ICT and the Environment in Developing Countries: A Review of Opportunities and Developments

John W. Houghton

Centre for Strategic Economic Studies
Victoria University, Melbourne, Australia
john.houghton@vu.edu.au

Abstract. Both developed and developing countries face many environmental challenges, including climate change, improving energy efficiency and waste management, addressing air pollution, water quality and scarcity, and loss of natural habitats and biodiversity. Drawing on the existing literature, this paper explores how the Internet and ICT can help tackle environmental challenges in developing countries through more environmentally sustainable models of economic development and environmentally friendly technologies and applications. This review focuses on the role of ICTs in climate change mitigation, mitigating other environmental pressures and climate change adaptation, providing an overview and pointing to examples of current activities and opportunities in each of these areas.

Keywords: Information and Communication Technology (ICT), The Environment, Climate Change, Mitigation, Adaptation, Developing Countries, Sustainable Development.

1 ICT and the Knowledge Economy

A major feature of the knowledge economy is the impact that ICTs have had on industrial structure, with a rapid growth of services and a relative decline of manufacturing. Services are typically less energy intensive and less polluting, so among those countries with a high and increasing share of services, we often see a declining energy intensity of production – with the emergence of the Knowledge Economy ending the old linear relationship between output and energy use and partially de-coupling growth and energy use.

Traditional development models have focussed on a shift from agriculture to manufacturing, the development of free markets, encouraging exports and industrialisation in labour-intensive consumer goods – a model borne out in The East Asian Miracle [1] and the emergence of China as the World's largest exporter of ICT and related consumer equipment. Sheehan suggests a re-think, based on the evidence from the emergence of India [2]. Looking at long-term trends in employment and sectoral GDP shares and growth rates, he suggests that India provides an example of a 'big-push' development driven by services. India's services sector now accounts for some 60% of GDP and has been twice as large as the industrial sector for more than 50

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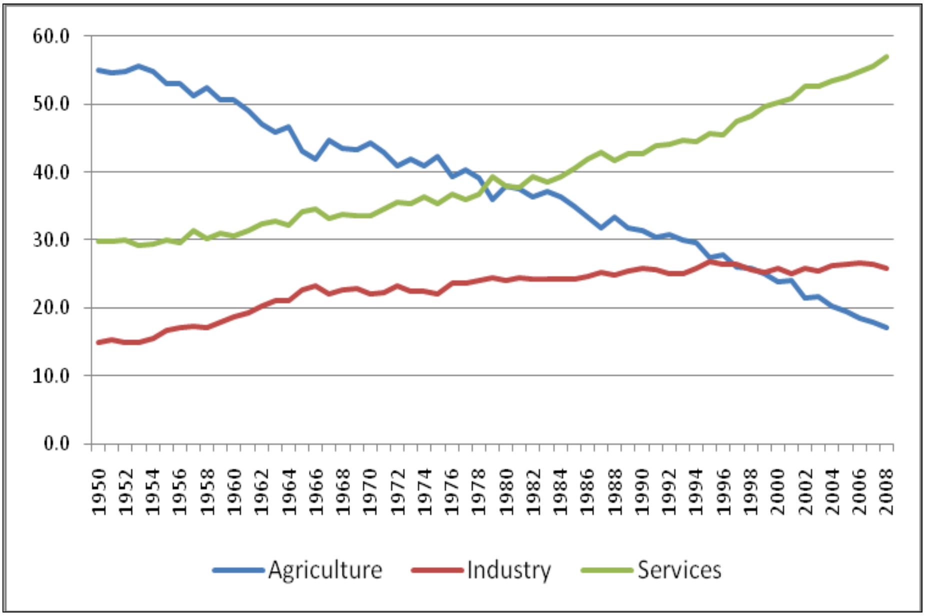

Fig. 1. Value added shares by sector, India 1950–51 to 2007–08 [4]

years. India's CO_2 intensity per unit of GDP is substantially lower than is typical of developing countries, comparable to that of Japan and lower than Germany's [3].

