The Transformational Role of Information and Communication Technologies in Moving toward a More Sustainable World: An Introduction

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ABSTRACT

This article discusses ways ICTs contribute to several aspects of global sustainability. We examine how economic development, education, energy, environment, and transportation at the country level benefit from ICTs, with several orders of effects on global sustainability. We also examine rebound effects. The anecdotal and theoretical research suggests that the impact of ICTs is felt primarily on sustainable development. We identify the key challenges to be addressed in bringing about an ICTs-based sustainable world. Studying the macro impacts of ICT investments can guide countries in setting policy and making selective investments in ICTs that will promote global sustainability.

Keywords: Information & Communication Technologies (ICTs); Sustainability; First, second, and third order effects; Rebound effects

1. Introduction

The purpose of this article is to present the potentially transformational role of ICTs in country-level sustainability at the macro level. By macro level, we are referring to the impact from the application of ICTs across countries and societies. The article is informed by anecdotal and theoretical research and by a variety of ICT propositions—in the areas of e-business, mobile computing, e-government, and the like—which have the potential to improve country sustainability. Once in place, these proposed ICT improvements may help to reduce poverty and climate change, and improve literacy rates and transportation efficiency. We posit ICTs have several orders of effects on sustainability in the areas of education, energy, environment, and transportation.

This article is organized to make several contributions: First, it introduces the contemporary literature on sustainability, which suggests ICTs' prospects are transformational vis-à-vis sustainability efforts. Second, it provides positive anecdotal examples of the association between ICTs and sustainability. Here, too, is a discussion of the different orders of effects of ICTs, useful for interpreting the impact of ICTs on sustainability. Third, various applications deployed by IBM under its ‘smart planet’ initiatives are described as a comprehensive case study. IBM is only one company, but the applications it employs are illustrative of the potential role of ICTs in promoting a sustainable world. Fourth, the article discusses the key challenges and issues that need addressing prior to going forward. Fifth, we offer conclusions and directions for additional research.

2. Background Discussion

In its 1987 report, “Our Common Future,” the Bruntland Commission defines sustainability as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs (http://www.worldinbalance.net/agreements/1987-brundtland.php).” While this definition gives the report an environmental focus, the document also recognizes that “development cannot be said to be sustainable if it is not equitable, or if it does not meet the pressing needs of the majority of the inhabitants of the globe.” The *Journal* modifies the definition in its editorial, stating: “global sustainability is a process that meets the needs of the present generation while enhancing the ability of future generations to meet their own needs (Stoner, 2012).” The World Summit for the Information Society (WSIS) is much more specific in its Declaration of Principles, “Building the Information Society: a global challenge in the new Millennium.” To wit:

> Our challenge is to harness the potential of information and communication technology to promote the development goals of the Millennium Declaration, namely the eradication of extreme poverty and hunger; achievement of universal primary education; promotion of gender equality and empowerment of women; reduction of child mortality; improvement of maternal health; to combat HIV/AIDS, malaria and other diseases; ensuring environmental sustainability; and development of global partnerships for development for the attainment of a more peaceful, just and prosperous

> world. We also reiterate our commitment to the achievement of sustainable development and agreed development goals, as contained in the Johannesburg Declaration and Plan of Implementation and the Monterrey Consensus, and other outcomes of relevant United Nations Summits (http://www.itu.int/wsis/docs/geneva/official/dop.html).

Furthermore, the WSIS says it views ICTs as powerful instruments for productivity and economic growth through job creation and employability, leading ultimately to improved quality of life overall. The Global e-Sustainability Initiative (GeSI) considers extending the influence of ICT to all aspects of socio-economic development and applying these technologies to both rich and poor countries in order to achieve the strategic principle of sustainable development across the globe (http://www.gesi.org ; http://www.itu.int/wsis/basic/about.html). Likewise, the United Nations Development Program (UNDP) says "ICT is an increasingly powerful tool for participating in global markets; promoting political accountability; improving the delivery of basic services; and enhancing local development opportunities (http://www.undp.org), " as reported in GeSI (2005) (http://www.gesi.org). These macro effects are believed to be widespread and complex (Berthon & Donnellan, 2011; Erdman et al., 2004). At the July 2000 G8 Kyushu-Okinawa Summit, delegates focused on the impact of information technologies and the growing challenges and risks of a global "digital divide." Summit participants recognized that ICTs can serve as effective tools for broad-based international development in regions where development's traditional toolkit falls short (http://www.g8.utoronto.ca/summit/2000okinawa/finalcom.htm).

The United Nations (UN) has paid particular attention to the role of ICTs in advancing the Millennium Development Goals (MDGs) through the UN ICT Task Force and the World Summit on Information Society (http://www.un-gaid.org). The UN defines ICTs in broad terms, calling them "tools that facilitate communication and the processing and transmission of information and the sharing of knowledge by electronic means." The definition allows room for the full range of electronic digital and analog ICTs, from radio and television to fixed and mobile telephones, computers, and such electronic-based media as digital text, audio-video recording and the Internet (including Web 2.0 and 3.0), social networking and web-based communities (http://www.un-gaid.org).

