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The ICT role in resource conservation and rebound effects

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Abstract

Information and Communication Technologies (ICT) sector takes a leading role in the new Economy experiencing an unprecedented growth rate. The author discusses environmental impacts focusing on resource consumption. In spite of increasing miniaturisation and resource efficiency of electronic products their consumption is growing threatening to give rise to rebound effects in material and energy consumption. The author addresses the problem and complexity of both direct and system-level effects from the ICT sector and discusses the role of government in coping with the potential environmental impacts.

1. Introduction

In 1949 the Popular Mechanics magazine wrote "…computers in the future may weigh no more than 1.5 tons" and the chairman of IBM added that there might be a market for only five computers worldwide…

A half a century later there were hundreds of millions of computers worldwide connected by Internet. A new sector of Information and Communication Technologies (ICT) has emerged forming a core for a New Economy – the economy based on information openness, unlimited communication capabilities, dynamism, huge investments into high-tech sectors, an economy, that relies on knowledge and technological innovation - things the economic boom of the late 90s is associated with. The technological advancements of the ICT sector allowed unprecedented growth and electronics has quickly penetrated into all spheres of economy worldwide inducing *structural changes* of many infrastructures, institutional arrangements, technological capabilities, and lifestyles.

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The predictions of the 50s were definitely wrong as the weight of modern computers is measured in kilograms and their number in millions. However, their total weight is thousands of tons, the mass that represents most complex products ever produced. The aggregated environmental impact of the life cycle of electronics is still largely unknown, but potentially it is very large knowing how much of raw materials have to be displaced and processed and the amounts of energy consumed.

This paper discusses potential rebound effects caused by the growth of the ICT sector. The focus is given to resource consumption by the sector itself and the consumption changes induced in other sectors of the economy. The discussion is oriented to the role of policy-makers to facilitate a better use of ICT in resource conservation.

2. Rebound effect and the ICT sector

During the last decade a number of sustainable development concepts and approaches have been introduced advocating eco-efficiency as a tool for resource conservation. Efficiency improvement strategies appeared on agendas of many international organisations such as UN, OECD and WCED.[2] However, in some cases the efforts backfired by increased resource consumption, when the efficiency improvements reduced the prices of natural resources and increased their consumption. The so-called *rebound effect* phenomenon occurs in those cases, when the rate of efficiency improvement becomes lower than the growth rate of consumption. The rebound effect is common in utility sectors such as water and energy and seriously addressed since 70s.[3]

Today computers have become a utility in some way – they are “consumed” within a limited time of up to 5 years and their role is increasingly perceived as a lubricant for the global economy. The developments in ICT sector increase computer performance and reduce price. The quick technological development has reduced the quality-adjusted computer prices by 20% per year inducing unprecedented growth in consumption [19]. This in turn gives positive signals to stock markets, which provides new investments and yet again fuels further ICT development. The result is a *rebound-like effect* – the growing computer efficiency in performance and resource use increases their consumption.

This development has both direct (micro-level) and indirect (macro-level) environmental impacts. The direct impacts are due to increased resource consumption and generation of toxic waste along the entire life cycle of ICT products. The indirect effects occur due to structural changes in other sectors, such as changes in peo-

[2] WCED - World Commission on Environment and Development.

[3] Early articles on the topic of rebound effect can be found in international magazines The Energy Journal and Energy Policy.

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ple's lifestyles, social institutions and technological processes, caused by the ICT development. The nature and magnitude of the effects is largely unknown as the area is still relatively poorly explored. Nevertheless, in some examples presented below the negative impacts of the rebound effects of the ICT sector are more visible than in the others.

