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Wullianallur Raghupathi
Fordham University, New York, Raghupathi@fordham.edu

Sarah Jinhui Wu
Fordham University, New York, jiwu@fordham.edu

Viju Raghupathi
Brooklyn College, City University of New York New York, vraghupathi@brooklyn.cuny.edu

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THE ROLE OF INFORMATION AND COMMUNICATION TECHNOLOGIES IN GLOBAL SUSTAINABILITY

A REVIEW

WULLIANALLUR RAGHUPATHI
(corresponding author)
Fordham University
New York, New York, U.S.A.
raghupathi@fordham.edu

SARAH JINHUI WU
Fordham University
New York, New York, U.S.A.
jiwu@fordham.edu

VIJU RAGHUPATHI
Brooklyn College, City University of New York
New York, New York, U.S.A.
vraghupathi@brooklyn.cuny.edu

Abstract. This article discusses ways in which 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, along 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 in sustainable development.

We thus identify the key challenges to be addressed in bringing about an ICTs-based sustainable world. Studying the macro impacts of ICT investments can also guide countries in setting policy and making selective investments in ICTs that will promote global sustainability.

Keywords: information and communication technologies; sustainable development; global sustainability

INTRODUCTION

The purpose of this article is to examine the potentially transformational role of ICTs in country-level sustainability at the macro level, with "macro level" referring to the impact of the application of ICTs across countries and societies. The article is informed by anecdotal and conceptual research and by a variety of ICT propositions—in the areas of e-business, mobile computing, e-government, and the like—that have the potential to improve country sustainability. Once in place, these proposed ICT improvements may help reduce poverty and climate change, as well as improve literacy rates and transportation efficiency. We posit that ICTs have several orders of effects on sustainability in the areas of education, energy, environment, and transportation. For example, ICTs can improve transportation via the use of smart meters to monitor traffic (resulting in congestion pricing) and make energy delivery and consumption more efficient with the use of smart thermostats. Tele- and video-conferencing can reduce travel needs, leading to reduced carbon emissions for the environment. Distance and online learning technologies can reduce the need for brick and mortar buildings as well as the need for transportation in delivering education. Finally, telemedicine, e-health, and m-health have the potential to make delivery of public health more efficient. ICTs thus have the potential to promote sustainability.

The remainder of this article is organized as follows. Section two provides a background discussion on sustainability and ICTs. Section three performs a contemporary literature review and provides positive anecdotal examples of the association between ICTs and sustainability. In addition, a discussion of the different orders of effects of ICTs, which is useful for interpreting the impact of ICTs on sustainability, is provided. Section four discusses the challenges and issues that need to be addressed prior to going forward. We offer conclusions in section five, and in section six we outline directions for future research.

BACKGROUND DISCUSSION

In its 1987 report entitled "Our Common Future," the Brundtland Commission defined sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). 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 of Management for Global Sustainability* modifies the definition in its first editorial piece, stating that "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 on the Information Society (WSIS) is much more specific in its Declaration of Principles entitled "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. (World Summit on the Information Society, 2003)

Furthermore, the WSIS says that it views ICTs as powerful instruments for productivity and economic growth through job creation and employability, which ultimately lead 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 alike, in order to achieve the strategic principle of sustainable development across the globe (GeSI, 2012). Likewise, the United Nations Development Program (UNDP) says that "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" (as reported in GeSI [2005]). These macro effects are believed to be widespread and complex (Berthon & Donnellan, 2011; Erdmann, Hilty, Goodman, & Arnfalk, 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 the traditional development toolkit falls short.

Through the UN ICT Task Force and the World Summit on the Information Society, the United Nations (UN) has paid particular attention to the role of ICTs in advancing the Millennium Development Goals (MDGs). 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 electronic-based media such as digital text, audio-video recording, the Internet (including Web 2.0 and 3.0), social networking, and web-based communities.

Globalization today is characterized by an important shift from agricultural and manufacturing-based societies 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, Mueller, Reichl, & Stobbe, 2001).

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

A study by Vodafone (2005) on the effect of mobile phones on the African continent provides evidence that mobile telephony has significantly improved economic growth. Moreover, this impact was twice as great in developing countries as it was 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 (Robecosam, 2014).

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. Green computing, therefore, has a positive wholesale effect on investment and society.