ICTs have played a key role in making services tradeable and the globalisation of IT and IT-enabled services. Looking at the intensity of IT and IT enabled services exports, Houghton and Welsh note that in only three countries did computer and information services account for more than 25% of total services exports during 2006 – India, where they accounted for almost 40% (down from 50% in 2004), Ireland 31% (down from 39% in 2004), and Israel 27% [5]. Their analysis suggests that IT and IT-enabled services exports can play an important role in a wide range of developed, emerging and developing economies, and may in the latter provide the basis for a more environmentally sustainable development path than has characterised industrialisation in the past.

Assessing the possibility of alternative development pathways, Berkhout *et al.* argue that the convergence of economic structures and growth rates, which plays such a central role in growth theories, does not imply that the emergence of socio-technical systems underpinning growth must also be convergent in terms of their technological composition and environmental quality, and they call for greater attention to the resource and environmental quality of development as the basis of more sustainable development pathways [6, 7].

2 ICT and the Environment

The relationship between ICTs and the environment is complex, as ICTs can play both positive and negative roles. Positive impacts can come from dematerialization and online delivery, transport and travel substitution, a host of monitoring and management applications, greater energy efficiency in production and use, and product stewardship and recycling. Negative impacts can come from energy consumption and the materials used in the production and distribution of ICT equipment, energy consumption in use directly and for cooling, short product life cycles and e-waste, and exploitative applications (*e.g.* remote sensing for unsustainable fishing [8]).

The impacts of ICT on the environment can be direct (*i.e.* the impacts of ICTs themselves, such as energy consumption and e-waste), indirect (*i.e.* the impacts of ICT applications, such as intelligent transport systems, buildings and smart grids), or third-order and rebound (*i.e.* the impacts enabled by the direct or indirect use of ICTs, such as greater use of more energy efficient transport). Exactly what the impacts of ICT are, and to what extent there may be rebound effects, are widely discussed topics. However, it is clear that attempts to measure the impacts of ICT on the environment should take account of the potential rebound effects and the entire life cycle, rather than just the direct impacts of the product or application itself [9, 10, 11].

Estimates of the direct impacts of the ICT industries vary with the definition of the industry and coverage of ICT-related energy uses, but the production and use of ICT equipment is estimated to be equivalent to 1% to 3% of global CO_2 emissions (including embedded energy) and a higher and growing share of electricity use. In 2006, it was estimated that ICT equipment (excluding broadcasting) contributed around 2% to 2.5% of worldwide Greenhouse Gas (GHG) emissions – 40% of this was reported to be due to the energy requirements of PCs and monitors, 23% to data centres, 24% to fixed and mobile telecommunications, and 6% to printers [12]. More recent life cycle assessments produce broadly similar results [13]. Data centres are a particular focus, and Koomey estimated that worldwide electricity use for servers doubled between 2000 and 2005, and he suggested that consumption would increase by a further 40% by 2010 [14].

Nevertheless, the indirect enabling impacts of ICTs are greater, and a number of studies have identified potentially significant net positive impacts from ICTs. For example, The Climate Group identified key areas of enabling impacts potentially leading to global emissions reductions by 2020 that were five times the ICT sector's direct footprint [15]. This paper explores some examples of the role ICTs play in climate change mitigation, mitigating other environmental pressures, and climate change adaptation.