Today, globalization is characterized by an important shift from agriculture and manufacturing to knowledge-based societies—driven mainly by ICTs—where knowledge and information increasingly represent new patterns of growth and wealth creation and open up possibilities for more effective poverty reduction and sustainable development (Griese et al., 2001).

Knowledge has become a principle force of social transformation. Mobile computing and phones contribute to social, economic, and political transformation. Take, for example, farmers in Africa, who obtain pricing figures via text messages and therefore know just where to sell their products, saving time and travel and improving net incomes. In India, barbers who do not have bank accounts can still use mobiles to send money securely to relatives in distant villages. Elections are monitored and unpopular regimes toppled with the help of mobile phones (World Bank, 2012).

A recent study by Vodafone (2005) on the effect of mobile phones on the African continent provides evidence that mobile telephony has improved economic growth significantly. Moreover, this impact was twice as great in developing countries than in mature economies, with developing countries averaging 20 phones per 100 people and increasing GDP growth by 0.6% (Vodafone, 2005).

In this global arena, the government of virtually every nation has expressed the goal of transforming its country into a learning economy and knowledge society. This ‘knowledge-based' and 'knowledge-led development'—deployed equitably and systemically—has the potential to help societies tackle many of the problems confronting them. This renewed focus on sustainability has even permeated corporate mission and strategy. Note, for example, that the Dow Jones Sustainability Index measures corporate performance in terms of quality of strategy and management as well as a company's ability to manage risks derived from economic, environmental and social developments (http://www.sustainability-indexes.com).

At the country level, ICTs have the potential to bridge the digital divide. They can be used to "manage the boundaries between knowledge and action in ways that simultaneously enhance the salience, credibility, and legitimacy of the information they produce (Cash et al., 2003)." At the company level, ICTs can help 'green the organization,' as well as manage resources more effectively. Thus, green computing has a positive wholesale effect on investment and society.

Research and calculations by GeSI and the Climate Group, a non-profit environmental organization, demonstrate how ICTs could help reduce emissions by as much as 7.8 billion tons by 2020, or five times the anticipated ICT footprint, in industries other than their own. (http://www.gesi.org/ReportsPublications/Smart2020/tabid/192/Default.aspx). Replacing face-to-face meetings with low- or no-emission alternatives, such as video conferencing, obviates the need for, say, carbon-producing air travel (GeSI, 2008b). John Chambers, CEO of networking equipment manufacturer CISCO, has said that his company reduced its carbon footprint by 11% using so-called telepresence equipment, resulting in increased productivity and reduced 'wear and tear' on executives (*The Economist*, 2008).

It has been suggested that the biggest role ICTs can play is in improving energy efficiency in power transmission and distribution (T&D) and in transporting goods (GeSI, 2008b). The report estimates ICT-enabled energy efficiency translates, in economic terms, into approximately $950 billion in cost savings through such applications as smart motor systems in Chinese manufacturing, smart logistics in Europe, smart building in North America, and smart grids in India. In addition to the potential savings in supporting energy efficiency in other sectors, there are potential savings in substitution, that is, replacing high-carbon physical products and activities (e.g., books, meetings) with virtual low-carbon equivalents (e.g., e-business, e-government and advanced videoconferencing). There are significant opportunities for improving environmental sustainability through ICTs, which can rationalize energy management in housing and/or business facilities, make passenger and freight transport more efficient, and enable a product-to-service shift across the economy (Erdmann et al., 2004).

The Erdmann et al. study indicates that in using ICTs to dematerialize across both public and private sectors, there is a potential reduction of 500 metric tons of CO_2 by 2020 (GeSI, 2008b). The reduction in transport emissions by switching to video conferencing and teleworking is small, according to GeSI, with potential savings of 140M and 220M tons of CO_2 annually by 2020, relative to the savings from the use of ICTs to improve logistics. Examples in this category include: the efficient planning of vehicle delivery routes with the potential to save 1.5 billion tons of CO_2; the use of data networking inside a ‘smart’ electrical grid to manage demand and reduce unnecessary energy consumption, saving 2 billion tons; and computer–enabled ‘smart building’ in which lighting and ventilation systems turn off automatically when people leave, 1.7 billion tons (Hawken et al, 2013; Lovins and Cohen, 2011; *The Economist*, 2008).

Additional alternatives include e-business (e.g., online grocery shopping), e-learning, and e-government. Regarding sustainable consumption, examples of direct dematerialization include e-paper, music and video on demand, Internet television and so on. The most obvious indirect effect of sustainable consumption is information, particularly intelligent products that inform users about the environmental impact of their choices and offer sustainable alternatives.

Despite the anecdotal evidence and the potential, the relationship between ICTs and the broader social goal of sustainability is not well understood (Berkhout & Hertin, 2004). Studies in past decades have examined and generally confirmed the positive role of ICTs on productivity and other macro level indicators (Brynjolfsson, 1993, 1994, 1996; Brynjolfsson & Hitt, 1996, 2000, 2003; Brynjolfsson et al., 2002; Hitt & Brynjolfsson, 1996), however, scant research has been conducted into whether and what types of ICTs favorably influence sustainability (Jokinen et al., 1998).

