5.14. Growth of production of paper for writing and printing, world total and selected countries

Index, 1990 = 1.0



Source: OECD calculations based on FAO, ForesSTAT database, May 2010.

Adaptation to climate change

77. Unsustainable development has already caused strong environmental impacts, some of which are likely to be irreversible. In some countries, climate change is altering agricultural capacity, flood and drought patterns, biodiversity, and sea levels. Adaptation to these changes will require preparing risk

assessments, improving agricultural methods, managing scarce water resources, building settlements in safe zones and developing early disaster warning systems. ICTs play a major role in communicating the information needed to adapt behaviour and to achieve systemic adaptation to changing environmental conditions (ITU, 2008).

78. Adaptation to the environmental impacts of climate change is a global challenge. Only a few years ago, it was regarded as primarily relevant to developing countries, *e.g.* desertification trends around the Sahara or a rise in sea levels which threaten small island states. More recent reports, however, point to serious impacts in OECD countries (Karl, Melillo and Peterson, 2009). Rising sea levels, for example, threaten some OECD coastal cities and regions. The top ten cities in terms of exposed population are almost equally divided between non-OECD and OECD countries: on the one hand, Mumbai, Guangzhou, Shanghai, Ho Chi Minh City, Kolkata and Alexandria; on the other, Miami, Greater New York, Osaka-Kobe and New Orleans (OECD, 2007).[25]

79. ICTs and the Internet are key technologies for tracking, analysing and predicting such changes and for developing appropriate communication and management strategies. This will help to sustain productivity in developed and developing countries. For example, energy companies worldwide will increasingly have to adapt generation strategies to changing weather and climate conditions and thus will need solid predictions (Dubus, 2010). In the area of agriculture and in particular in developing countries, ICTs can provide the means to integrate global forecasts with local needs (Kalas and Finlay, 2009). Improved access to data and better communication of the long-term risks to policy makers therefore facilitate the adjustment of economic development patterns to the impacts of a changing climate.

80. Technology transfer of ICTs to developing countries is a major challenge. The needed technologies are often expensive to develop and deploy. Moreover, local availability of skills might not be sufficient to use ICTs and the Internet effectively to achieve the desired changes in production, consumption and lifestyles. Therefore, the transfer of technology and the necessary funding remain pressing challenges for achieving positive systemic outcomes in the context of adaptation to climate change.

Conclusion

81. This chapter shows the important linkages between ICT products and producers, ICT-enabled innovation, the environment and climate change. It discusses empirical analysis of direct environmental impacts in different stages of the life cycle, ICTs as a major enabling technology for mitigation of environmental impacts across all economic sectors, and the contribution of ICTs to systemic changes to achieve more sustainable production, consumption and lifestyles. The analytical framework highlights the importance of analysing impacts on all three levels to assess the "net" environmental impacts of green ICTs.

82. Direct environmental impacts are considerable in areas such as energy use, materials throughput and end-of-life treatment. A basic PC's contribution to global warming is highest during its use phase, but significant environmental impacts also occur during the manufacturing and end-of-life phases. As the diffusion of the Internet and other ICT infrastructures increases, the relative share of ICTs in environmental impact categories such as global GHG emissions is likely to grow. It is therefore important for ICT producers to minimise the environmental impacts of their products and operations. Improved R&D and design can help to tackle direct impacts throughout the entire life cycle of ICT goods, services and systems. Government "green ICT" policies can be instrumental in promoting such life-cycle approaches (see the *OECD Recommendation of the Council on Information and Communication Technologies and the Environment*).