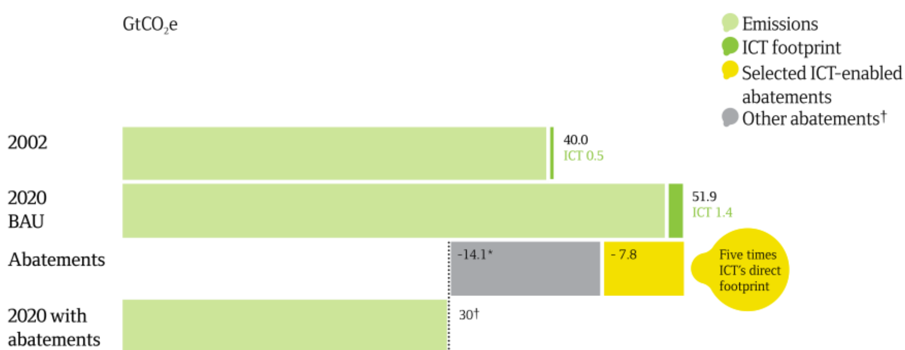

Fig. 2. ICT Impact: The global footprint and the enabling effect [16]

2.1 Mitigation: Avoiding the Unmanageable

Mitigation activities are directed at reducing the adverse impacts of climate change on the environment and are crucial to meeting emissions targets. Such activities can be focused on mitigating climate change directly or at a range of other environmental effects (*e.g.* water availability and salinity, desertification and deforestation).

2.1.1 Climate Change Mitigation

There are many studies and reports identifying areas in which ICTs can have a major impact on the environment, with a number identifying the energy efficiency in buildings and transport rationalization and substitution through dematerialisation, tele- and video-conferencing and tele-work as the major areas of impact based on sectoral energy use shares and trends, as well as application opportunities [17].

Developing and emerging economies face many challenges in the provision of infrastructures as economic growth progresses, with rapidly increasing demand for reliable electricity supply, transport infrastructures and commercial buildings. The very difficulties faced in meeting rapidly growing demands can, and are, driving investments towards more energy efficient solutions. The Climate Group cited a number of examples [18].

***Energy infrastructure*:** Smart Grids entail the modernisation of electricity distribution networks through the introduction of ICT and sensing network technologies. Smart grids enable improved monitoring and control of the energy network as a supply chain, which means reductions in energy losses, greater network operational efficiency, better quality and reliability of energy supply, greater customer control of their energy use, better management of highly distributed sources of energy generation (*e.g.* greater solar and wind generation), and reductions in greenhouse gas emissions. Smart meters add the possibility of two-way communication and supply between providers and users [19] and play a vital role in making energy and environmental issues visible to the household consumer, thereby informing and empowering consumers and enabling behavioural change.

Electricity generation capacity limitations and grid transmission and distribution losses are driving ‘smart grid’ developments in India and China which are both improving energy use efficiency and reducing the rate of expansion of what are largely coal-fired electricity generation systems. Electricity generation accounts for 57% of India’s total emissions and with rapidly increasing demand those emissions are forecast to increase by 4% per annum, twice the global average. But, it is estimated that as much as 32% of generated power is lost along the grid [20].

With infrastructure investments for the next 20-30 years now taking place, there is an opportunity to ‘leapfrog’ to smart grid systems, to reduce power losses and outages and realise greater energy efficiency, and Indian distributors are looking to smart grid investments (*e.g.* North Delhi Power). However, rebound effects are likely to be greater in developing countries where demand is far from saturated [21], so market and price signals will be particularly important.

***Motor systems*:** Motor systems convert electricity into mechanical power, and while invisible to most of us they are crucial to the manufacturing sector’s energy use.

Motors can be inefficient if they operate at full capacity, regardless of load. A motor is ‘smart’ when it can be controlled to adjust its power usage to a required output through a variable speed drive and intelligent motor controller. It is estimated that the motor systems in operation in China use 70% of total industry electricity consumption and are 20% less energy efficient than those in Western countries. By 2020, industrial motor systems in China will be responsible for an estimated 34% of power consumption and 10% of carbon emissions, or 1-2% of global emissions. Industrial energy use in China could be reduced by 10% by improving the efficiency of motor systems, as motor system optimisation alone could reduce China’s emissions by 200 $MtCO_2e$ by 2020 – comparable to total 2006 emissions from the Netherlands [22]. Recognising the potential, China’s government has implemented the *China Motor Systems Energy Conservation Program* to help reach its energy efficiency targets. It is unlikely that the necessary investments would be made without such initiatives.