3. Micro-level effects along the life cycle of electronic products

Looking at resource consumption along the life cycle of electronics is highly energy and material intensive. The extraction of raw materials and manufacturing phases require huge quantities of materials per mass unit of final product and the users phase requires considerable amounts of energy. The Wuppertal Institute in Germany has shown that the material intensity by weight to produce one personal computer is about two-thirds of the material intensity in car manufacturing (even excluding the manufacturing of car electronics). Semiconductor manufacturing becomes increasingly energy and material-intensive, as advancements in semiconductor technologies continuously require the use of new compounds based on rare elements and synthetic materials. Growing requirements for material purity and miniaturisation further increases energy consumption and waste generation.

In 1993 about half of the 700 different chemicals used by the computer industry in the US were hazardous [2]. According to 1995 data from Silicon Valley Toxics Coalition the production of a 6-inch wafer requires 8.6 m^3 deionised water, 9 kg hazardous chemicals and 285 kWh electricity [17]. Another study indicates that the production of a 8-inch wafer of Pentium CPU circuits requires 11 m^3 of deionised water, 120 m^3 of bulk gases, 12 kg chemicals, while producing 0.8 m^3 of hazardous gases, 14 m^3 of waste water and 4 kg of hazardous waste [1].

Manufacturing semiconductors, printed wiring boards and cathode ray tubes (CRT) is also associated with large material consumption and waste generation. A typical computer monitor with a CRT contains 1-2 kg of lead and out of 54 most used chemicals in silicon chips, electronic circuits and monitors, 15 are known or suspected carcinogens and 14 are heavy metals [3]. The growing share of laptop computers and flat screen monitors will hopefully reduce the share material consumption by CRT in the future.

The material consumption for ICT infrastructure (communication lines, routers, amplifiers, servers, filters and buildings) is also significant. As more computers are bought every year, the net material and energy consumption may outweigh the efficiency improvements in hardware production and performance.

A few life cycle assessments (LCA) on electronics suggest that energy consumption is a larger problem than material consumption. An Ecological Footprint methodology applied in a study by Frey (1999) on personal computers showed that a personal computer (PC) had a footprint of 1,800 m^2 dominated by fossil fuel use. The

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footprint of fossil use turned out to be 1,000 times larger than the footprint for resource consumption during entire life cycle [6]. The study suggested that the use phase as the main culprit, followed by manufacturing and material production. Unfortunately, the importance of resource consumption stage was undervalued, as it was indicated in the study. The footprints of water consumption, gold, silver, tin, lead and zinc were not found and not included, while these metals are widely used in electronics and manufacturing requires 74 m^3 of water per PC [6]. With a more comprehensive data the results may change significantly.

Another LCA study of a generic PC was performed in 1998 for EU eco-labelling scheme of desktop computers. It showed that the user phase has largest environmental impacts in all analysed impact categories and the impacts are almost totally related to the use of energy [20, Table 4-D]. The manufacturing and material production turned out to be next most important stages with 4-6 times lower environmental impacts. However, when it comes to resource consumption, the material production and manufacturing stages are the most material intensive for most of materials [20, Table 4-F]. The dominance of user stage impacts could be explained by the use of average European energy mix in the calculations. With the use of greener energy sources, the total environmental impacts will be significantly lower and more weight of most environmental impacts will shift to resource consumption in manufacturing stages.

One controversial article in *Forbes* stated that it takes 1kg of coal to produce enough energy to send 5MBt of data over Internet and that in 1999 the Internet equipment consumed roughly 8% of total US electricity consumption, which can grow to 50% within a decade [8]. According to the article the parallel development of ICT infrastructure and Internet eventually contributes to more information bits poured into the cyberspace constituting higher energy demand and energy efficiency improvements in electronics cannot outpace the growth in their numbers and increase in absolute energy demand. Luckily, these statements turned out to be a flaw after a number of peers proved that the estimates should be reduced by at least 88%.[4] Nevertheless, even with this correction the energy consumption of Internet will soon become a serious issue for many countries given the current growing rate of the ICT sector.