83. At the same time, ICT producers (including service providers) design and implement innovative ICT systems that enable more sustainable production and consumption across the entire economy. This ranges from product-specific improvements, *e.g.* embedded ICTs for energy-efficient vehicles, to entire systems, *e.g.* ICTs for smarter transport management. Large environmental benefits are possible in major industry sectors – *e.g.* transport, energy, housing – but to be effective products must be co-developed and their diffusion well co-ordinated by stakeholders. As levels of technology adoption differ across industry sectors and individual countries, context-specific analysis is important to determine optimal application scenarios for ICTs. Governments can promote cross-sector R&D programmes and local pilot projects, especially in areas where structural barriers, *e.g.* lack of commercial incentives, high investment costs, may hinder the rapid uptake of "smart" ICTs.

84. Information and communication are pivotal for system-wide mitigation of environmental impacts and adaptation to inevitable changes in the environment. Individual users and consumers can spearhead green and more sustainable growth through informed decisions about their consumption. ICTs can provide them with easy access to reliable environment-related information about goods and services. But individual users also require information about how to use ICTs to contribute to improvements in the environment. Further research into the systemic impacts – intended and unintended – of the diffusion of ICTs is important to understand how ICTs and the Internet contribute to environmental policy goals such as fostering renewable energy sources, reducing transport volumes, optimising household energy use and reducing material throughputs.

85. Measurement remains an important issue. This chapter has used available data to outline the main trends. In doing so, it points to obvious gaps in the analysis of direct, enabling and systemic impacts of ICTs. While there is empirical analysis of the environmental impacts of the main ICT product categories, categories such as embedded systems require further attention. Regarding enabling impacts, analysis so far is methodologically diverse, which makes cross-country or cross-technology comparisons difficult. Life-cycle approaches can provide a comprehensive picture of the system-wide environmental benefits and potential drawbacks of rolling out "smart" infrastructures. Further empirical analysis of enabling and systemic impacts is necessary to address the uncertainties present in the scenarios developed so far. This analysis needs to cross disciplinary borders to integrate engineering, energy and environment disciplines as well as social and behavioural sciences.

86. Green ICTs are of global relevance. It is essential to limit the direct environmental impacts of ICTs in emerging economies. At the same time, ICT applications can help limit accelerating energy use and material consumption in all countries. Financing and local skills issues are likely to be key factors in successful strategies to diffuse and deploy smart ICT applications globally.

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ENDNOTES

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1 The chapter is based on an upcoming OECD report on ICTs, the environment and climate change. See www.oecd.org/sti/ict/green-ict for details.

2 This work was mandated by the *OECD Seoul Declaration on the Future of the Internet Economy* (June 2008) and the *OECD Ministerial Declaration on Green Growth* (June 2009). This chapter does not address potential economic and employment impacts of green ICTs. These are partially addressed in Chapter 3 of this volume and will be analysed in more detail as part of ongoing work for the *OECD Green Growth Strategy*.

3 In general, positive environmental impacts can also be termed environmental “benefits” or “contributions”. The analytical framework developed here uses the word “impacts” for both positive and negative interactions with the natural environment on all levels. This differs somewhat from terminology used in environmental and economic accounting (EEA) approaches in which every economic and social activity interacts with the environment through inputs and outputs, *i.e.* depends on “environmental contributions” such as energy use and causes “environmental

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impacts" such as pollution (United Nations, 2003). The different use is intended since in this analytical framework, outputs (*i.e.* impacts) of ICTs can also contribute to environmental improvement.

4 The proposed three-level framework draws on Hilty (2008) and MacLean and St. Arnaud (2008).

5 Environmental impacts in this report include contributions and impacts as in the terminology of environmental and economic accounting approaches: every economic and social activity interacts with the environment through inputs and outputs, *i.e.* depends on "environmental contributions" such as energy use and causes "environmental impacts" such as pollution (United Nations, 2003).

6 User acceptance of some green ICT applications is conditioned by ease of use, affordability and reliability as well as adequate treatment of inherent security and privacy issues. Dealing with security and privacy issues is critical for ICT systems that enhance critical physical infrastructures such as national electricity grids. This is also important, where positive environmental impacts depend on the accumulation and interpretation of large amounts of disaggregated data. These issues will be further discussed in upcoming OECD analysis of ICTs, the environment and climate change.