Buildings**:** Energy consumption in buildings is driven by two factors – energy intensity and surface area. ICT-based monitoring, feedback and optimisation tools can be used to reduce both at every stage of a building’s life cycle, from design and construction to use and demolition. Energy modelling software can help architects determine how design influences energy use. Builders can use software to compare energy models with actual construction. Once the building is complete, ICT can measure and benchmark its performance and compare actual to predicted energy efficiency. Occupants can install a building management system (BMS) to automate building functions such as lighting, heating and cooling and if a building undergoes a change of use, ICT can be used to redesign its energy model and measure the impacts of this change. It has been estimated that such tools could reduce the emissions from buildings by 15% by 2020 [23]. Building standards and regulation are crucial elements in achieving such savings.

Transport**:** Globalisation has led to increasingly complex international supply chains and brings with it challenges for transport, storage and logistics operations. ICT can improve the efficiency of logistics operations in a number of ways. These include software to improve the design of transport networks, allow the running of centralised distribution networks and management systems that can facilitate flexible home delivery services. Specific levers include inter-modal shift, route optimisation and inventory reduction. The transport sector is a large and growing emitter of GHGs, responsible for 14% of global emissions, and it is estimated that optimising logistics using ICT could result in a 16% reduction in transport emissions and a 27% reduction in storage emissions globally [24]. Many policy and regulatory issues influence transport and logistics, from airline route regulation, to building planning and regulation, and noise and pollution regulations relating to transport [25], presenting a major challenge for policy coherence.

2.1.2 Mitigating Other Environmental Pressures

Emerging and developing economies are often dependent on agriculture and fishing for both cash crops and subsistence, and water can be a more pressing issue in emerging and developing economies than is energy use. Deforestation can also be a major concern in some regions. Hence, mapping, monitoring and managing lands, forests and waterways are crucial to the efficiency and sustainability of key sectors. Geographic Information Systems (GIS) provide major opportunities in land and waterway monitoring and management in Egypt [26], Africa and across South East Asia and the Himalayan region [27]. As elsewhere, information is the key to enabling people to make more sustainable choices and realise benefits from their actions, as well as for education, awareness and support.

Observational data are increasingly available to users around the world through a range of portals and systems, allowing for environmental observation and prediction. Examples include the Earth Observation Portal [28] and Climate Change Prediction Net [29], while conservation is the focus of the Society for Conservation's portal [30]. There is an increasing tendency to make geo-spatial environmental information more readily available through the use of common interfaces, such as Google Earth and Microsoft's Virtual Earth. This enables information holders to make geo-specific information available to users through a standard web interface at very low cost. Examples include: The Tropical Ecology Assessment and Monitoring Network [31], Atlas of Our Changing Environment [32], Climate Change in Our World [33], and others [34].

On the ground in emerging and developing countries there are a number of examples of how cellular mobile phones and wireless networks can provide a leapfrogging opportunity where fixed line networks are rudimentary or simply do not exist. Noting that agriculture is the mainstay of the Kenyan economy, Mungai provided a number of examples relating to mitigation, such as the SokoniSMS service, which enables farmers to receive market prices in various market centres through their mobile phones [35, 36] Equipped with this information, the farmers are able to determine the most profitable market to transport products to, circumventing middlemen who usually offer to buy the products at much lower prices and reducing the tendency to transport goods from market to market in search of buyers. Other initiatives include the use of geographical information systems in the Lake Victoria basin [37] and along the Nile basin [38] to support natural resource management and local development. These systems can be supplemented by location or eco-system specific information kits, such as The Mekong and Nile River Awareness Kits [39]. Integrated eco-system monitoring, sensing and modelling is also increasingly common (*e.g.* The Pearl River Delta [40]).

