Linking ICTs and Climate Change Adaptation:

A Conceptual Framework for e-Resilience and e-Adaptation

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Executive Summary

Background

Climate change constitutes a dynamic, interconnected, yet often uncertain field of study, where the magnitude of environmental impacts is closely related to the various development stressors that underlie vulnerability generally. Literature in the field suggests that challenges faced by developing countries in areas such as livelihoods and finance, socio-political conditions, health, habitat and migrations, food security and water, are intensified by the effects of climate change-related hazards, variability and trends (Hardy, 2003; IPCC, 2007; Parry et al., 2007). At the same time, the exacerbation of these existing vulnerabilities constrains the ability of developing contexts to cope with climate change; that is, to withstand and recover from climate-related shocks and disturbances, as well as to adapt, in the longer term, to changing climatic conditions. The coping abilities to withstand, recover from, and adapt to climate change – what can, overall, be termed 'resilience' – thus emerge as key factors for the achievement of development outcomes.

Despite the uncertainty and unpredictability associated with climate change, the best current indication is that climatic occurrences will increase in both magnitude and frequency, posing serious development challenges (IPCC, 2007; UNDP, 2007). The potential impacts of climate change are becoming increasingly evident through both acute and chronic manifestations. Acute impacts are the extreme hazards of 'shocks', which usually occur over a geographically limited area and require rapid response and relief (CISHDGC, 2010). They can include events such as heavy rainstorms or cyclones, which may produce effects such as landslides, flooding, disruption of transportation systems and the erosion of agricultural land, among others. Climate change threatens to augment the acute stress in vulnerable regions, typically as more and greater storms or more frequent high temperature episodes take place (Wilkinson and Buddemeier, 1994).

The chronic manifestations of climate change refer to subtler shifts in conditions (such as sea level rise, melting glaciers or changing oceanic acidity due to atmospheric CO_2 uptake), which happen over long periods of time and are, therefore, harder to identify. Chronic changes include climate trends (changes in expected conditions), as well as changes in the variability and intensity of weather cycles and events (e.g. changes in seasonality, temperature and precipitation, which can negatively affect productive sectors, particularly agriculture) (Cannon, 2010). Changes in trends and variability could have the largest and most significant aggregate impacts, particularly in low-income, resource-dependent populations. With limited resources and capacities to respond and adapt to both acute and chronic climate changes, developing contexts are particularly vulnerable to the uncertainty of their effects.

It is also within these contexts that the use of information and communication technologies (ICTs) is rapidly spreading (UNCTAD, 2009; ITU, 2010), creating new opportunities and challenges for developing countries that are at the forefront of climate change impacts. Defined as electronic means of capturing, processing, storing, and communicating information (Heeks, 1999), these tools offer an important development potential particularly in the low-income populations whose existing vulnerabilities are magnified by the effects of climate-related disturbances (IPCC, 2007; Moser and Satterthwaite, 2008). Yet, a review of available literature in the field of ICTs, climate change and development (Ospina and Heeks, 2010) suggests that adaptation remains one of the least explored areas for analysis of ICTs' potential in the global South.

Recognising the close links that exist between climate change vulnerability and the achievement of development outcomes, alongside the increasing use of ICTs within developing contexts, the aim of this paper is to set out a conceptual foundation that links climate change, livelihoods vulnerability, and the potential of ICTs in supporting systemic resilience. ICTs will be introduced as a system component that has the potential of contributing towards resilience and, therefore, helping to enable livelihood strategies that allow adaptation; that is recovery and adjustment in the face of climate change.

Contribution

The development of this 'e-Resilience Framework' is based on the recognition that the complex set of relationships that exists between climate change, adaptation processes and development outcomes cannot be fully understood through a series of compartmentalised elements. Instead, a systemic perspective is needed. This allows the identification of key components, processes and properties, as well as the feedback and interactions that play a role in the realisation of adaptation processes in vulnerable settings.

Within the emerging field of ICTs, climate change and development, this document responds to the need for building a solid conceptual basis upon which to analyse the role and potential of these tools, while recognising existing development challenges and vulnerabilities.

This document targets an audience of development strategists, academics and practitioners working in the fields of ICTs-for-development (ICT4D), climate change and/or related areas, interested in conducting more rigorous analysis of the linkages between ICTs and adaptation processes in developing countries. By drawing key principles from recognised conceptual approaches of the social sciences, the paper seeks to foster a more in-depth understanding of both the potential and the challenges associated with the use of ICTs within contexts vulnerable to climate change, while identifying the main concepts and systemic feedback that need to be considered in this analysis.

The proposed framework is developed in progressive, interrelated stages throughout the paper. The first section presents the conceptual underpinnings of livelihood systems' vulnerability to the potential effects of climate change. Drawing from the sustainable livelihoods approach, new institutionalism and Sen's capability approach, the analysis will explore the role of vulnerability determinants (assets, institutions and structures), capabilities and functionings in the realisation of adaptation processes in developing contexts.

Section 2 introduces the concept of resilience as a system property, arguing that, through a set of dynamic sub-properties, it plays an important role in enhancing the adaptive capacity of livelihood systems. Section 3 of the document develops the last component of the conceptual framework by exploring the potential of ICTs with respect to the sub-properties of resilience, introducing the concept of *e-resilience* and analysing the potential of ICT tools as enablers of adaptive processes within contexts vulnerable to climate change.

Recognizing that adaptive actions can be enacted at various levels, the study then analyses two broader roles of these tools. First, their contribution to adaptive actions at the national/macro level. Second, *e-adaptation*: the impact that ICTs can have on the key vulnerability dimensions impacted by climate change (i.e. livelihoods and finance, socio-political conditions, health, habitat and migrations, food security and water supply). Finally, this paper identifies challenges associated with the use of ICTs within adaptive processes, thus completing the analysis from a systemic perspective: from consideration of enabling environments and the role of national-level institutions and structures, to the realisation of adaptive functionings that reduce specific livelihood vulnerabilities to climate change.