Related studies (Bengtsson and Agerfalk, 2011; Erdmann et al., 2004; GeSI, 2005; Melville, 2010; Watson et al, 2010) have looked at various other relationships and dimensions, and many have identified the macro impacts of ICT as net positive. With this introductory article, we attempt to provide a contemporary exploration of the ways in which ICTs can contribute specifically to a more sustainable world. To scope the depth of this article, the sustainability metaphor is characterized by a number of world development categories—education, energy, environment, transportation, etc.—that collectively specify the sustainability level of a country (Erdmann et al., 2004; Raskin et al., 1998; World Bank, 2010). ICTs are represented as the group of factors in the global ICT index developed by the World Bank (2010) for each country (Minges & Qiang, 2006). A country's income level may also be included for control purposes. This article, therefore, provides an integrated up-to-date review as well as arguments and examples on which country leaders can base decisions to allocate their resources to ICT infrastructure selection and development and derive maximum benefits. In addition, we suggest concerted efforts to increase the collaboration and partnership required for global sustainability.

3. Contemporary Literature Review

According to Spagenberg (2005), what the *Journal* calls global sustainability can be understood in systemic terms (Stoner, 2012). It consists of four subsystems—social, economic, institutional and environmental—which are integrated dynamically to optimize their collective contributions to global and long-term human welfare. These subsystems are identified and based on a unique set of inherent and human-defined goals that emphasize the interactive nature of different facets of human development. The failure or omission of one subsystem can negatively affect the whole system (Hinterberger et al., 1996). This approach is used to analyze the relationships between these facets, such as detecting synergies or targeting conflicts between different objectives encapsulated in the term "sustainable knowledge society" (Spangenberg, 2005). These core objectives, as defined thus far in political and scientific discourse, include greater social cohesion; more and better jobs (social dimension); delinking resource use and economic development; safeguarding biodiversity and ecosystem health (environmental dimension); and an open, participatory approach based on equity and non-discrimination, justice and solidarity (institutional dimension). Global unsustainability arises from many factors, and so initiatives launched to create a more sustainable world need to work within and be adapted to the boundaries of particular ecological, cultural, social and economic systems. And, from a global perspective, those initiatives should integrate seamlessly across various dimensions and geographies (Clark & Dickson, 2003; Kates et al., 2005; Komiyama & Takeuchi, 2006). In e-speak, this totality of sustainability is called 'digital balance'. 'Digital balance' suggests that technology, processes, decisions, and so on, are not considered sustainable if they are not sustainable in every area; they must develop together and equitably. True digital economy means that instead of a physical flow of goods, products or services exist as information flows transmitted through information networks (Ahmed, 2007; Goehring, 2004; OECD, 2003).

One way to describe the impact of ICTs is to look at levels of materialization. A simple, yet comprehensive example is the manufacture and use of the typical automobile. When a car is manufactured, less energy and fewer materials are utilized nowadays than were in the past. This improvement in production eco-efficiency is called *dematerialization*. Consumers, meanwhile, can use the car more eco-efficiently by driving it economically and servicing it regularly. This improvement of eco-efficiency in the car’s consumption is called *immaterialization*. Another aspect of eco-efficiency is *amaterialization*. Amaterialization occurs when the automobile and its movement are substituted by telepresence. Diverse tele-services reduce the need to be in another place physically. Thus, new information technologies and teleservices promote ecological sustainable development (Alexander, 2000; EIC, 2004; European Commission, 2005; GeSI, 2007; Grantham & Tsekouras, 2004; Palmer, 2008). In the next section the different orders of effects of ICTs are summarized, providing a more abstract description of the orders of ICTs’s effects on sustainability.

3.1 The orders of effects of ICTs

Based on the discussion above, we draw broadly from the literature in several disciplines, including the conceptual basis for sustainability (Komiyama & Takeuchi, 2006; Lane, 2011; Larson, 2011), information systems and sustainability (see Alexander, 2000; Bengtsson & Agerfalk, 2011; Berthon & Donnellan, 2001; Clark & Dickson, 2003; Dias & Brewer, 2006; Grantham & Tsekouras, 2004; GeSI, 2008(a); IDC, 2004; James & Hills, 2003; Jensen, 2007; Kondratova & Goldfarb, 2003; Melville, 2010; Watson et al., 2010), global development (European Commission, 2005; Oliner & Sichel, 2000; Parikh, 2009; Prescott-Allen, 2001; Shih et al., 2008; UNESCO, 2002; WEC 2002, 2005; WWF, 2008), and the substantive number of publications at the NAS (1999), NRC (2010, 2011) and the World Bank (2010), to describe the various types of effects. Additionally, we consider the several macro studies on the effects of ICTs (e.g., Brynjolfsson, 1993; Brynjolfsson, 1994; Brynjolfsson, 1996; Brynjolfsson & Hitt, 1996; Brynjolfsson & Hitt, 2000; Brynjolfsson & Hitt, 2003; Brynjolfsson et al., 2002; Hitt & Brynjolfsson, 1996; Jensen, 2007; Meso et al., 2006; Meso et al., 2009; Oliner & Sichel, 2000).