The growing complexity and speed of ICT infrastructure cannot tolerate power cut-offs. Fast computers require a sizable infrastructure for reliable power supply, such as: batteries, flywheels, magnetic superconductors, and uninterrupted power supply units. For many dot-com companies a reliability level of up to 99.99999999% is required, which is equivalent to power interruption time of less than 0.003 sec/year [9]. Such infrastructure is not only expensive but is highly mate-

[4] The issue is well reflected in the website of Lawrence Berkeley Laboratories http://enduse.lbl.gov/projects/infotech.html

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rial and energy intensive. It seems that in the end the age of bits requires a lot of kilograms of heavy hardware.

The negative environmental effects of growing consumption of electronics are most visible in the end-of-life stage of the life cycle. The technology development induces forced retirement of electronic products after just a few years (e.g. it is 3-5 years for personal computers) and many countries perceive electronic waste as the most serious environmental problem, since its safe disposal is highly problematic. According to some estimates, there are 14-20 million computers scrapped yearly, around 10-15% of them re-used or recycled, 15% end up in landfills and the rest are stockpiled [7]. In US alone, which has 30% of worldwide computer sales and a 15% growth rate of the market, nearly 150 million computers will be recycled and 55 million landfilled in 2005 [10]. The recycling and reuse of post-consumer electronics is often not economically feasible and lacks appropriate infrastructure, which will require huge material investments to build.

4. Macro-level effects

The macro-level effects are the response of business and consumers to the increased productivity and saved time due to the use of ICT products and services. A positive macro-level effect attributed to the development of ICT sector has been reported in USA on total energy consumption, which according to the official statistics is decoupling from economic growth. During the end of 90s the US GDP increased by 8% while energy use increased less than 1% [18]. More surprising, the decline of energy use occurred without any significant price signals or policy initiatives [14]. Some researchers accredit the major part of this trend to the growth of service sector and the *structural changes* largely caused by the ICT sector.[5,6] Several studies indicate that while the economic growth contributes to growing energy consumption, the much less energy intensive ICT sector will reduce or reverse this trend [5,15,16]. The arguments are that the added value from ICT is created manipulating ideas and information rather than energy and materials, and that the sector raised overall productivity by improving efficiency of reorganising management processes, technological process, product design, improving resource planning, marketing, sales, creating new business models, such as e-commerce, and changing our life styles.[7]

At the same time the use of ICT has caused negative impacts by increasing consumption in other sectors. For example, contrary to most expectations, office com-

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[5] The structural change in this case is referred as "…the shift from energy-intensive industries as a source of economic growth, toward the less energy-intensive commercial services and light manufacturing segments of the (US) economy" (Laitner, 2000).

[6] See also (Romm et al., 1999), (Kelly, 2000) and (Laitner et al., 2000).

[7] For more information see articles by (Koomey et al., 2000) and (Kovacs, 1999).

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puterisation did not create a paperless office and the advent of desktop publishing increased paper consumption by several times. For example, the increase in US was five-fold between 1960-97.

The use ICT for distance work did not reduce road traffic either. As Internet made communication easier and cheaper so we find more needs for face-to-face meetings and the total number of kilometres travelled worldwide has increased. Product supply chains can extend, because of cheaper logistics and consumer's use of the car “capacity” freed by electronic home shopping for other purposes.

E-commerce is another area where ICT is dramatically changing the way we buy goods and services creating the so-called "frictionless market" where the cost of transaction is extremely low and information access is almost perfect. The Internet can successfully bring buyers and sellers together virtually in any place in the world and dramatically reduce the transaction costs in the process. The “one-click-shopping” makes it extremely easy to find, compare and buy products and services. It also has great potential cutting transportation to the end consumer.

Even though the e-commerce brings a lot of environmental benefits by optimising the retail processes, there is also no guarantee that the net effect will not be offset by increased consumption due to price reduction. Unfortunately, price and delivery time often become the two dominant criteria for purchasing decisions and only a few buyers take transport distances into account. As a consequence, quick over-night door-to-door deliveries often negate the reduction of environmental impacts of individual transportation. The result is growing consumption and long-distance transports.