Within contexts characterised by poverty and marginalisation, subject to the effects of both acute and chronic climatic effects, the proposed framework provides conceptual insights into the potential of ICTs within adaptation processes, including their role in reducing the prevailing vulnerabilities faced by developing countries in the midst of climate change uncertainty.

1. Climate Change Vulnerability: Conceptual Underpinnings

The prevailing vulnerabilities that poor people face lie at the core of their ability to cope with climate change, and therefore play a critical role in determining the severity with which climate change impacts will be felt in developing contexts (IISD, 2005; MacLean, 2008). The potential effects from heavy rainstorms, cyclones, heatwaves, sea level rise, extended periods of flooding or drought, changing patterns of temperature and rainfall, among others, need to be analysed within a broader set of development stressors and constraints. Understanding vulnerability is, therefore, critical in exploration of the potential effects of climate-related hazards and changing trends on low-income populations.

Available literature in the field evidences the existence of competing conceptualisations and terminologies of vulnerability (Fussel, 2007). However, a general understanding can be that vulnerability represents the likelihood of exposure to external shock combined with the ability to cope with the impact of that shock (Elbers and Gunning, 2003). Such shocks may be economic or related to security. Or they could be related to climate change.[1]

This definition suggests two things. First, that there is some concept of 'outside' (the context that is the source of shocks and variations), and 'inside' (the object of the shock that must seek to cope). This suggests the value of systems thinking in understanding vulnerability given its foundational notion of a system boundary that separates outside from inside. Second, that vulnerability relates partly to the external but partly to the internal; in the latter case to some notion of the capacity of the system to cope (Nelson et al., 2007, p. 396).

Vulnerability in our terms is therefore both a generic coping capacity (or capacity deficit) of systems in development – be they households, communities, regions or nations – and also a more specific set of externally-derived impacts (shocks and variations); in our case, related to climate change. The critical dimensions of those climate change-related impacts emerge as food security and agriculture, health, water supply, human settlement and displacement, socio-political issues, and livelihoods and finance (IISD et al., 2003; Parry et al., 2007; Magrath, 2008; Schild, 2008; OXFAM, 2009). Of course, these dimensions are not only relevant to climate change: they will also be appropriate for an understanding of other acute shocks and longer-term trends.

If the context is a source of acute and chronic risks that materialise via a set of potential impacts, what do development systems – such as communities – do to cope in the face of these threats? One thing they may do is not an active strategy (Thomalla, 2008; DHS, 2010), which is to withstand the external threat, resisting or absorbing and tolerating its impact. The other two things they may do are active. They may recover from the impact; that is act to return to some pre-existing state. In

[1] Not surprisingly, there are similar definitions of vulnerability related specifically to climate change. One of the most widely-used is that provided by the IPCC (2001), which describes vulnerability as the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes.

climate change terms, this would typically be in response to an acute shock such as a landslide. And/or they may change to accommodate the impact; becoming different from the pre-existing state. In climate change terms, this would typically be in response to a chronic trend such as temperature change or rising sea levels. These latter two – recovery and change – represent adaptation processes: "deliberate change in anticipation of or in reaction to external stimuli and stress" (Nelson et al., 2007, p.395). We can therefore summarise with the following 'equation':

Coping = Withstanding + Recovery + Change = Withstanding + Adaptation

Given its potential to address external shocks and trends, adaptation will be critical for the achievement of development outcomes, which include the realisation of increased income and well-being, improvements in food security, and more sustainable use of natural resources (DFID, 1999). Development outcomes also include "reduced vulnerability" (ibid.: p25), indicating a two-way relation between vulnerability and adaptation: the realisation of vulnerabilities requires adaptation actions, but those actions in turn affect vulnerabilities; at least the 'inside' component that relates to the capacity to cope.

The linkages that exist between the concepts presented thus far are illustrated in Figure 1, showing a chain of causality, with context – including climate change – affecting the various dimensions of vulnerability that developing countries are subject to; with those vulnerabilities both determining but in turn also being impacted by, processes of adaptation; and with the enactment (or otherwise) of adaptation determining the ultimate development outcomes for those affected by climate change.

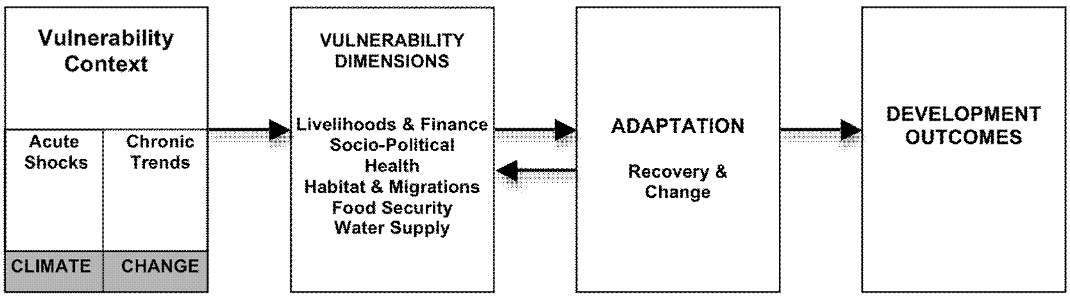

Figure 1. Vulnerability and Adaptation to Climate Change

These linkages suggest that, for the poor, whose socio-economic systems are heavily dependent on ecosystems services and products, the effects of climate change have the potential to intensify existing vulnerability dimensions, while placing further constraints on their ability to adapt and achieve development outcomes (IPCC, 2007).

However, in order to understand how adaptive processes are realised within developing environments, the identification of vulnerability dimensions is not sufficient. The analysis requires a more in-depth exploration of the components and processes that enable or constrain the ability of livelihood systems to adapt, while reducing their vulnerability to the effects of climatic variations and events. To understand this, we can draw on the idea mentioned above of 'adaptive capacities'. These are necessary preconditions to enable adaptation, including not only social and physical resources, but also the ability to mobilise them. In turn, adaptive capacity is generated by the interaction of broader structural determinants, which are dependent on each other and vary in time and space (Smit and Wandel, 2006). For example, a strong social network may allow greater access to resources and reduce the psychological stress caused by climatic disturbances, hence strengthening adaptive capacity.

