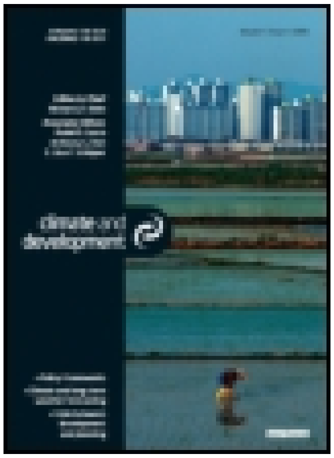

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Information and communication technologies and climate change adaptation in Latin America and the Caribbean: a framework for action

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RESEARCH ARTICLE

Information and communication technologies and climate change adaptation in Latin America and the Caribbean: a framework for action

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Despite ongoing interest in deploying information and communication technologies (ICTs) for sustainable development, their use in climate change adaptation remains understudied. Based on the integration of adaptation theory and the existing literature on the use of ICTs in development, we present an analytical model for conceptualizing the contribution of existing ICTs to adaptation, and a framework for evaluating ICT success. We apply the framework to four case studies of ICTs in use for early warning systems and managing extreme events in the Latin American and the Caribbean countries. We propose that existing ICTs can support adaptation through enabling access to critical information for decision-making, coordinating actors and building social capital. ICTs also allow actors to communicate and disseminate their decision experience, thus enhancing opportunities for collective learning and continual improvements in adaptation processes. In this way, ICTs can both communicate the current and potential impacts of climate change, as well as engage populations in the development of viable adaptation strategies.

Keywords: adaptation; information and communication technology; development; disaster risk management; Latin America

1. Introduction

Climate change will result in a wide range of negative outcomes in the Latin America and the Caribbean (LAC) region (Field et al., 2012; Intergovernmental Panel on Climate Change [IPCC], 2007; Vergara et al., 2013). However, while we know that information and knowledge of climate change alone is unlikely to be sufficient to mobilize most populations into action, access by diverse segments of society to appropriate and timely information remains a core concern of climate policy. Adaptation in many contexts will thus depend on the technical and human capacity to gather and manage the needed information flows.

Responding to climate change in the LAC region, however, is complicated by many factors including persistent social and economic inequity, the uneven quality of human settlements, and chronic poverty in areas also exposed to climatic hazards (Hardoy & Lankao, 2011; Hoffman & Centeno, 2003). Disparities in access to social services, reliable infrastructure and resources, information networks, markets, and opportunities for welfare improvement all generate vulnerable conditions and impede adaptation (Casillas & Kammen, 2010). In the LAC region, many of the most economically marginalized populations are also those who are directly dependent on environmental services for their livelihood (Martínez-Alier, 2005).

There have been multiple waves of interest in information and communication technologies (ICTs) in

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development, or ICT4D (Heeks, 2008; Unwin, 2009). The nature of ICTs as general purpose technologies – that is, technologies that are pervasive, incremental, and complementary of other innovations – enables existing ICTs to adapt to new circumstances quickly (Bresnahan & Trajtenberg, 1995). This characteristic also, however, makes it difficult to evaluate and measure their impact in new or changing circumstances (Guerrieri & Padoan, 2007).

In this article, we provide an analytical model and evaluation framework to assess the potential of existing ICTs to help address the technological and information challenges of climate change adaptation. We then identify and evaluate four distinct case studies in which existing ICTs are being used to meet new environmental challenges throughout the LAC region. A great deal of attention from international development agencies, governments, and non-profits has focused on the deployment of new ICTs to achieve policy goals (e.g. Hilbert & Katz, 2003; InterAmerican Development Bank [IADB], 2011). However, as distributed networks of information flows, involving diverse actors from public, private, and civil society sectors, already existing ICTs offer the potential to reach broad populations, and to engage them directly in processes of decentralized decision-making (Hanna, 2010). This engagement is especially important in the LAC region, where high poverty, poor infrastructure, and complex geography combine to exacerbate the vulnerability of populations to climatic variability and extremes. The promise of enhanced participation, information accessibility, and empowerment in decision-making speaks directly to the twin goals of reducing vulnerability to risk and enhancing the prospects for sustainable development (Eriksen et al., 2011; Tompkins, Lemos, & Boyd, 2008). Nevertheless, scientific efforts to systematically define and evaluate ICTs have not specifically focused on the considerable potential of existing ICTs to contribute to climate change adaptation.

In the next section, we present the results of a literature review to support our analytical model and our framework for evaluation, which we then apply to four case studies of existing ICTs that are being used to prepare for and cope with climate variability in the LAC region. While none of the case studies were intentionally designed for long-term climate change adaptation, each provides insights into the potential of new and existing ICTs to enable adaptation to extreme events and other climate-related impacts in the future.

2. Literature review

This section will examine three disparate strands of the academic literature. We will briefly review the broad literature on ICT4D, with particular regard to previous applications in sustainable development in the LAC region. We then turn to the literature on adaptation and ICTs to explore the potential opportunities and pitfalls of ICTs for adaptation to climate risks. Finally, we review approaches to evaluation of adaptation and ICTs in support of our proposed evaluation matrix.

2.1. *ICTs and sustainable development*

ICTs can be defined as "the application of both traditional and modern communications and computing technologies to the creation, management, and use of information" (IADB, 2011). ICTs span a wide range of technologies that we use in daily life, from mature technologies, such as land telephones, radio, and television, to still rapidly evolving technological systems, such as the Internet, mobile communication and computing, social networks, and remote sensing and geographic information systems, which have been rapidly adopted due to their continuously decreasing cost.

Interest in ICT applications has been stimulated by advances in ICT networks and infrastructure development, as well as by the demographic and economic changes in the region (Ferreira, Messina, Rigolini, Lopez-Calva, & Vakis, 2012). Nevertheless, recent studies of ICTs in the LAC region, using rigorous randomized control methodologies, are inconclusive about the benefits of ICTs in a number of areas such as industry, financial services, health, education, and governance (Balboni, Rovira, & Vergara, 2011; Chong, 2011, IADB, 2011). While mobile telephone technology and use has expanded widely in Latin America, challenges remain in reaching rural populations in poorly serviced areas, and populations with low computer literacy and formal education levels (Chong, 2011). Institutional support and communication infrastructure are also of mixed quality across the region.

