Information and Communication Technologies: Benefits and Challenges to the Environment

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Abstract* — The issue of Information and Communication Technology (ICT) and the environment is a complex and multifaceted one. ICT can play both positive and negative roles in sustainable environment. This study shows the important linkages between ICTs, ICT-enabled innovation and the environment. It analyses the environmental impacts of ICTs in different stages of the life cycle and also as an enabling technology for mitigation of environmental impacts across all economic sectors. Direct environmental impacts were noted to be considerable in areas such as energy use, materials throughput and end-of-life treatment. ICT usage could also generate new activities and wastes with grave implications on efficient environmental resource management. The contribution of ICTs to systemic changes to achieve more sustainable environment was discussed. It was concluded that it is important that the environmental impacts of ICT products and operations be minimized through improved research and development, implementation of innovative ICT systems and government ICT policies.

***Keywords:* Benefits, Challenges, Environment, ICT, Wastes**

I. INTRODUCTION

In the past few years, the availability and use of ICTs has grown dramatically around the world. In the developing world, this growth has been largely due to the growth of mobile telephony. According to a recent ITU report (ITU, 2007) "…by the end of 2006, there were a total of nearly 4 billion mobile and fixed line subscribers and over 1 billion Internet users. This included 1.27 billion fixed telephone lines, 2.68 billion mobile subscribers (61% of which were located in developing countries) and some 1.13 billion Internet users." While the use of ICTs in the developed world has reached high levels, its penetration in the developing world is still growing and there are marked differences between different categories of countries. ITU (2006) shows that countries of the Organization for Economic Co-operation and Development (OECD) in addition to Taiwan, China, Hong Kong, China, Macao, China, and Singapore, accounting for 18.7% of the world's population, have shown marked growth in ICT deployment and usage with the exception of fixed line access. Whereas in the least developed countries (LDCs) which are made up of the 50 least developed countries, recognized by the United Nations as requiring special attention in development assistance, accounting for 11.9% of the world's population, growth rates in the use of ICT have been very low. In developing countries however which account for 69.7% of the world's population, rates are growing but not at the same rate as seen among the developed nations of the world. While this information is important in determining access to ICTs and related applications, they do not give the true extent of the deployment and usage of ICT and its related applications. Nearly all urban areas of developing countries have access to some form of broadband connectivity; ICT penetration rates are lower in the rural areas both in developing as well as developed countries (ITU, 2008).

The low growth rate of ICT penetration in the rural areas has resulted in less access to computers and which includes both high speed computing resources as well as personal computers. The cost of ICT facilities is considered high for an average rural dweller making the use of community ICT facilities such as cybercafés or tele-centres, which are very popular in many parts of the developing world, very common. In the urban areas however, individuals usually have access to one form of ICT facility or the other such as desktop, laptop, mobile telephony, etc. This has resulted in large quantities ICT hardware being shipped to these countries. This has generated a lot of concern as regards to their use and disposal. Environmental issues are increasingly at the fore of public concerns in the industrialized as well as in the developing world with an increased percentage of people citing pollution and environmental problems as a top global threat. Today the impact of ICT on the environment is one of the broadest issues discussed by environmentalists. It relates to one of the Millennium Development Goals (MDG), as ICT is used to foster international integration and development. ICT in the environment sector is often used to: communicate traditional forms of environmental knowledge to communities and to facilitate the citizen monitoring of environmental issues; make a valuable contribution to sustainable environmental management by improving monitoring and response systems, facilitating environmental activism and enabling more efficient resource use; reduce the consumption of energy, water and other essential natural resources through more efficient agriculture and industrial procedures; play an important role in the fight against pollution—not only by providing more useful metrics and information, but also by enabling population decentralization and large-scale telecommuting; and provide an ideal platform for local voices to be heard, overcoming physical and social barriers, and for allowing special-interest groups and virtual communities to be formed (http://www.opt-init.org/framework/pages/2.2.5.html).

ICTs are powerful tool for civil society in protecting the environment. Environmental Information Systems (EIS) are the core of contemporary urban management systems and a prerequisite for proper and timely dissemination of information to the public (Gohar Minasyan, 2006). Technological advances require systems that can make optimum use of informatics and telecommunications infrastructures to address environmental management needs. Yet these can be open, flexible, modular and inexpensive to

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implement and operate. Overall, the right of access to information related to the quality of the environment that citizens live in, appears to be well matched with the concept of open source (Aarhus Convention) (Sands, 2003). Sometimes the relationship between ICT and the environment might seem distant or its nature may not seem obvious. Environmental issues relate to natural resources and their complex dynamics, including water, soil, forests, climate, and so on, and the world of ICTs is premised on a virtual construct of the world. The question then is what is the link between ICTs and the environment? Perhaps this is where the power of ICTs lies and this can have a great bearing on virtually every aspect of human life and the rapidly expanding surroundings of human habitats. Like any other area, an understanding of the environment is deeply dependent on correct, relevant, and recent information being available to all those people, whose decisions and actions affect this field.