The following section will explore further this idea of the capacity of systems in developing countries to adapt. It will build a picture of the generic vulnerability determinants (assets, institutions and structures), capabilities and functionings that lie at the core of livelihood systems, and that play a key role in adaptation. These livelihood components will be drawn from the principles of the sustainable livelihoods approach, new institutionalism, and Sen's capability approach. Reference to these frameworks will provide the conceptual foundations required to differentiate potential (i.e. adaptive capacities/capabilities) from actual livelihood strategies (i.e. adaptation as realised functionings), thus providing a more holistic understanding of interacting components within livelihood systems vulnerable to climate change.

1.1. The Capacity to Adapt to Climate Change: Livelihood System Components

Those most prone to suffer the effects of climate-related hazards are often marginalised geographically (e.g. live in hazardous places such as informal settlements or in remote locations), socially (e.g. lack social protection and health services), economically (e.g. low-income or resource dependent populations) and politically (e.g. excluded from political processes and effective representation in government structures) (Gaillard, 2010). Therefore, as noted above, alongside the component of vulnerability deriving from external shocks and trends, there is a component that is not hazard-dependent but is instead determined by constraints that are social, economic and political in nature, and which ultimately reduce the capacity of affected populations to respond and adapt to the effects of climate-related hazards and trends. This aspect of vulnerability and adaptive capacity are therefore two sides of the same coin: as one rises, the other falls.

Adger (2005) argues that this aspect of vulnerability – and, hence the capacity to adapt to climate change – is characterised by the presence of three main generic features, namely (a) the resources available to cope with exposure, (b) the distribution of these resources (social and natural) across the system, and (c) the institutions that mediate resource use and coping strategies. This suggests that, in addition to level of resourcing, it is structural factors that matter in determining vulnerability; both the organisational aspects that affect things like distribution of and access to resources, and also the absence or weakness of institutions. These could exacerbate the effects of hazards in vulnerable populations (e.g. if risk prevention and coping strategies are not put in place or are not organisationally-implementable to deal with the effects of climate-related events), hindering their capacity to adapt.

In order to understand how adaptive processes are achieved within developing contexts, the following section will explore the main vulnerability components (assets, institutions, structures and capabilities) that make up adaptive capacity; and the functionings that represent actual adaptation.

1.1a. Livelihood Systems: Assets, Institutions and Structures

What model should be used to investigate further the connection between vulnerability and adaptation to climate change? Figure 1 and the discussion to date suggest any such model should encompass elements such as vulnerability, context, processes/actions, and outcomes, plus resources and structures. The obvious choice, then will be the sustainable livelihoods approach (SLA), as summarised in Figure 2.[2]

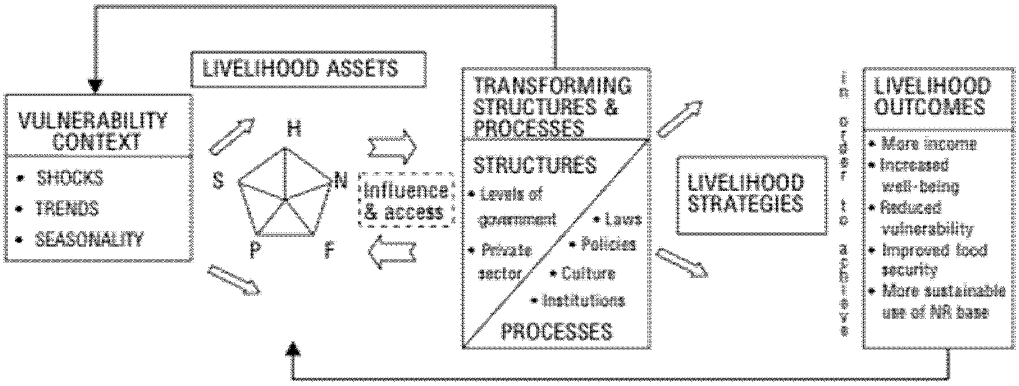

Figure 2. Sustainable Livelihoods Approach (DFID, 1999)

A number of elements within the SLA can already be seen within our climate change model: the vulnerability context of shocks and trends, the livelihood strategies of adaptation (recovery and change), and the livelihood/development outcomes. What follows, then, will be an investigation of the central elements of livelihood assets, structures and processes, which together form the capacity of a livelihood system to adapt to climate change.

The Role of Assets

Adger (2005) argues that the vulnerability of a given population is based on the context in which they reside plus the availability and use of natural and other resources. This and other research evidence points to the key role that access to livelihood assets[3] plays in determining vulnerability and, therefore, in the adaptive capacity of low-income communities (Duncombe, 2006; Smit and Wandel, 2006; Nelson et al., 2007). As shown in Figure 2's sustainable livelihoods model, the five

[2] Though of course there is some conceptual tautology here since ideas from the SLA were already used to influence the understanding outlined in Figure 1.

[3] For the purposes of this document, assets are being treated as equivalents to resources. However, the term 'asset' will generally be preferred given its association with conceptualisations of livelihoods and given the rather broader notion sometimes attributed to assets, with 'resources' sometimes seen to refer just to tangible assets.

core asset categories or capitals upon which livelihoods are built are human, natural, financial, social and physical capital.