In the academic literature, Heeks (2008) highlights the first wave of official enthusiasm for ICTs, while also critiquing the first phase of projects implemented by development agencies as inadequate in their consideration of issues of sustainability, equitable access, scale, and objective evaluation. Some scholars have pointed out the lack of theory to inform ICT applications, and the failure to find practical applications in development efforts (Raiti, 2006). Other literature has focused on the development of viable models for the delivery, use, and maintenance of both technologies and information, in the public or private sectors, such as in the work studying how to deliver services to the Base of the Pyramid where capacities are often constrained (see e.g. Kolk, Rivera-Santos, & Rufín, 2014; Prahalad, 2006).

2.2. *Adaptation and ICTs*

There are a number of studies that describe the potential of ICTs to enable sustainable development in the context of increasing climatic variability, extreme events, and long-term climatic change, particularly in relation to climate monitoring and mitigation (e.g. Corea, 2007; Erdmann, Hilty, Goodman, & Arnfalk, 2004; Hilty et al., 2006; Yap, 2011; Zanamwe & Okunoye, 2013). Nevertheless, ICT applications for climate change adaptation are relatively new, emerging from the more general exploration of ICTs in sustainable development and communication, as well as from greenhouse gas mitigation applications in OECD countries (Ospina & Heeks, 2010a).

While there is no universal definition of what type of decision or action constitutes an adaptation (Murtinho & Hayes, 2012; Smit & Wandel, 2006), most definitions of adaptation in relation to climate change refer to a decision process or to actions that aim to reduce the adverse outcomes and/or to enable populations to take advantage of new opportunities resulting from climate change (IPCC, 2007).

As a conscious decision process, adaptation can be conceived of as having distinct steps, or preconditions, corresponding roughly to ideas of information and knowledge flows within a decision-system (see e.g. work on "information chains", Duff, 1997): the adapting actor or organization needs to perceive a signal of change, have the capacity to act on that perception, and have the institutional support that enables instrumental action (Brown & Westaway, 2011; Risbey, Kandlikar, Dowlatabadi, & Graetz, 1999). Most individuals are making decisions within the context of numerous competing stressors and priorities. In the face of such uncertainty, the process of adaptation must necessarily be iterative, flexible, and conducive to learning as society grapples with emergent environmental risks as well as concurrent and interrelated changes in social and economic systems (Meinke et al., 2009; Nelson, Adger, & Brown, 2007).

Adaptation aims to reduce current and future vulnerability by reducing sensitivity and exposure to risk, enhancing the capacity to cope with change, and taking advantage of opportunities associated with climate change. As adaptation efforts are brought into the domain of development investments, the goals of adaptation become broader and can include enhancing social and environmental well-being, and building capacities to meet a diversity of future challenges, of which climate change is only one of many (albeit significant) threats (Eriksen et al., 2011; Lemos et al., 2013).

In their review of climate change and ICT applications, Ospina and Heeks (2010b) propose that ICTs have the potential to expand access to key livelihood assets for vulnerable populations, while also contributing to broader "e-resilience" by providing opportunities for learning, enhanced system flexibility, and cross-scale resource flows, among other aspects. Elsewhere, these authors highlight five potential functions of ICTs in the adaptation process: (1) informing decisions, (2) engaging stakeholders, (3) adaptation delivery, (4) facilitating learning and feedbacks, and (5) building institutional capacity (Ospina & Heeks, 2011).

Figure 1 builds on Ospina and Heek's (2011) framework to integrate the adaptation decision-process and the potential contributions of ICTs. In this figure, the *information, communication, and technology* aspects of ICTs are differentially emphasized. For example, in providing input into the decision process, ICTs are instrumental in the monitoring, collection, and packaging of information for diverse actors to evaluate for their use (function 1). ICTs also can serve as a communication platform, using social media and technology to facilitate the exchange knowledge and experience among diverse actors (function 2): in essence, creating "bridging capital" that has been identified as important for adaptive capacity (Adger, 2003; Pelling & High, 2005). ICTs can connect a diversity of actors including private sector communication service providers, public or academic institutions, software and hardware developers and innovators, and a diversity of information users who, in many cases, are also and simultaneously information producers (function 2). These communities may not otherwise have opportunities for coordination and communication.

As part of taking action for adaptation, ICTs can potentially facilitate access to specific resources and enhance capacity for adaptation (i.e. financial assistance, access to specific technologies) beyond information about the risk itself (function 3). Once decisions are taken, ICTs can serve in a monitoring role, again serving as platforms for information collection and compilation on decision outcomes (function 4). The experience of adapting individuals, when communicated as information back into an ICT system, creates conditions for knowledge and learning, and potentially can serve as a driver of collective action and institutional change (function 5). In doing so, ICTs may provide avenues to enhance the legitimacy and equity of adaptation processes.

2.3. *Evaluation of ICT contributions to adaptation*

While Figure 1 articulates the potential functions of ICTs in the adaptation process, it does not directly illuminate how ICTs in use for adaptation purposes should be evaluated. In a review of decision support systems for adaptation, the US National Research Council (2009) argued that such systems should be evaluated based on the utility of the information provided, improvements in the relationship between knowledge producers and users, and improved outcomes of the decision process itself.