Underlying the driving force of ICT is computer technology hardware which consists of all physical devices including cell phones and other electronic devices and software which consists of programmed instructions including embedded systems on which many electronic devices run. As noted by Idowu and Awodele (2010) it is not an understatement to conclude that advances and diffusion of ICT have drastically changed the social and environmental system of today, but the reverse effects also exist. Although, the global society is excited about the various uses of ICT, both as a private and corporate applications with all the obvious benefits, the question of how ICT revolution affects the environment which is one of the major twenty-first century challenges, has received limited attention to date (Idowu and Awodele, 2010). The manufacturing of ICT infrastructures is both energy- intensive and resource-intensive and the environmental impacts of the production, use, and disposal of ICT resources/materials are of great concern and not trivial. The aim of this study is to take stock of the impacts of Information and Communication Technology (ICTs) on the environment and to identify opportunities and best practices in the use of ICTs, the internet and sensor networks in environmental management and improved resources management. This study draws information principally from online research..

II. ICTS-ENVIRONMENT INTERACTION

ICTs and their applications can have both positive and negative impacts on the environment. 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. 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.

Life cycle assessments (LCA) demonstrate that ICTs have an environmental cost and impact as a result of their manufacture, use and disposal. LCA or life-cycle analysis, is a tool for estimating the total environmental impact of a given product or service throughout its lifespan, from cradle to grave (ITU, 2008). LCA has been the most common method applied to the study of the impact of ICTs on the environment (Yi and Thomas, 2007). This approach suggests that a review of the impact of ICTs on the environment is not complete without assessing and reporting on the environmental impact of ICTs throughout their life cycle, from the moment of the search for, extraction and refining of the materials used for the manufacture of ICTs, their creation on an assembly line, their marketing, inventorying and sale, to the point at which the device or technology in question is definitely removed from human use and all constituent components are safely disposed of so that they no longer represent any threat to the environment.

It is widely recognized that there are three order effects (Figure 1) of ICTs on the environment (Yi and Thomas, 2007) and they are:

1. First order or direct impacts: these are the impacts and opportunities created by the physical existence of ICTs and the processes involved in their manufacturing;
2. Second order or indirect impacts: These are the impacts and opportunities created by the ongoing use and application of ICTs;
3. Third order or systematic impacts: the impacts and opportunities created by the aggregated effects of vast and large numbers of people using ICTs over the medium to long term.

It has been widely observed that the bulk of the benefits of ICTs lie in the second order effects due to increased efficiency, transparency, speed of transactions, rapid market-clearing, etc. However, most of the negative effects of ICTs are associated with first order resulting from the direct environmental impacts from ICT infrastructure such as resources consumption (energy consumption during the production or manufacture of ICT equipment) and carbon emission during manufacturing, in the process of usage and disposal of hardware (electronic waste that result from ICT production, use and disposal). The third level effects are those involving behavioral 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. Therefore, systemic impacts also include the adjustments to individual lifestyles that are necessary to make sensible use of ICTs for the environment (OECD, 2010).

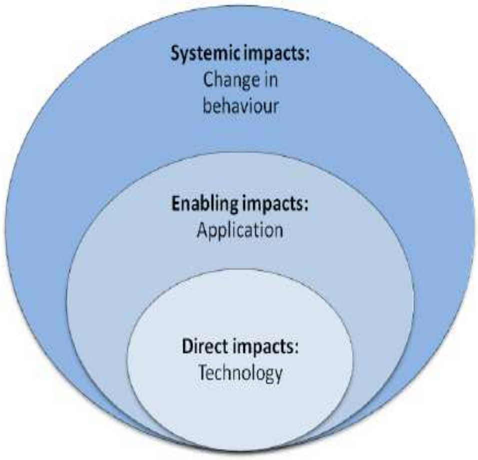

Figure 1: ICTs-Environment Impacts
Source: OECD (2010)

III. NEGATIVE IMPACTS OF ICTS ON THE ENVIRONMENT

Manufacture and use account for the bulk of the environmental impacts of ICTs (Eugster et al., 2007). 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. The environmental impact of assembly of ICT components into final products and distribution are relatively insignificant (Choi *et al.*, 2006).

Producing a PC impacts the environment negatively. In Overall, the desktop PC and screen are the major sources of environmental impacts, with differences depending on the screen technology (Eugster et al., 2007). Large amounts of energy are required to produce the electronic circuits and semiconductors that are used in computer motherboards and screens (Eugster et al., 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 (Williams, 2003). 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. This purification process is very energy-intensive.