The relationship to external vulnerability – including climate change-related vulnerability – is two-fold. In developing country communities, often highly dependent on agriculture and natural resources, climate-induced vulnerabilities can have a detrimental impact on availability of assets (in turn restricting the livelihood strategies that can be enacted). As well as being affected by context, those assets themselves play a key role determining the vulnerability of a given context to the effects of external disturbances such as climate change. Thus, lack of access to these resources significantly limits the ability of livelihood systems to cope with the effects of acute and chronic manifestations of climate change (Chambers and Conway, 1991; IISD, 2003). Conversely, the more varied the asset base (such as the means of production available to generate resources sufficient to reduce poverty), the more sustainable and secure is the livelihood, and the stronger the ability of the population to respond to the impacts of climate change. Therefore, livelihoods assets form the basis of both adaptive capacity and realised adaptation strategies (IISD et al., 2003).

However, the role of assets within adaptation cannot be analysed in a vacuum, as institutions, structures and capabilities also constitute important components of livelihood systems. These will now be analysed further.

The Role of Institutions and Structures

The SLA refers to a set of 'processes' that affect the conversion of assets into livelihood strategies; identifying laws, policies, culture, and institutions. It can readily be shown that these may either block or enable access to assets, and thus play an important role in the capacity of communities to cope with climate change (2009). However, what is not recognised within the SLA is that all these components are, in fact, institutions as understood by the ideas of new institutionalism; and can therefore be corralled under the single 'institutions' heading.

As defined by North (1990), one of the key new institutionalism theorists, institutions are humanly-devised constraints that shape political, economic and social interaction and human agency. They have been formed throughout history to create order and reduce uncertainty. These can be informal constraints such as sanctions, taboos, customs or codes of conduct (all of which are found within the notion of 'culture'), as well as formal rules such as laws, property rights or government policies (Dugger, 1995). Although these are typically referred to in the language of constraint, the notion of 'shaping' means more than just limitation; it also allows for the provision of opportunities for human action.

Institutions will thus have a key role to play in both the selection and implementation of adaptation processes and as such they are a key component of adaptive capacity. However, institutional forces are not free-floating. They are organised by both informal organisations (such as family groupings and power relations) and formal organisations (such as those of the public, private and NGO sectors) (Lowndes, 1996). This organisation also applies to assets, which are organised in terms of both distribution and access. Thus, alongside institutions, conceptualisations of adaptive capacity must also include organisation and structure. Hence, in practice, structures are seen to play an important role in fostering participation and empowerment of local communities in decisions that affect adaptive processes (Plummer and Armitage, 2007).

This suggests that adaptation processes also require effective governance and management structures as they entail steering processes of change through institutions, in their broadest sense (Nelson et al., 2007). Within systems affected by climate-related disturbances, structures themselves need to endure through processes of change, as well as cope with the changing conditions (ibid). Ultimately, within vulnerable livelihoods, both institutions and structures play a key role in determining access to resources, mediating the effects of hazards, and enabling the decision-making frameworks required for adaptation processes to take place (Burton and Kates, 1993).

The combination of assets, institutions and structures presented thus far in the analysis only constitutes part of the enabling foundation of adaptive processes within complex developing environments. In order to complement the analysis, whilst introducing the notion of agency, Sen's concept of capabilities will be explored as an important additional component towards the achievement of adaptive actions in vulnerable livelihoods.

1.1b. Adaptive Capacity as Capabilities

The SLA framework suggests that, given an understanding of context and then of assets, institutions and structures, we could understand that adaptation processes are part of the livelihood strategies that are selected by vulnerable communities. However, we can also incorporate ideas from Amartya Sen's (1999) work on development and capabilities to take us further. That Sen's ideas are compatible with our conceptualisation to date can be seen because the determinants of capabilities are assets, constraints and societal structures (Bebbington, 1999; Robeyns, 2005); corresponding to the elements identified in the preceding section.

We find two additional insights from the capability approach. The first derives from Sen's argument that development represents the expansion of freedoms (Sen, 1999). This is not an idea we will particularly pursue, given our main interest in concrete adaptation outcomes. However, this would lead to an understanding that the growth of adaptive capacity was itself inherently developmental, potentially regardless of the actual utilisation of those capacities. It also somewhat changes the perspective on other components; for example, "assets are not simply resources that the people use in building livelihoods: they are assets that give them the capability to be and act" (Bebbington, 1999, p.5).

The second insight is the differentiation between what a community is free to do – its 'capabilities'; and what it actually achieves – its 'functionings' (Heeks and Molla, 2009). The former are the opportunities afforded; the latter are the actually-lived livelihood actions. It is the distinction between capabilities and functionings, or between *potential* and *actual* livelihood strategies, what constitutes one of the most significant contributions of Sen's approach to the understanding of systemic adaptation. It suggests that the adaptive capacities that are available within a given system (as the social, economic and physical preconditions that are necessary to enable adaptation) (Nelson et al., 2007) cannot automatically be equated with actual achievements. Instead, there is a conversion process that will be subject to personal preferences, social pressures and other decision-making mechanisms, which ultimately determines the set of capabilities (as *achievable* functionings) that can be enacted into *actual* functionings (which would include processes of adaptation) (Zheng and Walsham, 2008).

Level of Analysis

Sen's work is typically based around the individual as the unit of analysis, and this prompts the question of the level of analysis to be used in our framework. As noted above, systems ideas require the drawing of a system boundary, which we can do – conceptually at least – to separate out the context from which vulnerabilities derive, and the development outcomes that derive from adaptation processes (and other realised functionings). But what will lie inside the boundary?

Inside, will be a 'livelihood system' which we can define – adapting Buckley's (1976) definition of 'system' – as "a complex of elements or components directly or indirectly related in a more or less stable way forming a causal network that purposively undertakes actions that have a developmental impact". Given the requirement from what has preceded that the livelihood components would include assets, institutions and structures, it is clearly not appropriate to select the individual as the analysis unit. And, indeed, it is argued that capabilities ideas can readily be scaled up to higher levels (Ibrahim, 2006).

Analysis of work on climate change adaptation shows three principal levels/units of analysis that are used (Brouwer et al., 2007; Stringer et al., 2009; Ibarraran et al., 2010): the micro, working at the level of the household; the meso, working at the level of the community; and the macro, working at the level of the region or nation. Each of these could be represented as three levels of system, each with its own boundary. However, given the porosity of those boundaries – for example, with institutions and assets created at national level readily having an impact at community and household level – we will merely register these as different levels within the overall livelihood system.