In terms of information utility, research on the use of climate services in decision-making has illustrated how information alone is unlikely to result in adaptation within complex decision-making processes of social change (Patt & Schröter, 2008; Vogel & O'Brien, 2006). Decisions are made in relation to multiple interacting stressors: information related to only one stress may be ineffective if it does not account for how decision-makers

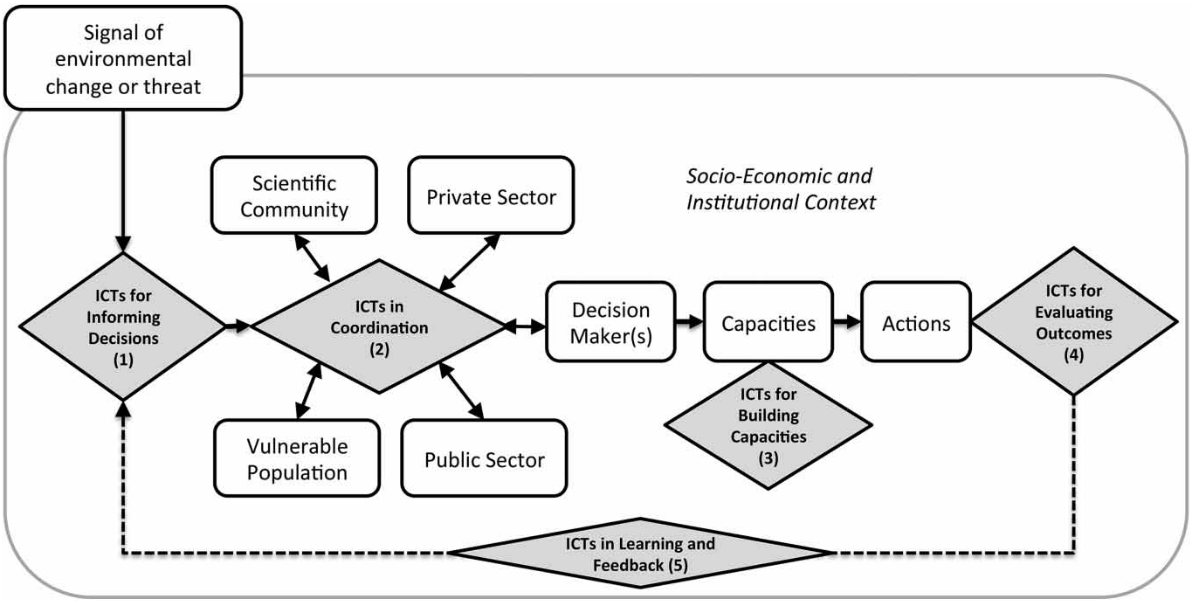

Figure 1. Analytical model of ICTs in adaptation.

prioritize risks (Eakin, 2000; Vogel & O'Brien, 2006). The utility of information is likely to be undermined if information providers do not consider the diversity of financial, technical, or other resources necessary to act (Eakin, 2000; Lemos, Finan, Fox, Nelson, & Tucker, 2002). The institutional context (i.e. formal and informal rules, norms and legal arrangements, organizations and perceptions) in which information is provided as well as whether the information is understood as credible, salient, and legitimate affect the likelihood of action (Cash, Borck, & Patt, 2006; Vogel & O'Brien, 2006).

The social complexity of information use requires tighter feedback and reciprocal cycles of learning between providers and users of information. Boundary organizations (i.e. entities that can translate and communicate information, and interact dynamically with different user communities) and the products they develop (i.e. maps, decision-making platforms, and other information products) have been shown to be particularly important, enhancing the use of climate information in decision-making (Cash & Moser, 2000; Tribbia & Moser, 2008).

In evaluating the social dimensions and outcomes of adaptation processes, Adger, Arnell, and Tompkins (2005) argue for three core criteria: equity, efficiency, and legitimacy. Equity demands that the interests of those who are most vulnerable to impacts are recognized and addressed in adaptation; efficiency acknowledges the trade-offs in any adaptation effort; and legitimacy highlights the political nature of adaptation decision-making.

Recognizing the difficulty of evaluating adaptations as specific outcomes, other scholars and studies have emphasized evaluation criteria such as learning and reflection, the degree of participation and public engagement, and access to a diversity of knowledge sources and perspectives (Osbahr, Twyman, Adger, & Thomas, 2010; Tschakert & Dietrich, 2010; Vogel, Moser, Kasperson, & Dabelko, 2007).

In a parallel fashion, there have been several efforts to establish procedures for evaluating the effectiveness of ICTs in general and more specifically for development efforts (e.g., Batchelor & Norris, 2005). Much of this literature is derived from information systems analysis, and understanding of ICTs as forms of information chains in which information is produced, disseminated, organized, interpreted, used, and finally evaluated in a cyclical fashion and according to the chain's weakest link (see Duff, 1997; Robinson, 2009). Understanding of adaptation processes reviewed above, however, challenges some of the more linear interpretations of information production and dissemination, and the distributed, networked, and dynamic nature of ICTs themselves in developing world contexts also complicate attempts to evaluate their effectiveness (Gómez & Pather, 2012; Heeks, 2008).

Various analyses using quantitative cost–benefit, project goal, and success–failure methods have been performed, but no particular methodology or criteria for ICT assessment has emerged as a standard (Heeks, 2008; Heeks & Molla, 2008). Conventionally, information systems have been evaluated according to the systems' perceived effectiveness from specific user standpoints and in relation to the specific function that the system is intended to play in a decision process (Seddon, Staples, Patnayakuni, & Bowtell, 1999). While system quality (i.e. adaptability, usability, timeliness, etc.) and information quality (i.e. salience, reliability, accessibility, etc.) is important as well as the degree to which the system is being effectively and efficiently used, ultimately measures of success in information systems are going to be context and user specific (DeLone & McLean, 2003).

Recently, scholars have argued that too much emphasis is being placed on tangible outcomes from ICTs (i.e. outcomes that can be quantified and monetized) and more attention should be placed on the more intangible social and political dimensions of ICT use (Gómez & Pather, 2012; Hayes & Westrup, 2012). In the development context, these intangible elements focus on ICTs roles in enabling and empowering social and economic change, promoting social cohesion, strengthening civic relationships, and enabling participation. Many of the more substantive impacts of ICTs in a development context may, in fact, be indirect – supporting social processes and interactions that ultimately lead to transformative change, but not necessarily *causing* these changes directly (Gómez & Pather, 2012). Gómez and Pather's argument coincides directly with the growing emphasis in adaptation on the quality of the adaptation process, rather than the tangible, yet highly uncertain and dynamic, adaptation decision outcomes.