People’s consumption of natural resources are restricted by two factors – income and time. The use of computers seems to both expand and change our lifestyles. The ICT allow us to save time by doing things faster and more efficiently. The irony is that people tend to fill the empty time slots with other activities, such as work, shopping or entertainment – all of it is tied with the use of energy and materials. The activities can be anything from low energy-intensive (e.g. cultural recreation, visiting museums, painting, etc.) to highly energy-intensive like travelling. Estimating such cross-sector rebound effects is particularly problematic due to a large degree of complexity of factors forming human behaviour.

Some interesting methodological approaches based on time-use analysis already exist providing valuable insights into time-budget related rebound effects [11]. The traditional explanation of rebound phenomena by income and price effects might be well supplemented by the time component especially in the ICT sector. With the current trend towards growing incomes and falling prices, the income constraints for rebound effects decrease and time budget constraints gain importance.

In digital economy cheap information is economic lubricant accelerating the creation of wealth. Indeed, the global information space increasingly provides unlimited information at close-to-zero cost and allows us doing things more efficiently. While

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doing things more efficiently we can produce more using fewer resources. Decreased demand of natural resources potentially causes price reduction and growing consumption if no governmental intervention in the market is done.

5. Discussion on government role

There are many good environmental initiatives on resource conservation initiated by industry, where it takes a lead introducing new environmental strategies such as eco-efficiency, dematerialisation and eco-design. Unfortunately, potential rebound effects caused by growing net consumption of products and services often compromise these intentions. Here governmental decision makers have an important role to play by encouraging less material intensive business and creating favourable market conditions. Using appropriate policy mixes based on regulatory, economic, information and regional planning instruments governments can create incentives for industry to develop new dematerialised businesses.

The ICT sector has an exceptionally large potential to replace many physical products with software-based substitutes and still promote economic growth without increasing material and energy consumption. However, even this sector can be prompt to rebound effect risk. Governmental efforts to reduce rebound effects from ICT sectors should be directed to both direct and system-level effects. Research in this area has to be encouraged and supported as the potential environmental impacts from ICT are still relatively poorly explored.

Addressing direct environmental impacts

Governments can address the issues related to product quality, its production or life cycle management using an array of regulatory approaches based on command and control, economic and information instruments as well as voluntary agreements with industry.

Command and control instruments

The command and control approaches are effective though not always efficient way of market intervention. For example, setting standards on energy consumption and recycled material content in electronic products or bans on certain substances such as lead and brominated flame retardants governments can be effective in a short time. However, such measures may harm international competition and always meet opposition from the industry. Besides, they rarely encourage producers to go beyond the requirements. Standard setting is also complex and long procedure requiring extensive administrative and enforcement apparatus.

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An example of international governmental regulation is the EU ROS Directive[8] regulating the use of certain hazardous substances in electric and electronic equipment. Such initiatives can become effective means to swiftly reduce the use of "problem" substances. At the same time the use of prescriptive tools, such as the EU ROS directive, has several limitations and has to be done with caution. It is crucial that the substitutes will not have higher toxicity and larger material intensity or distort the market due to high costs of equipment and recycling. Similar policy initiatives can also become a serious trade barrier – the argument often used by governments and industry associations [4].

Another example is EU Directive on WEEE[9] designated to create incentives for environmental product improvement by extending producer responsibility for end-of-life waste of electronics. The short life span of ICT products is linked to growing amounts of toxic electronic waste. It is anticipated that the Directive will lead to extension of product life through design for upgradability, re-manufacturing and recycling. It is expected that product redesign will take place and to slow product obsolescence, lower product ownership costs and improve product serviceability. The Directive might also lead to alternative business models where the use of physical products is substituted by function sales. The ICT products have an advantage in this sense as the majority of their functions can be delivered without actual ownership of the hardware.