Drawing on the recent literature (Mathews, 2003), three primary groups of effects are identified in which ICTs have the potential to play a wide range of important roles in enabling sustainability (Berkhout & Hertin, 2004; Goehring, 2004; Jitsuzumi et al., 2000a, 2000b; Jokinen et al., 1998; Mitomo & Oniki, 1999).

First order effects

First order effects, which have been analyzed and reported in the literature substantively, denote the impact and opportunities created by the physical existence of ICTs and the processes involved (Berkhout & Hertin, 2001). With the global energy budget increasing exponentially, using ICTs to monitor and manage energy production, distributions, and consumption efficiently, greenhouse gas emissions can be reduced by minimizing waste and optimizing the use of energy. Environmental monitoring is a positive ICT application. Additionally, jobs are created as ICT manufacturing increases. Positive direct impacts include the use of ICTs for environmental protection purposes, e.g., through electronic monitoring of toxic emissions, remote sensing, electronic controls, and generally improved ‘transparency’ about the use of environmental services (Erdmann et al, 2004; Esty, 2001).

On the other hand, the electronic waste generated by the production and use of ICTs could create a rebound effect. The main fields analyzed are energy consumption during production and use of ICTs and end-of-life waste. Examples of first order effects include energy consumption, waste from daily activities, carbon emissions generated by manufacturing, data centers, and the use of terminal devices (Berkhout & Hertin, 2001; Souter, 2012).

Second order effects

Second order effects refer to the impact and opportunities created by the ongoing use and application of ICTs (Erdmann et al, 2004), and these can be either positive or negative. ICTs have the potential to cut energy pollutants and water consumption (e.g., via the use of smart sensors and meters) (Souter, 2012). The impact and opportunity created by the application of ICTs to optimize energy supply and demand can result in a favorable effect on other sectors such as transportation and logistics. Other replacement and structural changes are made possible by electronic directories, telework and in-car navigation systems. There is strong evidence ICTs have raised labor productivity-efficiencies through intelligent production processes, intelligent design and operation of products, reorganization of supply chains (e-commerce) intelligent logistics and distribution, the process of e-introduction and networking effects. Rebound effects result from the ways in which those ICTs are used, in particular resulting from applications and access to content, such as the disappearance of jobs in sectors undermined by the loss of Internet-enabled businesses (such as music retail), or incomplete substitution may occur such as the use of white vans (delivery vans) in addition to private shopping trips by cars (Berkhout & Hertin, 2001; Souter, 2012).

Third order effects

Third order effects address the impact and opportunities created by the aggregated effects of large numbers of people using ICTs over medium to long-term periods, although they are not well understood because the conditions that create them are complex and intangible (Casal et al., 2005; Erdmann et al, 2004; Romm et al, 1999). Conditions might include changes in the nature of work and working relationships and in the relationships between diasporas and home communities in patterns of consumption and human settlement. ICTs also can have substitution effects, e.g., for physical travel, saving on travel, road congestion, with knock-on effects in road construction, etc. (Souter, 2012).

Rebound Effects

Rebound effects are the negative counter-effects that occur as a result of behavioral changes that themselves result from first and second order effects. An example is the likelihood that the reduction in vehicle usage resulting from telecommuting will be accompanied by increased use of vehicles for leisure activities (Souter, 2012) and the growth of long distance travel (Berkhout & Hertin, 2001). Rebound effects are pervasive across different effects, and the role of ICTs must be examined carefully in the context of trade-offs. A rebound effect also occurs when efficiency gains (directly or indirectly) trigger new demand, thereby counter-balancing the positive environmental effects. For example, there appears to be a positive correlation between the use of email and business travel, one instigating the other.

Replacement may occur in the economy with use of ICTs (e.g., replacement of printed books by e-books); however, it may be outweighed by the increased consumption of alternative energy resources.

A variation of the ‘first,’ ‘second,’ and ‘third’ order effects’ model is to consider the ‘*enabling effects’* of ‘direct,’ indirect,’ and ‘overall decision-making capability.’ Direct effects arise from the increased efficiency in manufacturing and other activities through the use of various types of ICTs. Examples include ICT control of air conditioning equipment to reduce energy consumption and energy savings in transport by the use of intelligent transport systems (ITS). Indirect effects are changes in the behavior of individuals and organizations arising from lifestyle and work-pattern changes enabled by the use of ICT. For example, telework/telecommuting (T/T) not only reduces an employee's daily commuting time but also the energy consumed in commuting. Other examples are the deployment of remote sensing devices to monitor the state of the global environment as well as the use of computerized bidding mechanisms for trading the right to emit carbon dioxide (CO_2). The promotion of the overall decision-making capability of a society refers to the implementation of sustainable public policies via information systems that gather, organize and disseminate relevant information. (Heinonen et al, 2001). In addition, ICTs can be used very effectively to communicate accumulated knowledge on sustainable development. Ultimately, by improving the overall decision-making capacity to implement sustainability policy, a society could move from a knowledge to a wisdom society (Teppayayon et al, 2009). There are numerous examples of the application of ICTs to various aspects of sustainability. IBM provides us with a comprehensive 'case study' incorporating key applications. Note that we are in no way promoting IBM's strategy or products.