Research and calculations by GeSI and the Climate Group, a nonprofit environmental organization, demonstrate how ICTs can 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 (GeSI, 2008b). 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, 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 that ICT-enabled energy efficiency translates, in economic terms, into approximately $950 billion in cost savings through applications such 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 from 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 also significant opportunities for improving environmental sustainability through ICTs that 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 a potential reduction of 500 metric tons of CO_2 by 2020 if ICTs are used to dematerialize across both public and private sectors (GeSI, 2008b). According to GeSI, the reduction in transport emissions by switching to video conferencing and teleworking (potential savings of 140M and 220M tons of CO_2 annually by 2020) is small, relative to the savings from using 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 in order to manage demand and reduce unnecessary energy consumption, saving 2 billion tons in the process; and a computer-enabled "smart building" in which lighting and ventilation systems automatically turn off when people leave, thus saving 1.7 billion tons (Hawken, Lovins, & Lovins, 2013; Lovins & 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 its 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 effect of ICTs on productivity and other macro level indicators (Brynjolfsson, 1996; Brynjolfsson & Hitt, 2003; Brynjolfsson, Hitt, & Yang, 2002; Hitt & Brynjolfsson, 1996); only scant research, however, has been conducted into whether or not (and what types of) ICTs favorably influence sustainability (Jokinen, Malaska, & Kaivo-oja, 1998).

Related studies (Bengtsson & Agerfalk, 2011; Erdmann et al., 2004; GeSI, 2005; Melville, 2010; Watson, Boudreau, & Chen, 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 provide scope for 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, Gilberto, Gutman, Hammond, & Swart, 1998; World Bank, 2010). ICTs are represented as the group of factors in the global ICT index that was 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 upon which country leaders can base their resource allocation decisions in order to derive maximum benefits from ICT infrastructure selection and development. In addition, we suggest putting up concerted efforts in order to reach the increased levels of collaboration and partnership required for global sustainability.

CONTEMPORARY LITERATURE REVIEW

According to Spangenberg (2005), what the *Journal of Management for Global Sustainability* calls global sustainability can be understood in systemic terms (Stoner, 2012). It consists of four subsystems—social, economic, institutional, and environmental—that are dynamically integrated in order to optimize their collective contributions to global and long-term human welfare. These subsystems are identified according to, and are 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, Luks, & Marcus, 1996). This approach is used to analyze the relationships between these facets, 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, 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. Moreover, from a global perspective, those initiatives should integrate seamlessly across various dimensions and geographies (Clark & Dickson, 2003; Kates, Parris, & Leiserowitz, 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 do so equitably. This implies that one must balance several dimensions (e.g., cultural, ecological, economic, and social) and not sacrifice one for the other. They must develop together harmoniously (Hietanen, 2004). 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 in the past. This improvement in production eco-efficiency is called *dematerialization* (Hilty, 2010). 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* (Hietanen, 2004). Another aspect of eco-efficiency is *amaterialization* (Hietanen, 2004). Amaterialization occurs when the automobile and its movement are substituted by telepresence, since diverse teleservices reduce the need to be in another place physically. New information technologies and teleservices therefore, promote ecological sustainable development (Alexander, 2000; EIC, 2004; GeSI, 2007; Grantham & Tsekouras, 2004; Palmer, 2008). In the next section, the different orders of effects of ICTs are summarized, thus providing a more abstract description of their effects on sustainability.

The Orders of Effects of ICTs

Based on the discussion above, we drew broadly from 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, 2011; Clark & Dickson, 2003; Dias & Brewer, 2006; Grantham & Tsekouras, 2004; GeSI, 2008a; IDC, 2004; James & Hills, 2003; Jensen, 2007; Kondratova & Goldfarb, 2003; Melville, 2010; Watson et al., 2010), global development (Oliner & Sichel, 2000; Parikh, 2009; Prescott-Allen, 2001; Shih, Kraemer, & Dedrick, 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. In addition, we considered several macro studies on the effects of ICTs (e.g., Brynjolfsson, 1996; Brynjolfsson & Hitt, 2003; Brynjolfsson et al., 2002; Hitt & Brynjolfsson, 1996; Jensen, 2007; Meso, Datta, & Mbarika, 2006; Meso, Musa, Straub, & Mbarika, 2009; Oliner & Sichel, 2000).