Economic instruments

Economic instruments are generally more efficient in internalising environmental costs and creating incentives for designing more environmentally friendly product and services. Taxes on virgin natural resources differentiate charges for renewable and non-renewable raw materials giving price signals to producers and creating market opportunities for new businesses that rely on dematerialised products and services. The collected revenues can be used to compensate higher costs for reuse and recycling and help building appropriate infrastructures for end-of-life management of electrical and electronic waste. The economic instruments are also more favourable, because they can address product related environmental impacts in several life cycle stages at the same time.

Informational instruments

Eco-labelling is another effective policy instrument to promote reduction of product-related environmental impacts. Different national and international labelling sche-

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[8] The EU Directive on "Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment" (ROS) requires substitution of cadmium, chromium (VI), lead, mercury and certain flame-retardants with exceptions for some electronic products groups. Provisional, 2000/0159COD, COM 2000 Nr. 347, June 2000, Brussels.

[9] EU Directive on Waste Electric and Electronic Equipment.

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mes for ICT products already exist (e.g. *Energy Star®, TCO, Blue Angel, EU eco-labelling scheme*). The schemes can be designed to be both voluntary and obligatory. In voluntary labelling schemes manufacturers are not directly penalised for being unable to reach a required resource intensity standard leaving it to consumers to chose which product to buy. Using obligatory labelling a producer might be not allowed to sell a product without informing consumers about the discounted lifetime costs from using a product or a service.

The success of eco-labelling schemes largely depends on active participation of consumers. For example, there is a little benefit using an *Energy Star®* labelled product if a user does not activate its energy saving features. Consumer involvement can be improved providing better information of environmental issues related to electronic products. Therefore, governments should facilitate consumer involvement by educating and spreading green product related information throughout all consumer groups from children to adults.

While policies, such as EU WEEE Directive, which that puts the responsibility for post consumer waste on producer, are in urgent need, the problem growing consumption should not be overlooked. Regulating the demand side, i.e. the consumption of ICT products is particularly difficult task as here consumer behaviour has to be addressed.

Addressing system-level impacts

Addressing the indirect environmental impacts from ICT sector is a more complicated task. The resource efficiency of electronic products has improved dramatically, but technology advancements may not outpace the effects of growing consumption, which raises concerns about rebound effects. The ICT sector impacts other sectors by changing resource production and consumption patterns, organisational structures and people's lifestyles. The environmental effects of these changes are still largely unknown and that is why the existing uncertainty is worth attention from policy makers.

Huge investments are being made within the sector with high expectations for economic growth the environmental improvements. Neglecting the issue of rebound effect creates a risk of misallocation of environmental efforts. Therefore, more research in this area is needed. Understanding whether, how and to which extent does the ICT sector affect environment is an important issue making trade-offs between economy and environment. Having more information on the ICT sector's role in structural changes governments will be better informed when developing new policy frameworks to address global environmental problems. More information helps to identify, track and evaluate alternatives when allocating financial resources for environmental programmes in different economic sectors. The investments and efficiency improvement efforts may lead to better results if turned from focus on ICT hardware to "soft" issues, such as better use of knowledge and information, improved

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managerial practices and creation of new business models based on less material intensive and more productive ICT products and services.

Policy makers should not underestimate the role of ICT sector in improving resource productivity either. They must support those technologies and those businesses that most effectively promote sustainable economic growth. Dematerialisation is one of the most effective means of product environmental improvements, and its potential can be particularly well utilised in the ICT sector. The policy approaches for ICT sector must be broad enough to create incentives for business dematerialisation and knowledge development and create of markets for new products and service.

Social costs of environmental impacts can be partly internalised by alternative prising mechanisms using environmental taxes, charges, fees etc. Implementing new instruments of energy taxation, transport policies and placing product responsibility on producer the governments can shape the environmental impacts of the ICT sector. Normative approaches addressing sustainable lifestyles through information and education should not be underestimated too despite the existing scepticism. New generations should adopt lifestyles that are different from today, based on social values and environmental responsibility.