ICT producers are major consumers of minerals, which has environmental and economic implications. In the manufacturing of ICT equipment, there is reliance on the use of heavy metals (Cd, Cr, Ag, Pb, Hg, Ga, Ge, Sn, Hf and Au) for their conductive, metallurgical and other properties consistent with ICT component design. Many of these metals, which are usually sequestered in mineral deposits and not naturally present in the environment, are highly toxic (Cd, Pb, Ag, Hg) and present a grave threat to human health and to ecological and living systems in particular when released into the environment in the form of biologically active chemical compounds as a result of unsafe extraction, use and/or disposal (Steinweg & de Haan, 2007). But the Internet also requires energy for its operation.

Using a PC contributes more to energy use and consequently to global warming than any other activity in the PC life cycle (Eugster et al, 2007) because of greenhouse gas emissions from the generation of the electricity required to power a computer. 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). Energy consumption of the Internet worldwide has been estimated at 5.3 % of global electricity consumption. One other source of energy wastage comes from PC power supplies that have traditionally operated at between 65 to 75% efficiency. The idea is to replace these with more efficient power supply units that operate at over 80 % efficiency with the objective of achieving 90% operating efficiencies at different load levels (ITU, 2008).

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 land-filled 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. Worldwide generation of "electronic waste" is around 20 to 50 million tonnes a year, according to the OECD Environmental Outlook to 2030 (OECD, 2008). 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. 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.

IV. ENVIRONMENTAL BENEFITS OF ICTS

The increasingly ubiquitous use of ICTs in all aspects of human endeavor is transforming the way that people live and work. ICTs have been demonstrated to contribute to economic growth and development by stimulating the productivity of people, organizations and nations.

A. Environmental Observation

Environmental observation includes monitoring and data recording technologies and systems (remote sensing, data collection and storage tools, telemetric systems, meteorological and climate related recording and monitoring system), as well as geographic information systems (GIS) as it applies to data recording and geo-referenced data formats. This also includes tools for not only acquiring the information but also tools for recording and storing observations in a standardized format. Remote sensors are used to help researchers gather information about environmental processes and systems. The sensors can be linked together in wireless networks which eliminate the need to wire all the devices and nodes and allows more flexibility in deployment of ICTs (Goleniewski, 2006). Much of this information has been archived and stored in accessible datasets or databases. Through the use of ICT facilities and applications, these datasets/ databases are made available to researchers regardless of their location. With the help of ICTs, geo-reference location-specific environmental data can be collected live for biodiversity research and conservation which is important in the analysis, correlation and validation of environmental models (Trotter et al., 2001). Environmental data can be collected directly in the field using hand-held devices, a technology readily available with the spread of wireless networks and devices. Some of these data sharing tools include ubiquitous broadband connections, integrated technologies such as Web 2.0 and service-oriented architecture (SOA) which together facilitate data collection, entry and sharing as well as the participation of a community of users —who serve as interest groups and source of primary research data.

B. Environmental Management and Protection

ICTs provide an unprecedented ability to collect and process environmental information that far exceeds the capacity of any individual, which may span time durations far beyond that of a human lifetime, and may encompass the entire terrestrial system from the depths of the ocean to upper reaches of the atmosphere (ITU, 2008). ICTs can help break down the complexity of the environment for easy understanding of the impact of human activities on the environment. ICTs can be used in a number of ways in the management of the environment as noted in ITU (2008):

- To help observe, describe, record and understand the environment (for environmental research and for comparative analysis), including tools to manipulate and visualize environmental information;

- To share information and data as well as processing power: data warehouses, clearing houses and data/information servers; environmental networks and grids, etc.;
- To facilitate and help coordinate environmental decision-making and management, including environmental early warning, risk assessment, mitigation and management, etc.;
- To help reduce and/or mitigate the environmental impact of human activity;
- To facilitate learning about the environment.

Environmental management can be achieved with the help of increasingly powerful and interconnected computing platforms such as GIS and GPS combined with extensive informational databases. Several ICT capabilities stand out as tools that are used to understand the global environment (ITU, 2008). They include:

- Satellite and direct sensor technology that provide the ability to record and store massive amounts of geographical and historical information with increasing geographic coverage;
- Geographic information systems (GIS) that allow the visualization and interpretation of the datasets made available through these observation systems;
- Micro processors which have provided computational power as well as increasingly intelligent algorithms that have allowed modeling of environmental systems for a better understanding of its complex physical and biological systems;
- Increasing bandwidth and very rapid distributed communications, processing and storage capabilities that facilitate data sharing and undertaking computationally-intensive tasks through the use of Grid and Cloud computing.