Noting the vulnerabilities of rural communities in South East Asia and the Himalayan regions, their dependence of eco-systems and pressures from unsustainable use and over use, Tyler and Fajber noted the importance of access to information and a number of innovative projects [41]. For example:

- In Indonesia, Bogor Agricultural University is working with farmers to use climate forecasts through climate field schools, and when seasonal forecasts suggested a drier than normal crop season in 2006-07, farmers stored a larger proportion of their first rice crop in anticipation of higher prices due to dry conditions for the second crop.
- In the Philippines, the Manila Observatory (MO) has partnered with SMART, one of the country's mobile phone service providers, for a pilot project providing telemetric rain gauges and phones in disaster-prone areas. Local farmers read the rain gauges and phone the information to the Observatory, while the Observatory can also use the phones to issue early

warning of storms to the farmers. In addition, the farmers can use the phones to access market information.

There are also many examples of supporting information networks (see below).

2.2 Adaptation: Managing the Unavoidable

Adaptation refers to actions designed to reduce the negative impacts of climate change that are already occurring. Unfortunately, the most vulnerable are at most risk, and for the developing world it is the role that ICTs can play in climate change monitoring and adaptation that is likely to be most important [42]. Examples of adaptation include preparing risk assessments, protecting ecosystems, improving agricultural methods, managing water resources, instituting better building designs and building settlements in safe zones, developing early warning systems, improving insurance coverage and developing social safety nets [43, 44].

2.2.1 Climate Change Adaptation

Monitoring and providing early warning of climate change induced events, such as storm and tsunami, drought and flood, famine and disease, play a vital role. Examples at the international level include:

- The *Famine Early Warning Systems Network (FEWS NET),* a USAID-funded network that brings together international, regional and national partners to provide early warning and vulnerability information on emerging and evolving food security issues. FEWS NET professionals in Africa, Central America, Haiti, Afghanistan and the United States monitor and analyse climate information for potential impacts on livelihoods and markets to identify potential threats to food security. Once identified, FEWS NET uses a suite of communications and decision support technologies to help decision makers act to mitigate food insecurity. These include monthly food security updates for 25 countries, regular food security outlooks and alerts, as well as briefings and support to contingency and response planning efforts [45].
- *Distant Early Warning System for Tsunami (DEWS)* is a tsunami warning system for the Indian Ocean, which aims to create a new generation of interoperable tsunami early warning systems based on an open sensor platform, which integrates sensor systems for the rapid detection of earthquakes, for the monitoring of sea level, ocean floor events, and ground displacements. Tsunami warnings can be sent via SMS to mobile cellular phones, by facsimile or as a television overlay [46].
- *PreventionWeb* serves the information needs of the disaster risk reduction (DRR) community, including the development of information exchange tools to facilitate collaboration, providing a common platform for the disaster risk reduction community to find and share DRR information, exchange experience, connect and collaborate [47].

Another area in which the use of ICTs supports adaptation is that of climate and impact models, which can be used to inform practitioners and decision makers in planning as well as predicting the impacts of climate change on agriculture (*e.g.* combined with crop models). SEI cite a number of examples [48] including:

- A South African study undertaken by the University of Pretoria that focused at the provincial level and found a significant correlation between higher historical temperatures and reduced dryland staple production, and forecast a fall in net crop revenues by as much as 90% by 2100.
- A Nigerian study that applied the EPIC crop model to give projections of crop yield during the 21st century. The study modelled worst case climate change scenarios for maize, sorghum, rice, millet and cassava, and found that there will be increases in crop yield across all low land ecological zones as the climate changes during the early parts of the 21st century, but towards the end of the century the rate of increase will tend to slow down.
- An Egyptian study that compared crop production under current climate conditions with those projected for 2050, and forecast a decrease in national production of many crops, ranging from -11% for rice to -28% for soybeans.
- A study that mapped climate vulnerability with a focus on the livestock sector and identified arid and semi-arid rangeland and the drier mixed agro-ecological zones across the African continent, particularly in Southern Africa and the Sahel, and coastal systems in East Africa as being particularly prone to climate change [49].