3. Developing an evaluation framework to assess ICTs for adaptation

In our assessment of ICTs and adaptive capacity in the case studies described below, we develop a rubric for evaluation, incorporating insights from the literature on evaluation of adaptation and ICTs, reviewed above. While ultimately having an impact on some aspect of vulnerability is essential for adaptation, we focus less on quantifiable outcomes of ICT use (i.e. cost-effectiveness, user satisfaction) and instead focus on the more intangible and subjective attributes of the decision process and the attributes of the ICT as an information system (involving technology, communication platforms, data, information, and knowledge) that can support that process. Rubrics are commonly used in academia as a reliable tool for reducing the inherent subjectivity in evaluating qualitative elements (Jonsson & Svingby, 2007). Rubrics are based on clearly specified criteria and levels of achievement for each criterion, so that the evaluator can identify the observable outcome of each criterion and classify it accordingly with the respective level of performance, instead of producing a rating without a clear justification. Rubrics are particularly useful when there are multiple objects of evaluation that are disparate in content, yet must conform to standard (qualitative) performance metrics, and for which their relative strengths and weaknesses must be based on expert judgement.

The review of both adaptation and ICT evaluation above emphasizes the importance of information salience as well as social equity: in our case, this translates into information that specifically addresses climate-related vulnerability. Information access and utility is a core feature of both adaptation and information system evaluation. In the adaptation literature, the emphasis on building capacity for transforming information into knowledge, reflecting on experience, and promoting iterative learning coincides with the call for a focus on the more intangible and indirect contributions of ICTs. In the context of promoting social cohesion and facilitating learning, ICTs are particularly important as infrastructure for communication, knowledge storage, and social interaction. Thus we argue that for an ICT to be considered to have the *potential* to enhance adaptation capacity, it should meet the following criteria:

- *Supports feedback*: Provides an active and assertive feedback channel from the users, and therefore enhances potential for learning, deliberation, and iterative change. Here, ICTs are evaluated primarily in functions 4 and 5 of the analytical model (see Figure 1).
- *Addresses vulnerable population*: Considers explicitly the needs and interests of vulnerable populations, and provides customized, credible, and relevant information to address their needs. Here, the ICT is evaluated primarily in relation to the potential to build capacity (function 3 of the analytical model, Figure 1).
- *Ensures information access*: Enables access to clear and useful information through the use of user-appropriate media, language, and technology, particularly for those who infrequently access digital information. Here the focus is on the function of ICTs in informing decisions and decision salience (function 1 in the analytical model).
- *Enables active participation*: Provides avenues for the actors involved in the ICT development, dissemination, and use to participate in diverse aspects of its content, design, structure, governance, and deployment. Here we focus on the role of ICTs in coordinating actors (function 2).
- *Impacts vulnerability*: Significant evidence of impact since implementation, both in reducing sensitivity and exposures, and in building risk-management capacities, institutional or governance changes, learning, or changes in practices. Here the focus is on ICTs in evaluating outcomes and building capacity (functions 4 and 3).
- *Information durability*: Provides for the capacity to collect and store data and information over longer periods of time, and thus provides the opportunity for analysis of trends in environmental signals, stakeholder participation, decision-making, and/or responses to environmental change to enhance learning and improve adaptation. Here we focus on the infrastructure that enables ICTs to function as

decision support, as well as tools for learning and feedback (functions 1, 4, and 5).

Although not all ICT implementations comply with all of these criteria, and inevitably some ICTs will be designed for some functions rather than others, we argue that most of these six elements should be present in a system that claims to support adaptation. In the case studies below, we explore how ICT applications in early warning systems, disaster prevention, and response, as well as environmental monitoring may contribute to support adaptation processes in LAC. We use the above criteria (described fully in Table 1) to qualitatively evaluate each case, and our analytical model (Figure 1) to reflect on the specific functions the ICT could play in adaptation processes.[1] Any ICT will meet these criteria to different degrees, or "levels". We use the rubric to describe these levels, and to associate them with specific qualifications in relation to their contribution to adaptation: very low (1), low (2), medium (3), high (4), and very high (5). We use this framework, assets, and levels to evaluate four different ICT technologies and implementation strategies.

4. Case studies: adapting to climate change in LAC

Given the importance of context and the differential roles that ICTs can play in the adaptation process, we selected four cases that represent different institutional and sector contexts, different types of actors, and different roles of ICTs in the adaptation process. The cases focus on four stressors: changing weather patterns, urban flooding, hurricane disasters, and pest management. These issues, while certainly not the only concerns associated with climate change that the region faces, represent the range of stressors – in relation to both crisis response as well as emergent risks – to which ICTs are being employed. ICTs in all these cases could, if designed and managed appropriately, make a difference in adaptive capacity. We explore these cases in detail below.

4.1. *Case study 1: Unidad Tormenta Mexico City*

4.1.1. *General description*

The Unidad Tormenta (UT) ICT was launched in 2007 as a programme to capture citizens' and government authorities' observations of real-time flood events in Mexico City, communicate these events to first-responders and to the community at large, with the overall objective of enhancing the efficiency of flood management and response. Mexico City's lacustrine topography and soils, with significant soil subsidence caused by groundwater exploitation, has translated into chronic problems of localized flooding during the rainy season, particularly in the primary transportation routes. While climate change scenarios anticipate overall drying trends towards the end of the century, climate change may increase the intensity of rainfall events in the city, increasing the risk of localized floods (Romero Lankao, 2010; Sheinbaum & Martínez Vásquez, 2006).

UT coordinates actions and resources of diverse agencies: Public Safety, Civil Protection, Mexico City Water System (SACM), firefighters, and the local administrators of the city's 16 boroughs. UT consists of a call centre, housed in the SACM offices. Using primarily cell phones, land lines, and Twitter, citizens, traffic officers and local police, and water officials can all call in to report observed flooding in specific locations. The call centre then enables immediate response by sending service vehicles and operators to the site to address the situation. SACM uses text messages to communicate with the local response teams to direct them to the appropriate location. Typically the response entails clearing drains, pumping water if necessary, and fixing any compromised infrastructure. In areas that have repeated flood problems, SACM coordinates with the local city borough administration to make more permanent adjustments to infrastructure: placing larger pumps in the area, augmenting the capacity of drainage systems, or other infrastructural changes. In areas that also show repeated problems, SACM will locate response teams on a temporary basis during the rainy season, to increase the efficiency of response, and to ensure the appropriate equipment is on site to handle any problems that arise.