3.2 IBM Case Study Examples

A comprehensive example is evident in the role 'smart' or intelligent systems play in sustainability (Pitt et al., 2011). Consider ICTs' part in emission savings: *Smart Motor Systems:* applied globally, optimized motors and industrial automation can reduce emissions (China); *Smart Logistics:* through a host of efficiencies in transport and storage, smart logistics could deliver electricity and heating savings (Europe); *Smart Buildings:* better design, management and automation could reduce buildings emissions (North America & Europe); *Smart Grids:* smart grid technologies create opportunities for reducing emission via the so-called energy internet. For instance, reducing T&D in India's power sector by 30% is possible through monitoring and management of electricity grids, first with smart meters and then by integrating more advanced ICTs. The IBM Smarter Planet web site (http://www.ibm.com/smarterplanet/us/en/smarter_cities/overview/index.html) gives numerous examples of the application of ICTs to various sustainability-related problems. Transport officials in Brisbane, Singapore, and Stockholm use smart systems to reduce both congestion and pollution, for example. And Energy Australia is working with IBM to apply 12,000 smart sensing devices throughout the electricity distribution network to make power grids more reliable, efficient and ready to integrate renewable energy sources. The Australian government has pledged up to $43 billion toward building a high-speed broadband network that will be accessible to 98% of the population. It has also invested $12.9 billion in Water for the Future, an initiative to secure water supplies and improve cities' water infrastructure and resource planning at the Murray-Darling Basin, significant for agriculture. These and the examples below are all drawn from the IBM Smarter Planet web site (http://www.ibm.com/smarterplanet/us/en/water_management/ideas/index.html).

Masdar City, under construction near Abu Dhabi in the United Arab Emirates, is another example of an urban planning initiative to build a sustainably smart city. Its planners are working with top scientists, engineers and innovators to create interconnected systems and manage them through an integrated city dashboard. Masdar City's leaders want to administer their metropolis in real-time, shaping what could be the world's first economically and environmentally sustainable city, with zero carbon emissions.

There are numerous examples of ICT applications in transportation whereby air quality is improved by reducing carbon emissions. One example is found in Stockholm where a dynamic toll system based on the flow of vehicles into and out of the city has reduced traffic by 20%, decreased wait time by 25% and cut emissions by 12%. Also, in Singapore, controllers receive real-time data through sensors to model and predict traffic scenarios with 90% accuracy. And in Kyoto, to analyze urban impact, city planners simulate large-scale traffic situations involving millions of vehicles.

These tangible improvements are possible because cities are infusing their entire transportation systems with intelligence—streets, bridges, intersections, signs, signals and tolls—creating interconnected and smarter systems that reduce congestion, shrink fuel use and cut CO_2 emissions. By extension, new traffic systems improve driver commutes, better inform city planners, increase the productivity of businesses, and generally raise the quality of life.

It is believed rail is two to five times more energy efficient than road or air transportation. One ton of rail freight can be moved 423 miles using one gallon of fuel. A single freight train can replace 280 trucks, reducing fuel use, congestion, and emissions. Passenger travel also lowers emissions, producing1/3rd to 1/10th less CO_2 than cars or airplanes. Unfortunately, though, growing urban populations are driving an unprecedented need for rail, and governments are increasing demands on railroads to ensure safety. The need for rail is outpacing capacity, straining the planet's existing systems, creating bottlenecks and limiting the ability of fragile economies to grow. Trains may be delayed in congested hubs or forced to stand aside on one-track lines. To address these issues, passenger reservation and ticketing systems need to be modernized. (http://www.ibm.com/smarterplanet/us/en/rail_transportation/ideas/index.html).

IBM's solution, in the planning stages now, is a smart rail system infused with enough intelligence to increase capacity and utilization and reduce congestion, a system in which schedules are dynamically adjusted to cope with weather-related outages; delays are reduced by self-diagnosing subsystems; smart sensors detect potential problems before they cause delays or derailments; train cars monitor themselves; and passenger travel patterns are analyzed to minimize environmental impact. The Union Pacific Corporation is reported to be testing a wireless monitoring system that will capture and analyze critical data on trains, from air pressure to brake monitoring to wheel-bearing temperature to axle health. Commuters on Singapore's public transport system use smart cards to pay for train and bus fares, and the data collected helps shape routes and schedules. Netherlands Railways uses advanced analytics software to weigh 56,000 variables, including infrastructure and passenger demand, to administer and schedule more than 5,000 passenger trains per day, thereby improving operational efficiency by 6% with an estimated annual savings of 20 million euros. And California anticipates that high-speed trains can help eliminate more than 12 billion pounds of greenhouse gases and save 12.7 million barrels of oil each year.
(http://www.ibm.com/smarterplanet/us/en/traffic_congestion/ideas/index.html).