Having identified the various levels and components of livelihood systems that make up the capabilities of that system, the following section will explore the way in which those capabilities (i.e. potential livelihood strategies) can translate into functionings (meaning, in the context of climate change, actual adaptive processes and actions).

1.2. Adaptation to Climate Change: Livelihood System Processes and Realised Functionings

Beyond the capabilities required for households, communities or broader livelihood systems to cope with climate change, actual adaptation processes are the result of their ability to implement adaptive decisions, thus transforming that capacity into action (functionings). Capabilities can therefore be understood as the capacity to implement adaptive decisions. In turn, adaptation processes can lead to system transformations when new livelihood strategies are adopted (e.g. when climate-related disturbances force systems to depend on new, diversified livelihood options), as well as to system adjustments, when systems are improved to reduce vulnerability and strengthen future adaptive capacity.

The concept of functionings is key to understand that adaptation is about decision-making processes and the capacity to implement those decisions (Nelson et al., 2007); an ongoing process in which assets, institutions and organisations interact towards the generation of adaptive capabilities, which ultimately enable adaptive actions which contribute to the achievement of development outcomes. Based on the analysis conducted thus far – and recognising that the role and relevance of these elements will always be situation-specific (ibid) – Figure 3 illustrates the linkages between the core components and processes of vulnerable livelihood systems, all of which can contribute to climate change adaptation as a realised functioning (though also recognising there will be realised functionings that are not directly climate change-related).

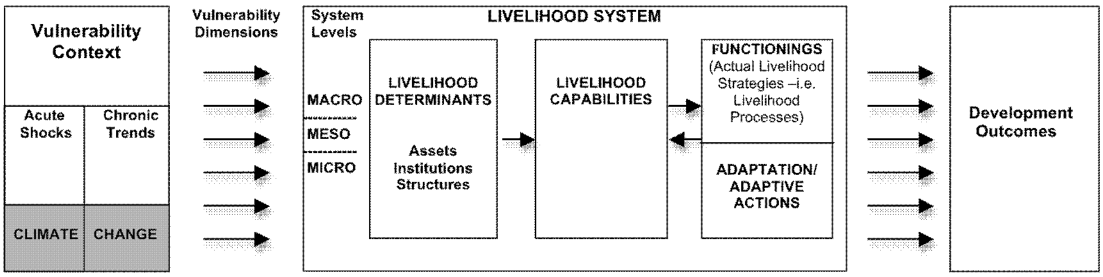

Figure 3. Adaptation to Climate Change: System Components and Processes

Based on the foundations provided by the sustainable livelihoods approach, new institutionalism and the capabilities approach, the model reflects key elements to consider in the analysis of adaptation in developing countries. It illustrates the components (e.g. asset-based, institutional and structural determinants of capabilities) and processes (adaptive functionings) that play a role in the achievement of adaptation and development outcomes, within systems vulnerable to climate change that can be understood at macro, meso and micro levels and relating to six key vulnerability dimensions. It recognises the forces shaping the processes of decision-making action within the SLA can be understood as institutions in a new institutionalism sense. And it reflects a division of livelihood strategies into potential (capabilities) and actual (functionings).

In moving from the model in Figure 1 to that in Figure 3, the analysis conducted so far has shown that drawing insights from a range of conceptual sources provides a more complete picture. It has shown, for example, that the identification of degrees of exposure and sensitivity to climate-related stimuli is not sufficient to understand the complex challenges faced by livelihood systems. Instead, a deeper knowledge of vulnerabilities and their related adaptive capacities is required (Smit and Wandel, 2006).

This process of providing a more complete picture – and also moving closer to understanding the potential role of ICTs – can be taken one further step by drawing insights from an additional conceptual source: the literature on resilience. Resilience is seen as the systemic property that allows livelihood systems to cope with the effects of climate change-related hazards, variability and trends (UNISDR, 2010). While adaptation research is often actor-based and focused on reducing vulnerabilities to specific risks, the resilience approach to climate change emphasises the functioning of a livelihood system as a whole (Nelson et al., 2007). It therefore allows us to analyse in greater depth the relationships that exist between system components and processes; something that is particularly relevant given the systems approach that is taken in this paper and that has been developed in Figure 3.

The following section will provide a more in-depth look into the concept of resilience as a property of livelihood systems, as well as its linkages with the components and processes presented up to this point.

2. Systemic Resilience to Climate Change

Resilience is a much-debated concept and one whose definition differs among different writers. In narrow, 'dictionary' terms, resilience means the ability to 'bounce back'; that is, to recover to some original state following an external disturbance. One finds this as a definition in the climate change literature (e.g. Norris et al., 2008). However, other definitions add two further abilities to our understanding of resilience. One ability – very much related to the first – is the ability to withstand an external disturbance (e.g. Adger, 2000). The other is the ability to change in the face of an external disturbance; going beyond sustainability and renewal to changing and occasionally transforming in a way that enables the survival of the system (e.g. Gallopin, 2006; Magis, 2009).

Seen in this light, then quite simply, resilience is the systemic ability to cope with external disturbances, be they acute shocks or chronic trends. It involves the ability to do the three things previously identified as 'coping': withstanding, recovery and change; the first two being associated with acute climate change-related events, the latter with chronic climate change. It allows that the livelihood system may alter in some way, but also sustain in terms of some aspects of its overall purpose, boundary and identity. And it can be seen as synonymous with 'adaptive capacity'[4]; for example defined as "the ability of a system to adjust to climate change (including variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (ibid, p. 300), a definition which allows resilience to be understood not just as a reaction to the threats associated with climate change, but also as a proactive embrace of the opportunities.