4.1.2. *Access (high), feedback (very high), and information durability (high)*

SACM makes an effort to disseminate information about flooded areas back to the general public through various mechanisms. Mass media regularly call the unit during rain events for up-to-date reports on flooded areas. In addition, SACM maintains a website, on which any viewer can take note of any reported flood event, its location, the time the event was reported, and the time it took to be resolved.[2] Over the course of the rainy season, the viewer can also see the number of reports per city borough, and how many were resolved and in what time frame. Since 2011, the unit has also maintained a Twitter site, which now has approximately 8700 followers.[3]

4.1.3. *Vulnerability impact (high)*

According to officials in the unit, the primary indicator of success for the new operation is the reduction in the duration of any reported flood event, and the number of events reported that are satisfactorily addressed through SACM operations. The programme has also enabled SACM to channel resources to improve infrastructure in a more efficient, coordinated, and targeted manner.

Table 1. A framework for evaluating ICTs for climate change adaptation.

	Very low	Low	Medium	High	Very high
Supports feedback	Does not allow feedback	Allows feedback but the option is not clearly accessible, or does not work	Allows feedback but there are no answers or learning efforts from the managers	Allows feedback but the answers provided are not entirely relevant and only initial efforts in learning	Allows feedback, participants receive relevant answers, evidence of learning and resulting change in ICT design/ implementation
Addresses vulnerable population	Does not serve/consider any sectors of the general population	Considers a small sector of the general population, not including the vulnerable sector	Considers all the population, including the vulnerable sector, but does not provide specific information for this sector	Considers explicitly the vulnerable population, but provides general information	Considers explicitly the vulnerable population and provides customized, relevant information
Ensures information access	Does not provide any public information	Provides little information and it is not understandable, accessible, or useful for all relevant populations	Provides general information, but not all information is salient to adaptation decisions	Provides salient and accessible information, but improvements in clarity and utility are needed	Provides relevant, accessible information, clear, user-friendly, and useful for all types of users
Enables active participation	Not all of the necessary actors are participating, and their participation is not active	Many of the necessary actors are participating, but their participation is not very active	Many of the necessary actors are participating, and their participation is mostly active	All of the necessary actors are participating, and their participation is mostly active	All of the necessary actors are participating, and their participation is very active
Impacts vulnerability	No evident impact since the implementation, neither in reducing sensitivity/exposure nor in building capacity	Little evidence of impact since implementation, either in reducing sensitivity/exposure or in building capacity	Some evidence of impact since implementation, either in reducing sensitivity/exposure or in building capacity	Significant evidence of impact since implementation, either in reducing sensitivity/exposure or in building capacity	Significant evidence of impact since implementation, both in reducing sensitivity/exposure and in building capacity
Information durability	Provides information only when event occurs; no further use of information	Provides information when event occurs, keeps record of historical data; no further use of information	Provides information when event occurs, keeps record of historical data, and summarizes or analyses data; no evidence of further use of data in reports or policy	Provides information when event occurs, keeps record of historical data, and summarizes or analyses data; data have been used in reports or policy; no evidence of new policies or activities towards adaptation	Provides information when event occurs, records historical data, analyses data; data have been used in reports or policy; data have been used for policy creation, monitoring, enforcement, planning, or similar activities towards adaptation

4.1.4. *Addresses vulnerable populations (high) and participation (medium)*

Empirical evidence, based on interviews and documents describing the programme's success, do not emphasize the participatory aspects of the programme, or its ability to increase the attention of public investment in more socially and geographically marginalized communities. Nevertheless, given the wide-spread availability of cell-phone technology and Internet access in the city, it is likely that the programme enhances the accessibility of the average citizen to SACM's resources, and permits a more diverse participation in the governance of flood risk and water management in the city.

4.2. *Case study 2: Enhancing Resilience to Reduce Vulnerability in the Caribbean*

4.2.1. *General description*

The Enhancing Resilience to Reduce Vulnerability in the Caribbean (ERC) project aims to strengthen regional and national disaster management systems through sharing knowledge for climate change adaptation and disaster risk reduction across Caribbean institutions (Caribbean Disaster Emergency Management Agency, 2011). The project is geared towards improving the speed, efficiency, and accuracy of the decision-making process as it relates to disasters through more efficient use of digital information.

The Caribbean region, with 45 million inhabitants, is vulnerable to a diversity of hazards (Carby, 2011), of which storms and hurricanes are the most widespread. Caribbean settlements are predominantly coastal, with heavy reliance on primary industries such as fishing, tourism, agriculture, and mining. Although the islands are similar and relatively close in proximity, they have distinct socio-economic and political characteristics. The diversity is evidenced in the various languages and governance structures reflected in country-specific ways of mitigating and responding to hazards.

4.2.2. *Information access (high) and durability (medium)*

The ERC project utilizes a web-based platform called DEWETRA that integrates Google Maps, in order to allow multiple layers of information to be used and manipulated in an intuitive and simple process (Enhancing Resilience to Reduce Vulnerability in the Caribbean [ERC], 2012). DEWETRA was launched in 2011 and enabled disaster managers in each country to track significant weather events, build event scenarios, and evaluate the potential impacts of events on communities and infrastructures (ERC, 2012). To facilitate the process, hazard maps, weather data, land cover, road networks, critical infrastructure, and earth observations can be introduced into the platform. Additionally, DEWETRA serves as a database of historical information and experiences that can help other islands for better preparation for disaster events although at this time there is little evidence of systematic historical analysis.