Power (energy) is another important element in sustainability. According to IBM, the world's creation and distribution of electric power is largely wasteful. With little or no intelligence to balance loads or monitor power flows, enough electricity is lost annually worldwide to power India, Germany and Canada combined for an entire year. If the U.S. grid alone were just 5% more efficient, IBM contends, the savings would amount to permanently eliminating the fuel and greenhouse gas emissions from 53 million cars. By combining energy production and usage with intelligence, power could be managed much more efficiently, saving money in addition to energy. One can visualize an intelligent utility system that operates not unlike the Internet, connecting instrumentation (meters) in the home to plant turbines to the network itself. The system could link to thousands of power sources, including climate-friendly ones, such as wind and solar (http://www.ibm.com/smarterplanet/us/en/smart_grid/ideas/index.html). As per IBM, all of this instrumentation then generates new data, which advanced analytics can use to generate insight. The end result is that better decisions can be made in real time: decisions by utility companies on how they can better manage delivery and balance loads and decisions by governments and societies on how to preserve our environment. "The whole system can become more efficient, reliable, adaptive, and smart (http://www.ibm.com/smarterplanet/us/en/smart_grid/ideas/index.html)."

Smart grid projects are already helping consumers save 10% on their bills and reducing peak demand by 15%. One can realize the potential savings when scaled to include companies, government agencies and universities. The investment by the federal government could yield almost a quarter of a million jobs, first in digitizing the grid and then in related industries like alternative energy and automotive. Such an investment could enable new forms of industrial innovation by creating exportable skills, resources and technology (http://www.ibm.com/smarterplanet/us/en/smart_grid/ideas/index.html).

ICTs can play a critical role in education by better integrating the collection of cottage industries that make up today's education 'system.' In the U.S., there are more than 15,000 local school districts delivering K-12 programs, and they face a conundrum. Local involvement is crucial, but local systems, measurements and management processes waste precious resources. Developed countries, on average, spend nearly 4% of their GDP on education and costs are rising, up 42% between 1995 and 2004, according to an OECD study. And this is the situation in countries around the world. IBM reports in China, for example, there are nearly 500,000 primary and middle schools, each managing its own infrastructure (http://www.ibm.com/smarterplanet/us/en/education_technology/ideas/index.html).

A smarter education system would reduce waste and upgrade infrastructure, crucially important during an economic crisis when funds are needed for improved instruction. Most importantly, smarter education reshapes learning not around administrative processes but around the two key components of any education system: the students and the teacher. IBM gives the example of a town in Illinois, where educators are mining student data electronically, from academic records to information on student mobility and attendance. IBM also refers to a Florida county with one of the largest school systems in the U.S., whose Teacher Workbench initiative provides educators with instructional resources linked to timely student data. These resources will help teachers identify each student's needs and thus individualize instruction to improve student achievement while protecting confidentiality. Smarter systems also ensure that schools don't bear the education burden alone. They enable the inclusion of supporting organizations and communities —from colleges to health and social service agencies to families—transforming each school into a student-centered educational ecosystem (http://www.ibm.com/smarterplanet/us/en/education_technology/ideas/index.html).

On its web site, IBM describes how in China, the Ministry of Education is expanding access and improving knowledge-sharing through its open source "Blue Sky" e-learning platform, which has been used by nearly 800,000 Chinese students and teachers since July 2006. The state of Brandenburg in Germany is harnessing web-based tools that help teachers and other education experts across a widely dispersed region to connect systematically for the first time. In

Broward County, Florida, parents can access a 'virtual counselor' to track their children's attendance, assignments and progress (http://www.ibm.com/smarterplanet/us/en/education_technology/ideas/index.html). Additional examples provided by IBM include a program in Ohio, where student data is fed to performance dashboards to help teachers, share courseware and lesson plans. Coming soon is the opportunity to create education 'clouds,' like the one reported at North Carolina State University, which uses the cloud to provide computing power and IT tools to students and faculty for research, student learning and administration (http://www.ibm.com/smarterplanet/us/en/education_technology/ideas/index.html).

According to IBM, despite intense fiscal pressures around the world, economic stimulus programs offer the opportunity to foster real innovation in the way education is delivered. Many regions and states are exploring new models, including shared service delivery for routine functions (http://www.ibm.com/smarterplanet/us/en/education_technology/ideas/index.html). Other anecdotes on the use of ICTs in sustainability are documented in Ananthaswamy (2008), Murray (2008), Palmer (2008), The Economist (2009) and Zachary (2008).

In the environmental domain, ICTs can foster sustainable development by enabling better resource and energy use and by dematerializing transactions (GeSI, 2008a; Harter et al., 2010; Jitsuzumi et al., 2001). For example, mobile technologies enable m-banking, eliminating the need for physical branches. Other smart ICT applications have the potential to contribute to higher energy efficiency by making offices, homes and transportation system more 'intelligent' with, say, smart thermostats. Moreover, ICT-based services and working methods, such as teleworking and videoconferencing, can result in lower carbon emissions from business activities. In education, such ICTs as the Internet, inexpensive computers, and CD-ROMs enable e-learning and distance learning. Distance learning can increase access to education for student and teachers in areas where the conventional method cannot assure the services with quality (http://www.ibm.com/smarterplanet/us/en/education_technology/ideas/index.html).