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

First order effects. First order effects, which have been analyzed and substantively reported in the literature, denote the impact and opportunities created by the physical existence of ICTs and the processes involved (Berkhout & Hertin, 2001). For example, with the global energy budget increasing exponentially, using ICTs to monitor and efficiently manage energy production, distribution, and consumption can lead to a reduction in greenhouse gas emissions. Environmental monitoring is also a positive ICT application. 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, 2004). Moreover, jobs are also created as ICT manufacturing increases.

On the other hand, the electronic waste generated by the production and use of ICTs could create a rebound effect. The main fields analyzed were energy consumption during production, use of ICTs, and end-of-life waste. Examples of first order effects include energy consumption, waste from daily activities, and 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 that 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, particularly as a result of applications and access to content. Examples would be the disappearance of jobs in sectors undermined by the loss of Internet-enabled businesses (such as music retail), or incomplete substitution wherein delivery vans are used 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, Wunnik, Sancho, Burgelman, & Desruelle, 2005; Erdmann et al., 2004; Romm, Rosenfeld, & Herrmann, 1999). Conditions might include changes in the nature of work, working relationships and in the relationships between diasporas and home communities with regard to patterns of consumption and human settlement. ICTs can also have substitution effects, e.g., for physical travel, saving on travel, road congestion, 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 which themselves result from first and second order effects (Bomhof, van Hoorik, & Donkers, 2009; Sissa, 2013; Souter, 2012; Tomlinson, 2010). An example is the likelihood that the reduction in vehicle usage resulting from telecommuting will be accompanied by an increased use of vehicles for leisure activities and the growth of long distance travel (Berkhout & Hertin, 2001). Another example is the increase in the manufacture and use of computers and other electronic devices as paper flows are replaced by e-flows—while there is a reduction in paper usage (and a decrease in tree cutting), there is increased potential for e-toxic waste to be generated. 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, with one instigating the other (Berkhout & Hertin, 2004). Replacement may also occur in the economy with the 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. Rebound effects are pervasive across different effects, and the role of ICTs must be carefully examined within the context of trade-offs.

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 (Madden & Weißbrod, 2008). 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 in order to reduce energy consumption, and the use of intelligent transport systems (ITS) in order to increase energy savings. Indirect effects are changes in the behavior of individuals and organizations that arise 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 (Marciano, 2013). 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, Jokinen, & Kaivo-oja, 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 being a knowledge-based society to one based on wisdom (Teppayayon, Bohlin, & Forge, 2009).

There are numerous examples of the application of ICTs to various aspects of sustainability. To an extent, the application of ICTs in sustainability and development is pushed by industry and corporations. 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, Sabbagh, Shehadi, & Karam, 2010; Jitsuzumi, Mitomo, & Oniki, 2001). Mobile technologies, for example, enable m-banking, thereby 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 systems 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, ICTs such as the Internet, inexpensive computers, and CD-ROMs enable e-learning and distance learning. Distance learning can increase access to education for students and teachers in areas where the conventional method cannot assure quality services.

As documented in the literature, ICTs contribute to the overall productivity and economic growth of a country (Fors & Moreno, 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 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).

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 (ICT4S, 2013; Madden & Weißrod, 2008). By addressing these challenges and issues collectively, countries can hasten the maturing process of ICTs application in global sustainability.

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. Regarding Goal 1, which is to eradicate extreme poverty and hunger, ICTs can create jobs via the leap frog effect (e.g., mobile computing), thus providing income and creating purchasing power for food. For Goal 2, the achievement of universal primary education, ICTs can enable distance and online learning via the Internet and mobile devices. For Goal 3, the promotion of gender equality and the empowerment of women, ICTs can promote e-democracy as well create economic opportunities via broad band, micro financing and crowd sourcing, and mobile computing and devices (e.g., mobile currency to enable banking). For Goals 4, 5, and 6, which focus on different health dimensions, such as reducing infant mortality, improving maternal health, and combating HIV/AIDS, malaria, and other diseases, ICTs can play a critical role via e-health, m-health, telemedicine, and other applications that promote education, communication and dissemination, and delivery of public health. This particular role is discussed in a previous work (Wu & Raghupathi, 2012). The MDGs, therefore, are significant for ICTs because they operationalize country-level policy decisions and sustainable development activities. At the same time, governments may also be held accountable. As for the WDIs reported by the World Bank, these maintain data for countries regarding various development indicators (World Bank, 2010). When linked to the MDGs, the report provides a robust measurement framework for 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 operationally linked 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. Through these relationships, one can measure and track the correlations over a long period of time.