4.2.3. *Feedback (low) and participation (medium)*

Currently, managers can only provide general feedback through e-mails, telephone, and online discussions with the Caribbean Institute for Meteorology and Hydrology (CIMH) and Caribbean Disaster Emergency Management Agency (CDEMA) developers. DEWETRA has a mechanism to collect feedback from those who deploy the platform, but this feature is not yet functional.[4] There is also capability for an impact report tool, where response teams at the scene of a disaster can send information directly to the platform.

4.2.4. *Addresses vulnerable populations (high) and vulnerability impacts (high)*

The overall aim of DEWETRA is to enhance integrated decision-making by providing timely and accurate information to the formally organized disaster management community in the Caribbean. This information serves to equip civil protection agencies to protect vulnerable populations, infrastructure, and property. Specifically, the real-time information generated through the platform helps reduce confusion and addresses resource management issues for these decision-makers, in areas such as response team deployment, evaluation planning, identification of areas at risk, relief, and damage assessment efforts and, eventually, coordinating building code requirements, zoning, and risk mapping. DEWETRA enables a more explicit targeting of relief efforts on vulnerable populations in flood- and landslide-prone areas. This reduces waste, by deploying limited resources to critical areas first, and establishing priority areas with requisite ranking order. It is expected that through these activities, DEWETRA will eventually impact national disaster policies and thus the adaptive capacities within the Caribbean region.[5]

4.3. *Case study 3: early warning system for potato late blight disease*

4.3.1. *General description*

The Chilean potato blight (CPB) ICT is an early warning system for potato producers that employs cell phones as communication tool to indicate to farmers when to protect potato crops from pest hazards, which are likely to increase under climate change (Bravo & Acuña, 2008). CPB was launched in 2007 and is currently used by 350 farmers in the main potato-growing regions in Chile. The system is supported by a network of automatic weather stations that collect meteorological information on each location. The data are transmitted by GPRS wireless modems to a server, where a mathematical model is run and the output warning generated in a website.[6] Warning messages are produced on a daily basis through e-mail and cellular phone text messages. CPB establishes different levels of alarm when observed weather conditions are likely to produce a disease outbreak, based on planting date, irrigation, and disease prevalence in previous seasons (Bravo & Acuña, 2008). The warning system operates automatically from data collection, transmission, model integration, and alert output (Bravo & Acuña, 2008).

4.3.2. *Vulnerability impact (low)*

When the alert is received, the farmers proceed with pesticide sprays on a more efficient basis than using permanent cover sprays during the whole season. This has also reduced the management costs and crop damage by late blight disease. Together with other improved crop management techniques, potato yields have increased (Solano, Acuña, Dieguez, & Morales, 2011). Farmers' profits may also be positively affected, although there are many other variables that influence crop value beyond pest control. Nevertheless, as yet, it is unclear if the ICT is making a substantive impact on the incidence of potato blight.

4.3.3. *Participation (low), access (high), and addresses vulnerability (high)*

Support, expertise, and resources for the establishment of the ICT were provided by the Ministry of Agriculture, while a Chilean consortium of large potato growers and companies to improve potato production has also contributed to its development and adoption to improve potato production (Bravo & Acuña, 2008). The participation in this programme is voluntary and the farmers make their own decisions, informed of the disease risk by the warning system (Bravo & Acuña, 2008). While the system makes use of commercial cell-phone providers, public funding has been necessary to support the data processing and the maintenance of the infrastructure for the forecast development. Small to medium size farmers receiving the ICT benefits participate in the project, but have not contributed to funding or information necessary for the system. The implementation approach for this project could be described as a top-down process in terms of power and information flow. However, while the design of the CPB was intended for large and mid-size potato growers with Internet access in the countryside, more recently small farmers are using the system as well, receiving text messages in their cell phones. CPB therefore has expanded its capacity to address the needs of vulnerable populations through the strong penetration of cellular phone use in rural Chile.

4.3.4. *Feedback (very low) and durability (medium)*

CPB does not allow direct feedback from users. In meetings with staff from the agricultural research and extension institute, the users can provide some indirect feedback to improve the system. In the absence of formal feedback among users and data providers, the system does not record where the forecasts are being used, how potato blight is being observed, or what types of responses farmers are pursuing. A database of disease risk in different seasons and regions could provide a basis for drawing more substantial conclusions about trends in disease outbreaks in relation to global change; however this has yet to be developed.

4.4. *Case study 4: monitoring air quality in Colombia and El Salvador*

4.4.1. *General description*

ICTs to assist in the monitoring and communication of air quality (AQ) to urban planners and constituents are increasingly prevalent in LAC. In Bogotá (seven million inhabitants), Colombia, and San Salvador (two million inhabitants), El Salvador, AQ ICTs are in place to improve early warning of unsafe air pollution conditions. These AQ ICTs use real-time measurement, data monitoring, and trend analysis of contaminants as an input into urban, public health, and environmental planning. Some systems are targeted to public agencies, while others offer the data to the citizens through freely accessible media. These latter systems inform users of the current AQ in their locations, as well as allow access to reports and analyses.

4.4.2. *Information access (medium) and participation (medium)*

In San Salvador, the AQ system is an example of an ICT targeted at public agencies. The platform has only recently been developed and is not yet publically available.[7] In Bogotá, indicators of AQ, contaminant behaviour, and annual reports for the city are available in different web pages.[8] Nevertheless, this information is neither directly intended for public consumption, nor published in mass media. Although some of these websites allow the users to leave comments, there is no explicit intent to use this feedback in the design or implementation of the monitoring system.

4.4.3. *Durability (very high)*

In both cases, the type of sophisticated data and equipment involved in AQ monitoring requires centralized management, provided and maintained through public sector agencies. A substantive quantity of information is being collected and reserved for analysis. Nevertheless, the public sectors in both cases have limited resources, and this constraint translates into limitations on the amount of information and analysis performed. In both cities academic institutions are supporting the public sector in data analysis. Non-governmental agencies or civil society organizations have not been directly involved in the project, although potentially represent important interest groups.