In a study by Fuhr and Pociask (2007) who investigated the use of advanced technologies, including broadband services and telecommunications technologies and their specific effects on energy use and the environment, it was reported that significant reduction is expected in GHG emissions as a result of the use of broadband technologies. The study was concluded by stating that the potential impact of changes stemming from the delivery of broadband is estimated to be an incremental reduction of more than 1 billion tons of greenhouse gas emissions over 10 years.

C. Environmental Analysis

ICT applications are used to carry out required computation and processing of environmental data for analysis and comparison. This may include land, soil, water and atmospheric quality assessment tools, including technologies for analysis of Greenhouse Gas (GHG) emissions and pollutants, and the tracking of both water quality and availability (ITU, 2008). Environmental analysis often draws on archived geographically distributed computational and data resources. Analyzing these sometimes complex environmental systems and their components over time and space is facilitated through numerical analysis and the use of specialized applications such as geographic information systems (GIS) and various models used to better understand complex environmental phenomena. The use of computers and modeling software has been helpful for developing and using models to understand complex environmental systems. However, according to Reed et al.118, it is the increased availability of environmental datasets that is critical to allowing modelers to improve their simulation and forecasting models (Reed et al., 2002). This is particularly so in the case of weather and climate phenomena but also applies to understanding ecological systems.

D. Environmental Planning

Environmental planning starts with a study and an assessment phase that is based on the information available from environmental observation and analysis. This is then used to develop policies and strategies. Environmental planning and decision-making uses many of the applications used for environmental analysis (ITU, 2008). Decision support systems for environmental decision-makers are useful to assist in the planning process and to help implement the activities stipulated under the plan of action.

V. ICTS AND SUSTAINABLE ENVIRONMENT

The production of goods in industrialized countries has reached saturation point. Economies could only grow substantially in sectors that are not directly related to the production of materials. In other words, economic growth depends on the transition to a de-materialized society, or to digital weightless economy. In such a society, an economy's weight shifts to activities that provide services benefiting people without consuming significant amounts of raw material, power and space. It is expected that ICT would play an active role in at least the following roles to achieve a society that is environmentally and economically sustainable.

i. Reducing materials, especially papers, currently used as information media
ii. Substituting physical transportation with telecommunications
iii. Improving efficiency of energy use by ICT supported controlling systems
iv. Providing people with information on environmental issues and raising public awareness regarding the issues
v. Creating new businesses that are not energy or material consuming

ICT is said to release us from geographic and time constraints which in effect could change the structure of modern cities and the demographic features of countries. Some of these opportunities relate to ICT use in more efficient facilities management. For instance, sensor-based broadband applications can foster effective responses to environmental change as well as improving efficiency of current building and grounds systems. The potential total emissions avoidance from the implementation of smart building solutions, for example, are estimated to be as high as 1.68Gt $C0_2$ by 2020 (World Econ. Forum Report, 2009).

In this era of heightened concern regarding climate change, traffic and travel management has become a critical concern, particularly for urban environments. If there is less traffic, there is less CO_2 emitted into the environment. It is estimated that the amount of fuel wasted by congestion in U.S. urban areas alone has increased 480%, from 500 million gallons to 2.9 billion gallons from 1982 to 2005 (World Econ. Forum Report, 2009). ICT-based services and solutions can help to optimize traffic flows and, where possible, avoid them completely (ICC, 2010). For instance, improvements in supply chain logistics can minimize travel among distribution points and networks. Also, optimization of loading and route management for goods transport vehicles, taking more traffic off the road and lowering logistics company costs. Travel substitution (virtual meetings, teleconferencing and flexible work arrangements facilitated by IP networks) could reduce CO_2 emission resulting from an avoidance of in-person meetings, with travel cost savings, productivity savings, and Green House Gas (GHG) reductions due to cars off the road.

VI. CONCLUSION

As the development and deployment of ICT infrastructures and internet facilities increases, the relative share of ICTs in environmental impact categories such as global GHG emissions and waste generation is expected to increase. It is therefore important for ICT producers to minimize the environmental impacts of their products and operations. Improved R&D and design can help to tackle direct impacts throughout the entire life cycle (manufacture, usage and disposal) of ICT goods, services and systems. The design and implementation of innovative ICT systems can enable more sustainable "green" production and consumption across the entire economy. Government ICT policies can be instrumental in promoting such life-cycle approaches. Enormous environmental benefits are possible in major industry sectors such as transport, energy, housing but ICTs must be co-developed and their diffusion well co-ordinated for it to be effective. Information and communication are pivotal for system-wide mitigation of environmental impacts and adaptation to inevitable changes in the environment.

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