The resilience of livelihood systems is therefore the central facet of those systems in order for us to understand their ability to cope with climate change (and other sources of vulnerability). As such, it warrants further analysis here. But if resilience is taken as synonymous with adaptive capacity (itself the flipside of the internal component of

[4] Though one could argue that adaptive capacity is solely related to recovery and change, while resilience is slightly broader and related to recovery, change <u>and</u> withstanding.

vulnerability), then it can be argued that resilience has already been understood: as the system components summarised in Figure 3. This is true … but partial. Some of the resilience literature (e.g. Gallopin, 2006) sees it as an ability created by the assets, institutions and structures of the livelihood system.

But other parts of the resilience literature (e.g. Norris et al., 2008) provide a new insight; one that helps us to understand livelihood systems not just in terms of system components, but in terms of system properties and sub-properties. Seen in this way, the components – assets, institutions and structures – act together to form a livelihood system that has a set of sub-properties that can collectively be called 'resilience'.

The potential adaptive capacity of a system – its created capabilities – therefore derives from both components and properties. Developing that system by increasing its capabilities can be understood either as a strengthening of components or as a strengthening of properties (of course this is a conceptualisation: in practice the two are completely intertwined). Similarly, we can also understand Figure 3's 'back arrow' as meaning that adaptation processes affect both the components and the properties of the system: the system's assets, institutions and structures; and also its property of resilience.

Having recognised the importance of resilience, as well as its links with the components and processes of livelihood systems, the following section will explore the concept in more detail by presenting a set of resilience sub-properties, and analysing the way in which they can contribute to adaptation.

2.1. Resilience as Sub-Properties of a Livelihood System

As suggested above, resilience is a key property of livelihood systems. Some discussions of resilience treat it monolithically, but others break it down into a set of sub-properties (e.g. IISD et al., 2003; Folke et al., 2005). Those sub-properties are a function of the system's components, and they enable it cope (for example with climate change). As a reminder, coping is the ability to withstand external shocks, and the ability to adapt to shocks and trends. Adaptation, in turn, includes not only recovery from short-term climate change-related shocks but also change in the face of longer-terms climate trends; those changes including both response to threat but also grasping of potential opportunities from climate change.

What then, are the sub-properties of resilience, which enable a livelihood system to withstand and adapt in the face of climate change? Those proposed here are drawn from various sources. The first – robustness – relates mainly to the ability to withstand. The others relate mainly to the ability to recover and to change.[5]

- **Robustness** refers to the ability of the system to maintain its characteristics and performance in the face of environmental fluctuations, including shocks (developed from Carlson and Doyle (2002) and Janssen and Anderies (2007)). Within robust systems, reinforcing influences between components and processes

[5] Hence the argument that adaptive capacity relates just to the six latter properties, while resilience relates to those six plus robustness.

help spread the risks and effects of disturbances widely, so as to retain overall consistency in system performance independent of fluctuations (Gunderson, 2000). This could include the strengthening of assets or of connection between assets. Examples of climate change-specific actions to improve the sub-property of robustness include investment in flood barriers such as levees, terracing on hills and resistant infrastructure, as well as the selection of crop varieties that (while perhaps not having an optimal yield) may be better able to survive under changing climatic conditions. It also includes the strengthening of institutions and structures so that they do not collapse in the face of climate change manifestations.

- **Scale** refers to breadth of assets and structures a system can access in order to effectively overcome or bounce back from or adapt to the effects of disturbances. It involves, for example, access to networks of support beyond those existent at the immediate community level, thus enabling access to resources that may not otherwise be available. Evidence emerging from the disaster management and recovery field (Few et al., 2006) suggests the key role that access to extended markets, networks and other structures can play in order to enable systemic resilience. In practice, it can manifest through the ability to access assets (e.g. financial, human) at the regional, national or international level.

- **Redundancy** is the extent to which components within a system are substitutable; for example, in the event of disruption or degradation. One part of this can be asset diversity, but this is not simply an issue of scale but the ability to access assets that are both in some sense 'surplus' and also interchangeable. Redundancy may also involve the availability of processes, capacities and response pathways that allow for partial failure within a system without complete collapse (RF, 2009). Collaborative and multi-sector approaches can contribute towards redundancy as they facilitate the existence of overlaps and multiple sources of support/expertise that can help fill the gaps in times of need, thus allowing the system to continue to function in the event of climate-related disturbances.

- **Rapidity** refers to how quickly assets can be accessed or mobilised to achieve goals in an efficient manner (Norris et al., 2008). This can be critical particularly when responding to an acute climate-related disturbance. Within climate change-vulnerable contexts, this sub-property can be manifested in the availability of financial mechanisms for savings, and in access to credit and insurance. Rapid access to information, both incoming to and outgoing from the system, will also be key to making quick decisions and mobilising quick support after climate-related events.

- **Flexibility** refers to the ability of the system to undertake different set of actions with the determinants at its disposal, while enabling them to utilise the opportunities that may arise from change. Hence, Folke (2006) argues that system resilience includes the opportunities that disturbances open up in terms of recombination of evolved structures and processes, renewal of the system and emergence of new trajectories. This suggests the relevance of flexibility to respond to the challenges posed by climate change, as well as to the opportunities that it may pose in developing contexts. Climate change resilience entails flexibility at all three systemic levels – the micro, meso and macro – with each of them being able to respond and contribute to each situation, and shift as necessary under unpredictable circumstances (RF, 2009). Flexibility in the face of climate change can come from various sources, including the existence of knowledge (e.g. from social networks) that can suggest different courses of action for problem solving.

- **Self-organisation** is the ability of the system to independently re-arrange its functions and processes in the face of an external disturbance, without being forced by the influence of other external drivers (Carpenter et al., 2001). Fuchs (2004) argues that self-organisation is a threefold process based on cognition, communication, and co-operation, and the concept of information can help to grasp the dynamics of self-organising systems. According to this author, cognition refers to the individual dimension (i.e. the elements of social systems), communication refers to the interactional dimension, and co-operation to the integrational dimension (i.e. the social system itself that is constituted by the interaction of its elements). This definition reflects the various aspects of self-organisation, and at the same time demonstrates that the access to information alone is not enough to enable this sub-property, particularly in developing contexts characterised by asset deprivation, and institutional and structural constraints.