As documented in the literature, ICTs contribute to the overall productivity and economic growth of a country (Fors & Morens, 2002). In addition to preventing waste and generating savings through efficiency, knowledge systems assist with the coordination of sustainability efforts, both locally and globally. As the information economy expands and information societies are formed (Heinonen et al., 2001), developing countries— rural areas, in particular—can move toward parity (Greller & MacKay, 2002) in many of the indicators, such as education level, transportation, public health, and quality of the environment. Through ICT-enabled sustainable development, countries can envision improved growth and better quality of life overall (Hughes & Johnston, 2005).

4. Key Challenges and Issues

Despite the anecdotal evidence and reports of various applications and projects, there is no concerted and coordinated effort to comprehensively apply ICTs across the globe. This section identifies a few important high-level challenges and issues based on the literature review above. By addressing these challenges and issues collectively, countries can hasten the maturing process of the application of ICTs in global sustainability.

(i). Linkages to Millennium Development Goals (MDGs) and World Development Indicators (WDIs)

From a macro perspective, MDGs are the universally accepted targets for addressing poverty from the perspectives of income, hunger, health, etc., while promoting gender equality, education, and environmental sustainability. They are also basic human rights (Sachs, 2005).

Since the MDGs provide a focal point for global development policy, it is appropriate to associate ICT applications with each MDG. Thus, regarding Goal 1, eradicate external poverty and hunger, ICTs can create jobs via the leap frog effect (e.g. mobile computing), providing income and creating a purchasing power for food; Goal 2, focus on achievement of universal primary education, ICTs can enable distance and online learning, via the internet and mobile devices, etc.; Goal 3, gender equality and empowerment of women, ICTs can promote e-democracy as well create economic opportunities via broad band, micro financing & crowd sourcing, and mobile computing & devices (e.g., mobile currency to enable banking); Goals 4, 5, and 6 focus on different health dimensions, such as reduction in infant mortality, improvement in maternal health, and combating HIV/AIDS, malaria, and other diseases. ICTs play a critical role via e-health, m-heath, telemedicine, and other applications by promoting education, communication & dissemination, and delivery of public health. This particular role is discussed in our prior paper (Raghupathi & Wu, 2012). The MDGs are significant for ICTs because they operationalize country-level policy decisions and sustainable development activities. Simultaneously, governments may be held accountable. The WDIs reported by the World Bank maintain data for countries on various development indicators (World Bank, 2010). When linked to the MDGs, the report provides a robust measurement framework for the sustainable development progress made at the country level. Indeed, ICTs can be directly linked to the achievement of the WDIs.

In order to have a direct positive impact on global sustainable development, ICTs need to be linked operationally to the achievement of the MDGs and WDIs. Furthermore, resource allocation can be more focused by targeting specific ICTs and their role in achieving individual

MDGs and WDIs. Via these relationships, one can measure and track the correlations over a long period of time.

(ii). Translational ICTs

Another key challenge in advancing the role of ICTs in global sustainability is what this article labels translational ICTs. This enterprise is an effort to carry application knowledge from the "laboratory to the field," building on interdisciplinary applied research and studies of ICTs, and using them to develop innovative processes and techniques to promote sustainability in agriculture, education, energy, environment, health, sanitation & water management, urban planning, and so on. As ever, the goals are to create jobs, reduce poverty, and improve quality of life, especially in Africa, Asia and South America. But several serious challenges stand between social systems and technical systems. For one, many of these initiatives are plagued by cost and schedule overruns. Second, there is public resistance to the use of technologies over privacy and security issues. Third, technology, by definition, entails risk. The consequences of failure could be costly and therefore devastating. Fourth, such initiatives have been for the most part vendor-driven and not as a result of consensus efforts through the collaboration of all concerned stakeholders. Fifth, while ICT capabilities may be great, one must consider the public policy and regulatory environment surrounding the use of the technology. Sixth, to date implementations have been ad hoc and haphazard, posing difficulties in the development of knowledge systems, benchmarks, and best practices for 'translational sustainability.' Seventh, the rebound and reverse effects of the introduction of ICTs into specific countries must be studied; while the technology may benefit one area, it may have negative effects in another.

(iii). ICTs Innovation, Law and Practice

ICTs innovation can be used interchangeably with commercialization. Considering the deep chasm in 'technology transfer' from developed to developing countries, the various issues in this regard must be addressed from a global perspective. These include intellectual property regimes and protocols, licensing law and agreements, the commercialization of university technologies, antitrust law, tax effects of technology creation & transfer, technology export controls, global financing of technology innovation, security & privacy, and trade law. The trade-offs include the reward for innovation versus making the technology affordable and available to developing countries. What is a reasonable intellectual property policy (e.g., in enforcement of patent law)? What is appropriate pricing of the products? Should international organizations and financial institutions make available low-interest loans and grants for technology application? What safeguards are needed to prevent misuse and to facilitate security and privacy? How does one monitor possible rebound effects? These and other questions suggest the major challenges to be surmounted in technology transfer.