4.4.4. *Vulnerability impact (high)*

There are already indications that the systems are supporting policy improvements. For example, El Salvador now has initiated new AQ policy made possible due the data collected and measured with the technology.[9] In Bogotá there is evidence of usage of the information in government agencies to analyse the relation of AQ monitoring network with factors like mobility, health, etc.[10]

4.4.5. *Feedback (medium)*

Currently, the general public is not involved in the cycle of monitoring–analysis–decision–action–feedback. While the AQ systems in Bogotá and San Salvador are new, and thus do not have long data records yet, they offer the potential for the analysis of patterns in the behaviour of the variables and correlations with other variables associated to mobility, health, and other aspects of urban quality of life (e.g. licence plate-based mobility restriction). However, the development of early warning systems and pollution forecasting, available directly to the general public, has not been pursued.

5. Discussion

Our analysis confirms that ICTs are already altering the process of decision-making and response to diverse sustainability and climatic-related challenges in the LAC region. As others have documented (Hilbert & Katz, 2003; IADB, 2011), ICTs are changing – or have the potential to change – which actors are participating in decision-making, how information is collected, understood, and disseminated, and how society can learn from management and response.

All of the ICTs have strengths and weaknesses in relation to their contribution to adaptation, as indicated in Figure 2 and Tables 2 and 3. The strengths and weaknesses highlight the different roles ICTs are currently playing in relation to the adaptation process, and where they might be improved to enhance their contribution. While the functional emphasis of each ICT may be distinct, the evaluation criteria highlight how the ICT could potentially be expanded to enhance its contribution to adaptation processes in a more integrated fashion.

For example, UT integrates user feedback into its design, and as such provides a foundation for iterative learning and accountability and stakeholder coordination (function 5). In contrast, the AQ networks are working upstream in the decision process, playing a role in packaging and communicating signals of environmental change to decision-makers and preserving the data for future use (function 1). The ERC network is playing a key role in coordinating information use and knowledge for diverse stakeholders at a regional scale, and providing access to specialists who then apply the data to specific contexts and needs (function 2). In this case, the ERC is in essence creating a boundary object that can be modified and deployed by stakeholders to meet their needs. However, the ERC does not facilitate the direct participation of vulnerable populations, nor does it yet enable direct feedback from users. In contrast, the CPB notification system is focused more downstream in the decision process, helping address the needs of a specific population vulnerable to climate change (function 3).

The diversity of challenges from climate change and the variety of ICT applications imply that ICTs will inevitably play different roles in adaptation processes. Our analysis highlights how some of the ICTs could be expanded to address other roles in climate change adaptation and where they do more to enhance adaptive capacity (Table 3). For example, the CPB network, while focused on the needs of a vulnerable population, could easily be expanded to allow feedback from users to text back information, such as requesting additional information for individual needs, such as localized or crop-specific advice. The ERC network could enhance the capacity for regional learning by archiving its information about specific emergency events to develop plans for future emergencies. The case studies illustrate that ICTs can, and are, serving to facilitate the participation of diverse actors in decisions and responses to environmental challenges. Most of the ICTs studied, particularly the CPB system, could be improved by including the vulnerable populations themselves into the development of the ICT system. Studying the needs of specific populations for customized and relevant information may lead to other relevant actors participating in the design and implementation of each ICT system.

The ICTs address issues that are currently highly salient to decision-makers; they are responding to existing demand for information, and emerging and existing threats to society. Though the case studies we reviewed emphasize improved coping with existing challenges, they potentially set the stage for longer-term adaptation through learning, even if this was not one of their initial goals. Here it is important to emphasize the need for the ICTs to generate information in formats that are available to stakeholders for the purpose of ongoing analysis and learning, supporting the evolution of both the information system as well as their responses. Analysis of existing ICTs through the lens

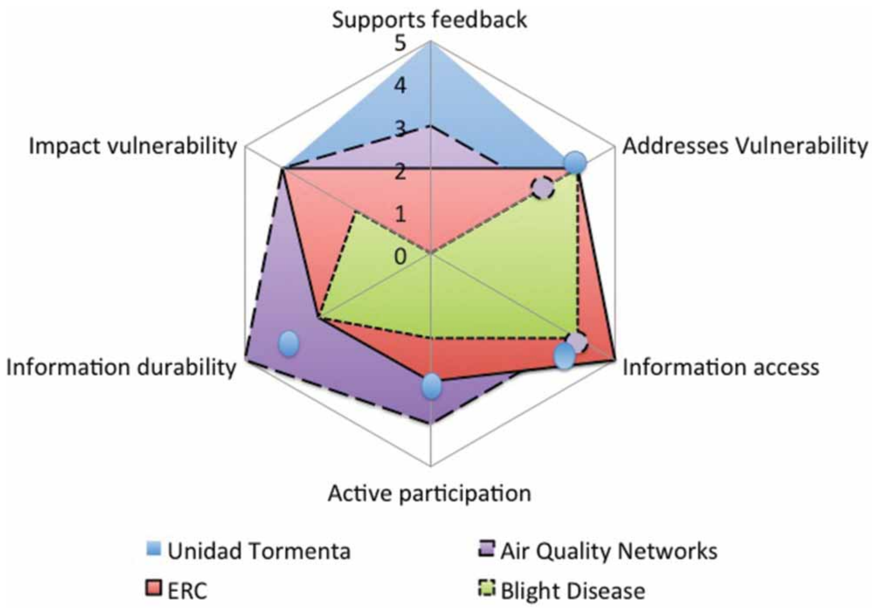

Figure 2. Results from applying the ICT framework to four case studies in LAAC.
Notes: This figure depicts both assets and levels for every ICT. Bubbles represent a specific ICT (by colour) if its level is not visible in the figure.

Table 2. Results from applying the ICT framework to four case studies in LAAC.

	Supports feedback	Addresses vulnerability	Information access	Active participation	Information durability	Impact vulnerability
UT	4	4	4	3	4	4
ERC	2	4	4	3	3	4
Blight disease	1	4	4	2	3	2
AQ networks	3	3	3	3	5	4

Notes: Evaluation done by the authors based on available case study material, for the purpose of illustration. The Unidad Tormenta case study received the highest overall ranking (23/30) followed by the AQ network (21/30), the early warning system in the Caribbean (20/30), and the system for early detection of potato blight disease (16/30).
1 = "very low", 2 = "low", 3 = "medium", 4 = "high", 5 = "very high" (see Table 1).