Similarly, ICRISAT's integrated climate risk assessment and management system uses remote sensing and GIS techniques to study rainfall patterns and prepare advisories for farmers in drylands of Asia and sub-Saharan Africa [50].

Having identified areas of vulnerability, ICTs enable a range of responses, with information networks playing a crucial role. There are many examples:

- *The Arid Lands Information Network (ALIN)* states that its strategy is informed by the belief that knowledge is a source of competitiveness, where value lies in new ideas, practices, information on opportunities and new technologies as drivers of this process; that knowledge improves lives, reduces poverty and empowers people; that access to knowledge is fundamental to development and progress; and that ICTs are key for enabling access to knowledge. ALIN provides an information sharing forum that helps people to adjust to climate change [51].
- *RANET* uses radio and the Internet for the communication of hydro-meteorological information for rural development, and includes the use of SMS emergency altering systems and community-based weather observation [52].
- *The Open Knowledge Network (OKN)* and *openeNRICH* also provide regular information relating to climate change adaptations, such as the recent exchange “Climate change increases food insecurity in Kyuso, Kenya” (09-07-2009) [53].
- Focusing on mountain regions the *Mountain Forum* and its regional partners provide information to enable residents of mountain regions to adapt to climate change (*e.g.* Climate Change and the Himalayas [54]) [55].

Periodicals, such as I4D [56], telecentre magazine [57], newsfordev [58], Worldchanging [59] provide many examples, and a number of international ICT4D agencies operate environment related programs (*e.g.* IICD [60]). Links and overviews can be seen through such sites as scidevnet [61] km4dev [62] and t4cd [63].

3 Summary and Conclusions

ICTs are all but ubiquitous and the potential uses and impacts of ICTs on the environment in emerging and developing economies are many and varied. No short paper can cover all aspects, and this paper does no more than provide examples. However, it is possible to note some of the key areas of impact and potential in more general terms, highlighting some of the major policy issues arising for both developed and developing countries.

Specific applications with particular relevance to emerging and developing economies include: detection and early warning (*e.g.* storm, flood, earthquake and tsunami warning); energy efficiency applications (*e.g.* intelligent building systems, intelligent transport systems, smart grids and home automation); and information, education and capability building (*e.g.* technology awareness and transfer, public education and support).

Key issues for emerging and developing economies include: access to infrastructure and ways to enable investments in smarter greener energy, transport and building infrastructures, as well as access to the broadband networks and ICT equipment and services necessary to enable their operation; access to data and how the masses of data collected can be brought together to provide a holistic picture of an eco-system or environment (*i.e.* who owns the data, who can use it and what can it be used for?); affordability and how emerging and new technologies can be implemented in contexts of severe budgetary constraint; and capability and how the necessary skills can be brought to bear on environmental issues in developing and emerging economies.

Areas for concern for developing and emerging economies include: understanding life cycle impacts in the many different contexts and circumstances that exist in developing and emerging economies, while operating within the constraints of available data (*e.g.* insufficient national statistical collections to support input-output analysis and life cycle assessments); managing possible rebound effects, which are likely to be greater in rapidly growing markets where there is unmet demand for energy and resources [64], and the related difficulties of establishing an equitable international price for carbon and regulating for appropriate price signals; and ensuring that there is sufficient technology transfer and enabling funding flows to emerging and developing countries.

Fundamentally, ICTs are about information and communication, and it is these roles that are vital. Data must be collected, analysed and interpreted, transformed into information that enables individuals to make smarter greener choices, and communicated to individuals in such a way as to inform and educate, influence and change behaviours. It is not simply a matter of price signals shaping behaviour, even if it were possible to get those signals right, but also about informing, monitoring performance and providing non-price feedback in such a way as to motivate and reward individuals and communities for creating sustainable livelihoods.

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