(iv). ICTs and sustainability science for sustainable development

A core sustainability science research program (Clark, 2007) that examines the various questions related to the role of ICTs in global sustainable development must be developed. What models are available or can be developed to understand the 'complex dynamics' that arise from the socio-technical systems? How can these dynamic interactions and conceptualizations be incorporated to achieve a balance between natural, social, and technical systems and sustainable development? How are the long-term trends in ICT use, environment and sustainability transforming natural-social-technical systems? What factors determine the 'limits resilience and sources of vulnerability' (Clark, 2007) for such systems? What incentives and public policies can most effectively guide the deployment of the applications? What organizational structures and forms would support the ICTs-based global sustainability? These and other questions need answers as we go forward with the transformation. The goals for ICTs in sustainable development are not in isolation or defined by scientists alone. The numerous stakeholders including government, NGOs, aid-givers, and citizens must be engaged in balancing human needs with conservation and alleviating poverty (Clark and Dickson, 2003). Additionally, cost-benefit analysis, decision analysis, and risk analysis must be conducted and the public informed fully regarding the various pros and cons of the introduction of the ICTs.

(v). Knowledge systems

While the application of ICTs is not new, there is a lack of systematic scholarship and action research in examining the various facets of the relationship between ICTs and sustainability. This dearth of benchmarks and replicable knowledge systems challenge the goal of global sustainability through ICTs. As Cash et al (2003) point out, "Scientific information is likely to be effective in influencing the evolution of social responses to public issues to the extent that the information is perceived by relevant stakeholders to be not only credible, but also salient and legitimate." For ICTs, credibility implies the technical soundness of the application and its underlying principles; salience deals with the appropriateness of the evaluation and testing to the policy makers; and, legitimacy "reflects the perception that the production of information and technology has been respectful of stakeholders' divergent values and beliefs, unbiased in its conduct, and fair in its treatment of opposing views and interests (Cash et al, 2003)." In order to marshal ICTs for sustainability, policy makers have a greater chance of success if they "manage the boundaries between knowledge that simultaneously enhance the salience, credibility, and legitimacy of the information they produce." Such boundary management between ICTs and stakeholders can be managed effectively by addressing the three key issues of communication, translation, and mediation. According to Cash et al. (2003), "active, iterative, and inclusive communication" between policy experts and ultimate decision makers or resource allocators is desirable to build the knowledge systems that embrace salience, credibility, and legitimacy. Also, experts and decision makers must use the same metaphors so as to avoid losing knowledge in translation. Therefore, mutual understanding is required. Through intervention or mediation, the different perspectives and views can be harmonized and reconciled among the various stakeholders. In summary, successful knowledge systems must be implemented to promote the effective use of ICTs in sustainability.

5. Conclusions

This article examines the potential transformational role of ICTs in promoting world sustainability. Although introductory, we make a number of important contributions to the literature and provides strategic direction to country-level policy makers in governmental and non-governmental organizations and in the private sector regarding the role of ICTs in enabling and promoting sustainability. First, it is only recently that case studies and anecdotal narratives have emerged regarding the use of ICTs in sustainability initiatives. There is a need for understanding the impact at the national as well as global level. The findings from future studies can inform global policymakers to strategize on sustainability resource allocation and invest to maximize the global sustainability benefits. Second, many of the prior studies have focused on 'green ICT,' which addresses how ICTs can become self-sustaining (e.g., green data center, etc.) (Berthon & Donnellan, 2011). This article, however, examines the strategic and transformation role of ICTs in enabling sustainability. A country's income level, to a large extent, may explain its level of sustainability. It seems obvious that poor countries faced greater challenges in natural resource utilization. Indeed, poor sustainable practices would have negative effects on economic development. The flip side is high-income countries have greater carbon emissions. Donor countries, global institutions and nonprofit agencies and foundations can make better choices in terms of investments. In addition, while ICTs may make substantive contributions to sustainability beyond the wealth effect, some of the effects may take longer to be observed (e.g., reduced carbon emission, increased literacy rate, safer and smarter transportation). The article identifies the key challenges and issues in the successful use of ICTs. This addresses the "now what" goal of the *GMGS*.

6. Future Research

Future research may focus on cross-country and regional as well as empirical and longitudinal studies. Best practices also need to be documented. What works in one region may not in another. Cultural, political and economic environments have to be considered. Other variables relating to health, urban planning (NRC, 2010), and water and sewerage planning may reveal additional associations and effects (e.g., smart city design). Others may research the diffusion of ICTs for effective sustainability practices in developing countries and the development of coordinated global strategic models of ICT integration and use. Additionally, the innovation, leapfrog effect, and globalization aspects have to be addressed. An important aspect to study in sustainability is the *rebound effect*, which occurs when efficiency gains stimulate new demand that counterbalances, or even outweighs positive environmental gains. For example, the efficiency improvements (time, fuel, energy), made possible by technological advances, are counteracted by an increasing demand (growing consumption volumes) of energy, products, services, passenger and freight transport. Another rebound effect is rematerialization, e.g. virtual information products are accessed via the Internet and then printed out or burned onto a compact disc or DVD. The different types of 'effects' theorized in the literature have to be tested empirically. Finally, the effects of ICTs on sustainability have to be studied in conjunction with other types of technologies such as alternative & clean air technologies, biotechnologies & genetically modified food, nano technologies, and medical technologies. Finally, the whole range of challenges and issues needs to be addressed.

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