  To understand this further, we can call on the 'information chain' model (Heeks, 2005), which distinguishes stages that run from the provision of information to the asset and institutional capacity and freedom to make decisions and take actions on the basis of that information. Thus, for self-organisation to take place after the occurrence of a climate-related event, communities must be able to first access relevant data, assess its qualities, and apply it to their own particular needs (ibid). Additionally, communities must be able to access the key components that need to be present for the functioning of information chains, namely "overt resources (money, skills, technical infrastructure), embedded/social resources (trust, motivation, knowledge, power) and relevant raw data" (Heeks, 1999, p.7). Therefore, beyond access to assets and capabilities, self-organisation also involves control and hence power over assets and processes, as well as other psycho-social aspects that are necessary to enact actions (e.g. belief, motivation, hope, perceived self-efficacy) and self-organise in face of a climate change-related shock or trend. In practice, self-organisation also reflects enabling socio-political organisational structures and associated collective action that ameliorate vulnerability (e.g. presence of microcredit structures) (Brouwer et al., 2007).

- **Learning** is an attribute closely linked to the dynamic nature of livelihood systems, and relates to the capacity of the system to generate feedback with which to gain or create knowledge, and strengthen skills and capacities. Within systems that are vulnerable to the uncertain impacts of climate-related change, experimentation, discovery and innovation as part of learning processes, can constitute key factors in the ability of the system to spring back and adjust to new conditions. At the same time, understanding the problem is key for the implementation of appropriate responses; hence, the importance of accessing new knowledge that pertains to local priorities and adaptive options. Learning can also play an important role towards local empowerment, and the implementation of preventive and response actions to minimise system disturbances.

These resilience sub-properties constitute dynamic features that interact with available assets, institutions, structures and capabilities (system components) in a given livelihood system, and ultimately enable adaptation as realised functionings (system processes). The realised adaptations contribute towards achievement of development outcomes, including feedback into the capacity of the system to withstand or adapt to future disturbances and climate-related uncertainties. These connections form the model that is summarised in Figure 4.

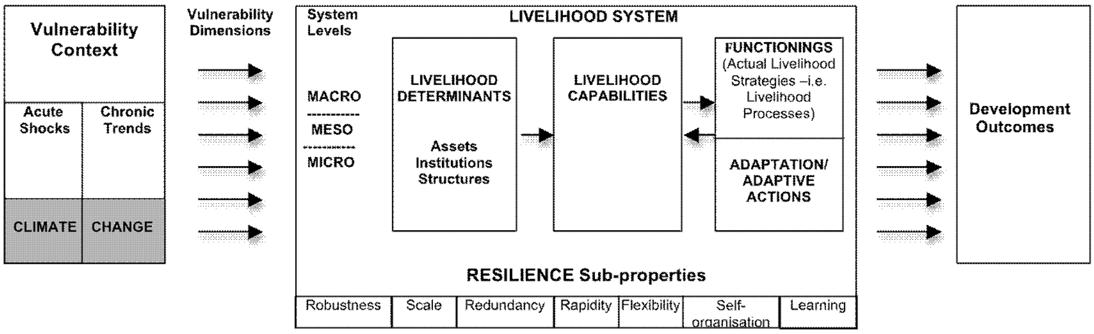

Figure 4: Adaptation to Climate Change: Resilience as a System Property

To summarise, the analysis of systemic adaptation to climate change is mainly concerned with the relationships between components, properties, processes and outcomes in a given system (Nelson et al., 2007), as reflected in Figure 4. Here, climate change-related shocks or trends within a particular context act as a stimulus that requires a response. The capacity of the system – whether at household, community or national level – to respond through adaptation can be understood in two ways. First, as a set of components. Second, as a set of (sub-)properties. Together these interact to create the adaptive capacity of the system, which can be thought of as the system's capabilities – what it is able to be and to do – in making a response to acute or chronic climate change manifestations. Therefore resilience interacts with assets and other components to shape the trajectory of functioning and adaptation after a disturbance (Norris et al., 2008).

A system with a high level of vulnerabilities will not just have lost adaptive components, but also resilience, both of which in turn imply a likely loss of adaptation, and a constrained ability to achieve development outcomes (Folke, 2006). Conversely, the reduction of existing vulnerabilities would mean a gain in adaptive capacity seen either in terms of components or resilience properties, potentially leading to better adaptation.

3. e-Resilience and e-Adaptation

Vulnerability, adaptive capacity and resilience are concepts that have been broadly discussed and analysed in the climate change adaptation literature for many years. They constitute closely linked, albeit complex areas of analysis that are key to understand the effects of climate-related hazards and shifting trends in developing contexts.

At the same time, within those contexts, ICTs – particularly mobile phones – have been diffusing rapidly (Heeks, 2010). This diffusion has been accompanied by an increasing body of literature on the potential and challenges of digital technologies. Part of that potential is the ability to address climate change. Yet a review of the literature on ICTs and climate change shows not only is the literature overall fairly limited to date, but there are particular deficiencies in discussion of developing country priorities and climate change adaptation (Ospina and Heeks, 2010).

Review of the existing literature on ICTs, climate change and development (ibid.) indicates that the potential of digital technology has not yet been integrated into a systematic understanding of adaptation and resilience, let alone from the perspective of a conceptual framework. This section of the paper will address that gap by exploring the potential of ICTs to strengthen resilience and its sub-properties, and thus contribute to adaptation processes in contexts vulnerable to climate change.