Table 3. The existing and potential functions of the case-study ICTs in adaptation.

ICT function	UT	ERC	Blight disease	AQ networks
1: Informing	✓	✓	✓	✓
2: Coordinating	✓	✓	?	✓
3: Capacity building	?	✓	✓	?
4: Evaluating	✓	?	?	✓
5: Learning	?	?	?	?

? = ICT's role could be expanded to enhance contribution to adaptation.
✓ = ICT is already substantially contributing to this function.

of adaptation can permit these systems to be scaled up and replicated throughout the region in adaptation planning and policy to consider environmental commonalities, beyond institutional differences. In the LAC context, where resources are scarce and experimentation with such systems potentially expensive, facilitating the acquisition of best practices and experience is important.

Our analytical and evaluation framework provides useful insights into the different ways ICTs can contribute to climate change adaptation; there are many contextual issues that require further discussion and research. First, more empirical analysis of existing cases is required, ideally building on our framework to structure a systematic meta-analysis of ICTs strengths and weaknesses for adaptation. ICTs are proliferating in diverse sectors and differ in structure, organization, technology, and problem application. A systematic evaluation of these issues through the lens of adaptation to climate change may provide important lessons to improve both the theory and practice of ICT applications for adaptation, from micro scales (e.g. district) to aggregated spaces (provincial or larger divisions).

Second, while any individual ICT may prove to be successful in many aspects of enhancing capacity, it is important to consider issues of scale and scope in extending and replicating the experience of one ICT to other domains or broader geographic areas. For example, some ICTs – such as the UT case – are using existing cellular and Internet networks to disseminate and collect information with relatively no impact on existing communication infrastructure. However, if the AQ ICTs were further developed to involve citizen submission of atmospheric data through distributed sensors (e.g. mounted on cars) the volume of data could quickly overwhelm existing commercial networks. In this case, a nationally organized and managed system might be necessary. Decisions about what infrastructure is required, and what actors will manage it, have implications for data accessibility, use, and distribution that must be explored in relation to proposed criteria for sustainable adaptation (Eriksen et al., 2011).

Third, and related, are the challenges in mediating the public–private–civil society relationships that are both essential for ICTs to achieve their adaptation potential, but also pose problems in terms of information ownership, distribution of costs and benefits, and the relative roles of each participating actor in achieving adaptation objectives. The governance of adaptation in general is a challenging topic (e.g. Adger, 2001; Duit, Galaz, Eckerberg, & Ebbesson, 2010) and there are complicated institutional concerns when the cost of any adaptation investment is borne by some actors but the benefits are accrued by others (Tompkins & Eakin, 2012). In these cases, the public sector, as well as humanitarian organizations and development agencies – as actors that should have a clear vision of the public contribution of adaptation efforts – will have critical roles to play in ensuring that ICTs reach vulnerable populations, while enhancing equity and sustainability.

There are also issues of information accessibility, ethics, and risk management that we have not fully addressed. ICTs are attractive in that they often have a distributed structure, facilitating active and spontaneous public participation in information and knowledge creation, dissemination, and use. Such participation – particularly among vulnerable populations – is likely to be empowering and potentially transformative (Gómez & Pather, 2012). As is desired in adaptation, empowerment can mean that communities and individuals are mobilized to take specific actions to address vulnerability. In Mexico City, for example, UT provides new accessibility for citizens to emergency response agencies; Twitter, Facebook, and other interfaces create a public dialogue about flood events that enhance public sector accountability to vulnerable communities, while raising public awareness and debate about the changing environment. ICTs such as this one can also provide needed feedback on hazard experience from more marginal and geographically distant communities, enabling their participation in technology development and adaptation policy. However, given that some information may generate panic in the public, like in the ERC case, information for public release needs to be presented in a suitable manner.

6. Conclusion

ICTs clearly have a role to play in adaptation to climate change. In LAC, they are already becoming integral components of disaster planning and response, environmental monitoring, and risk management. Given this fact, the region offers a real-world laboratory for the observation and evaluation of these tools in a context of rapid social and environmental change, especially considering the territorial complexity of the region, the centralization of public resources, the lack of adequate environmental data, and the heterogeneity of the impacts and needs for adaptation. Our analytical and evaluation frameworks together provide initial heuristics to support ICT development and deployment in adaptation. These frameworks could help inform ICT policy for adaptation, enabling existing ICTs experiences to be more effectively assessed and potentially replicated as well as tested to enhance adaptation in the region. Like any tool, ICTs are not panaceas, yet they offer a potential to bridge gaps between environmental change and field data, information and action, and iterative learning. Our analysis demonstrates that with some effort in design and assessment, ICTs can potentially play an important role in enhancing prevention efforts towards equity and accountability of adaptation decisions and informed public policies, and the social and environmental sustainability of adaptation measures.

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Notes

1. All of the cases are continually evolving and thus the evaluation should be considered our best assessment at the time of the research for this manuscript.
2. http://www.sacm.df.gob.mx:8080/web/sacm/unidadtormenta.
3. https://twitter.com/@SACMEX.
4. A pilot testing of this tool was conducted in June 2013, and the results are pending.
5. In Grenada's case, the outcomes from their simulation exercise have already been included in the national progress

report on the implementation of the Hyogo Framework for Action (2011–2013).
6. http://www.inia.cl/remehue/tizon.
7. http://www.snet.gob.sv/googlemaps/calidadaire/monitoreo.php.
8. Air quality indicators are found at: http://201.245.192.252:81; the OAB data are available through http://oab.ambientebogota.gov.co/index.shtml.
9. See http://estadisticas.cne.gob.sv/docs/Legislacion/ambiental/Norma_Calidad_Aire.pdf.
10. See http://pqr.contraloriabogota.gov.co/intranet/contenido/informes/AuditoriaGubernamental/Ambiente/PAD_2012/Ci cloIII/Calidad%20del%20aire.pdf.

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