Translational ICTs

Another key challenge in advancing the role of ICTs in global sustainability is what this article labels translational ICTs. These enterprises are an effort to carry application knowledge from the "laboratory to the field," building on interdisciplinary applied research and studies of ICTs, and then using them to develop innovative processes and techniques to promote sustainability in agriculture, education, energy, environment, health, sanitation and 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 (Herzog, Pierson, & Lefevre, 2013; Rice, 2003). 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 due to privacy and security issues. Third, technology, by definition, entails risk. The consequences of failure could be costly and therefore devastating. Fourth, such initiatives have for the most part been vendor-driven, and are not the 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 such technology. Sixth, implementations to date 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.

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 and transfer, technology export controls, global financing of technology innovation, security and privacy, and trade law. The tradeoffs 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 the appropriate pricing of products? Should international organizations and financial institutions make low-interest loans and grants available for technology applications? What are the safeguards 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.

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 (Devex, 2013). What models are available or can be developed in order to understand the "complex dynamics" that arise from socio-technical systems? How can these dynamic interactions and conceptualizations be incorporated in order 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 of resilience and sources of vulnerability" (Clark, 2007) for such systems? What incentives and public policies can most effectively guide the deployment of applications? What are the kinds of organizational structures and forms that would support 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 nor 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 & Dickson, 2003). The government will play a key role in public-private partnerships to promote the role of ICTS in sustainable development, especially in developing countries where infrastructure is mostly in the public sector. This is especially true for "smart city" design. In addition, cost-benefit analysis, decision analysis, and risk analysis must be conducted, and the public fully informed regarding the various pros and cons of introducing ICTs.

Knowledge Systems

While the application of ICTs is not new, there is a lack of systematic scholarship and action research that examines the various facets of the relationship between ICTs and sustainability. This dearth of benchmarks and replicable knowledge systems is a challenge to 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 evaluation and testing for 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). Policy makers will thus have a greater chance of success marshaling ICTs for sustainability, if they "manage the boundaries between knowledge that simultaneously enhance the salience, credibility, and legitimacy of the information they produce." Such boundaries 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 in order to build the knowledge systems that embrace salience, credibility, and legitimacy. Experts and decision makers must also use the same metaphors so as to avoid losing knowledge in translation. Mutual understanding, therefore, is required. Through intervention or mediation, different perspectives and views can be harmonized and reconciled among the various stakeholders. In summary, successful knowledge systems must be implemented in order to promote the effective use of ICTs in sustainability.

Cyber Security and ICTs in Sustainability

Cyber security threats have rapidly emerged as the single most important risk and threat to global development. Developing countries are particularly vulnerable due to lack of resources and infrastructure that can mitigate the threats. On one hand, ICTs are playing a major role in the management of power grids, healthcare, agriculture, transportation, and other critical systems; on the other, these very ICTs pose significant threats given the variety and range of cybercrimes and cyberterrorism. Addressing cyber security issues comes to the forefront as a major strategic challenge. There must be a coordinated and concerted effort to meet this challenge collectively from a global perspective (Gercke, 2011; ITU, 2007; Low, Lim, & Samudhram, 2011).

CONCLUSIONS

This article examines the potential transformational role of ICTs in promoting world sustainability. Although the article is introductory, we identify a number of contributions to the literature and provide 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 policy makers on how to strategize for sustainability resource allocation and investment in order to maximize 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, attempts to examine the strategic and transformational 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 face greater challenges in natural resource utilization. Indeed, poor sustainable practices would have negative effects on economic development. The flip side is that high-income countries have greater carbon emissions. Thus, 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, it may take a longer time before some of the effects can be observed (e.g., reduced carbon emission, increased literacy rate, safer and smarter transportation). This article identifies the challenges and issues in the successful use of ICTs, thus addressing the "now what" goal of the *Journal of Management for Global Sustainability.*

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 do so 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. Considering the challenges and issues discussed above (Houghton, 2009), action research is also called for in the development of models for ICT applications in developing countries (Thongmak, 2013); otherwise, the digital divide with regards to the application of ICTs in sustainability will widen even more. Innovation, the leapfrog effect, and the aspects of globalization need to be addressed. Also, 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) for energy, products, services, and 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 and clean air technologies, biotechnologies and genetically modified food, nano technologies, and medical technologies.

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