References

Anzovin, S. *The Green PC Revisited*. ComputerUser.com Ltd., 1997.

Brynjolfsson, E. *Information Technology and Productivity: a review of the literature. Advances in Computers*. MIT, Sloan School of Management, Cambridge, MA; University of Pennsylvania, Wharton School, Philadelphia, PA, 1996.

Cook, C.D.T., Clay, A. *Silicon hell*. SFBG News, 2000.09.15.

Dworak, T., Kuhndt, M. *Discussion Paper on Return of Used IT-products, Reuse and Recycling*. Wuppertal Institute, Eco-Efficiency & Sustainable Enterprises Team, Wuppertal, Germany, October 2000.

EIA, *Annual Energy Outlook 2000*. Washington, DC, U.S. Department of Energy, 1999.

Frey, S. *Environmental Assessment of Electronic Products Using LCA and Ecological Footprint*. Joint International Congress and Exhibition. Electronics goes green 2000. Berlin, Germany, 2000. *See table 5*. Available: http://www.brunel.ac.uk/research/cleaner/GreenBusiness.html {2001-08-17}

Goldberg, C. *Where Do Computers Go When They Die?* Technology Circuits. New York Times on-line, 1998.xx.xx.

Mills, M.P., Huber, P.W. *Dig more coal -- the PCs are Coming*. Forbes Magazine, 1999.

Mills, M.P. *Forget Oil. It's The Century of the Electron*. The Wall street Journal, 2000.

Matthews, H.S.M., Francis C.; Hendrickson, Chris T.; Hart, Diana J. Disposition and End-of-Life *Options for Personal Computers*. Pittsburgh, Carnegie Mellon University, 1997.

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Jalas, M. *A Time-Use Approach on the Materials Intensity of Consumption*. Helsinki, Helsinki School of Economics and Business Administration, Department of Management, 2000.

Kelly, H. *Information Technology and the Environment: Choices and Opportunities Released*. Digital Divident, iMP Magazine, 2000.

Koomey, J.G. *Rebuttal to Testimony on 'Kyoto and the Internet: The Energy Implications of the Digital Economy'*. Berkeley, Energy Analysis Department, Environmental Energy Technologies Division, LBNL, University of California, USA, 2000.

Kovacs, C.M. *Environmental Benefits from the Dematerialization of Services Case study: Digital publishing. Screening LCA on two alternative services for scientific information provision.* Amsterdam, University of Amsterdam, IVAM Environmental Research, 1999.

Laitner, J.A., Jonathan G., Worrell, E., Gumerman, E. *Re-estimating the Annual Energy Outlook 2000 Forecast Using Updated Assumptions about the Internet Economy.* The Eastern Economics Association Conference. Crystal City, Virginia, US, LBNL, 2000.

Romm, J.R., A.; Herrmann S. *The Internet Economy and Global Warming*. Washington, DC, The Centre for Energy and Climate Solutions, The Global Environment & Technology Foundation, 1999.

SVTC. *Water Use and other Materials and Wastes Associated with Semiconductor Production*. Silicon Valley Toxics Coalition (SVTC), USA, 2000.

USDC, *Digital Economy 2000*. US Department of Commerce. Economics and Statistics Administration, 2000.

Brynjolfsson, E., Hitt, L. 2000. "*Computing Productivity: Firm-Level Evidence*", MIT, Sloan School of Management, Cambridge, MA; University of Pennsylvania, Wharton School, Philadelphia, PA. 46 pg.

IPU & Atlantic Consulting, 1998. *LCA Report: EU Eco-label for Personal Computers.* Third Report in the Study of the Product Group Personal Computers in the EU Eco-label Scheme, for EC DG XI.

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