7 The OECD held a workshop on "Enhancing the value and effectiveness of environmental claims" in April 2010, www.oecd.org/document/48/0,3343,en_2649_34267_44582320_1_1_1_1,00.html.

8 The discussion of life-cycle environmental impacts of computers is based on Eugster, Hischier and Duan (2007). The study is very comprehensive, taking into account the international division of labour in PC production. In this section, results from other LCA studies are used to supplement analysis by Eugster, Hischier and Duan.

9 In reality, the shares of electricity used and emissions generated can be quite different. This can be the case, for example, when a greater number of households than businesses consume electricity generated from renewable energy sources. In this case, business ICT infrastructures would have a relatively higher share of the carbon footprint than household ICT equipment. Moreover, shares would differ significantly if life-cycle emissions are considered.

10 See the presentation by Jens Malmodin, Ericsson, at the OECD high-level conference on "ICTs, the environment and climate change", 2010, http://itst.media.netamia.net/ict2009/demand/135.

11 Detailed studies have only been conducted in a limited number of countries. However, comprehensive studies exist for five out of the seven most populous OECD member countries: France, Germany, Japan, the United Kingdom and the United States. In these cases, studies were commissioned by government and were conducted by academic or other research institutions. The methodology is in most cases publicly available and can therefore be reviewed. Other studies, *e.g.* in Australia and Portugal, have been conducted on the initiative of the private sector.

12 Total anthropogenic GHG emissions in the IPCC 4AR also include emissions from activities such as deforestation. If these are removed, the share of transport is higher.

13 See the presentation by Suraj Mukundarajan, Infineon, 2010, www.isaonline.org/microsites/Excite/10/presentations/IFX_AutoExcite_2010_Suraj.pdf.

14 IN EU surveys telework refers to work from any location, but predominantly from home.

15 For data on telework supply by industry sector in the European Union, see the European Commission's series of studies "e-Business W@tch", www.ebusiness-watch.org/studies/on_sectors.htm.

16 A regularly updated database of smart meter installations in Canada and the United States is available at www.coincident.com/smart-meters/main.html.

17 For comprehensive overviews of what constitutes a smart grid, see MEF (2009) and the US Department of Energy's website on "The Smart Grid: An Introduction", www.oe.energy.gov/SmartGridIntroduction.htm.

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18 See the presentation by Rahul Tongia, Center for Study of Science, Technology, and Policy, Bangalore, at the OECD high-level conference on "ICTs, the environment and climate change", 2010, http://itst.media.netamia.net/ict2009/demand/201.

19 This is the result of a survey conducted by Microsoft of 200 electricity sector professionals. Press release available at www.microsoft.com/presspass/press/2010/mar10/03-11SmartGridPR.mspx.

20 Based on energy industry surveys conducted by IDC Energy (Smart Utility and Meter-to-Cash Study, March 2010) and Oracle (Smart Grid Challenges & Choices: Utility Executives' Vision for the Next Decade, March 2010).

21 According to company information, E-Boks has 2 million users who receive on average 50 documents per year each.

22 Reports of the Environmental Technology Verification Program can be found at www.epa.gov/nrmrl/std/etv/vt-ams.html#radio. The programme does not imply outreach or contracting mechanisms. Verified technologies and detailed test results are published on the US EPA website, but this does not automatically lead to take-up by national authorities. However, the rigorous and open test methodology can give vendors a competitive advantage when bidding for public or private tenders.

23 A good, if dated review was conducted by Sarah Darby of the Oxford Environmental Change Institute, commissioned by UK DEFRA (Darby, 2006).

24 See the presentation by Paulo Ferrão, MIT-Portugal programme at the OECD high-level conference on "ICTs, the environment and climate change", 2010, http://itst.media.netamia.net/ict2009/demand/133.

25 For more information about OECD work on cities and climate change, see www.oecd.org/env/cc/cities.