One way to understand the potential contribution of ICTs to climate change adaptation – and based on the model of livelihood systems summarised in Figure 4 – would be to chart its role as a component of livelihood systems vis-à-vis other system components: supporting human capital, supporting financial capital, etc; supporting formal institutions, supporting informal institutions; and so on. However, that understanding is already fairly well reflected in both literature and practice generally within the ICTs-for-development field, even if the main focus has been on ICTs addressing particular livelihood strategies or broader development goals, and even if the links to climate change are so far poorly made. Where a link has occasionally been made between ICTs and climate change – whether in literature or practice – these technologies have mainly been conceived as tools to address specific climate change challenges.

What has been missing in all cases – those dealing with climate change or with other development issues – is an understanding of the foundational issue – resilience – and the way in which ICTs can support the development of resilience. In response to this gap and as a contribution to the conceptual framework that has been developed thus far, the following section will explore the links between ICTs, resilience and adaptation in vulnerable livelihood systems, focusing first on how these tools can strengthen resilience sub-properties, and then on how they can address adaptation more broadly.[6]

[6] Though at the same time recognising that, as noted above, there is only a conceptual rather than practical separation between understanding ICTs' contribution to system components (assets, institutions and structures), and ICTs' contribution to system properties (resilience). As such, discussion of ICTs' role vis-à-vis resilience will necessarily incorporate discussion of ICTs and assets, institutions and structures.

3.1. ICTs and Resilience: 'e-Resilience'

For the purposes of this analysis, the role of ICTs in climate change resilience will be explored based on the linkages that exist between ICTs as a system component, and the set of resilience sub-properties previously identified. This approach will serve as the basis to explore the technologies' potential contribution to adaptive capacities at the system level, and should be seen as illustrative rather than comprehensive.

- **ICTs and Robustness**

  ICTs can help strengthen the physical preparedness of livelihood systems for climate change-related events through applications such as geographic information systems (GIS), and positioning and modelling applications. These can contribute to design of defences and determination of their optimal location; both making the livelihood system more robust. Illustrating this potential, remote sensing and GIS technology have been used to map and then rehabilitate and sustainably manage mangrove forests in Kenya (Kairo et al., 2002). Given mangroves' role in reducing storm damage, this technology has helped enhance coastal defences and make these areas more robust in the face of climate events such as increased cyclone intensity (Kelly and Adger, 2000).

  ICTs can also strengthen institutions and organisations needed for the system to withstand the occurrence of climatic events, including the support of social networks and the facilitation of coordinated action (Duncombe, 2006). For example, ICTs can strengthen social networks through enhanced communication within those networks; communication that increases the network bonds by building trust and a sharing of norms and values.

- **ICTs and Scale**

  ICTs can help increase the breadth and depth of assets to which households, communities, etc have access. ICT can facilitate access to a broader set of capital assets, fostering the ability of livelihood systems to recover from climate-related events. Illustrating this potential, ICTs available in Village Resource Centres in rural India have enabled end users to interact with scientists, doctors, professors and government officials located in urban locations (Nanda and Arunachalam, 2009). This has increased the information assets available (e.g. oceanic weather forecasts), and human capital (e.g. via tele-health and e-learning), all of which help when climate-related events occur.

  ICTs can increase the scale of available assets by combining the distant and the proximate. In relation to information assets, for example, in remote areas of the Philippines, participatory 3-dimensional modelling – a community-based tool which merges GIS-generated data and local peoples' knowledge to produce relief models – is being used to establish visual relations between resources, tenure, their use and jurisdiction, thus contributing to the ability of the community to deal with climate change hazards and trends (IAPAD, 2010).

  Mobile applications have improved the breadth of structural access by enabling integration of local producers – small entrepreneurs and farmers – into regional and global supply chains, which also broadens the scale of asset availability, typically in terms of financial and physical capital. In India, the Foundation of Occupational Development (FOOD) promoted the use of cell phones enabling women entrepreneurs from poor communities to exchange goods, place and receive orders, and develop new markets for their products (InfoDev, 2003). Such applications can also increase the scale of institutional forces. For example, m-microfinance services extend the reach of microfinance organisations (Garcia Alba et al., 2007). Not only does this increase the scale of financial assets and organisational structures; it also scales the penetration of the institutional norms and values associated with microfinance organisations. Finally, access to extended social networks through ICTs can also help asset, institutional and structural scale by improving the links between local systems and the meso/macro-level organisations that play a key role in the provision of enabling environments for adaptation.

- **ICTs and Redundancy**

Redundancy with respect to ICTs refers to the potential of these tools to increase the availability of resources to such an extent that there is some spare, excess or possible substitutability of assets. One of the key ways in which ICTs can contribute towards system redundancy is by supporting access to additional financial capital. Mobile phone and Internet usage among Tanzania's small farmers was found to increase their participation in markets and provide information for improved productivity (Lightfoot et al., 2008). This may enable the generation of spare income usable in strengthening local preparedness and response in the event of climatic events (e.g. buying additional food to store, or improving the building structure of the household). Likewise, the advent of m-finance systems has facilitated remittance flows which may be called upon during an acute shock to substitute for income that can no longer be produced locally, thus offering some measure of redundancy (Porteous and Wishart, 2006)

Just as asset redundancy can improve the resilience of livelihood systems, so does redundancy in institutions and organisations (e.g. markets), which allows systems to continue to operate even in the event of partial failure of some of its components. One example is the broadening of job markets through use of ICTs such as mobile applications (e.g. job searching mechanisms such as Babajob, which uses web applications and mobile technology to connect informal sector workers – maids, cooks, drivers, etc – with potential employers in India) (Babajob, 2010; VanSandt et al., 2010). Then, if there was a collapse or failure of the informal networks through which most poor people find jobs, the spare capacity provided by the ICT system can enable continued operation. Another is the use of m-commerce systems such as those offered in the Philippines by SMART Padala, through which users can make purchases from a variety of participating retailers (Wishart, 2006). Releasing commerce from the constraints of geography (i.e. enabling purchases from retailers outside the local area) provides 'commercial redundancy' through substitutable trading links.

- **ICTs and Rapidity**

ICTs can enable swift access and mobilisation of financial assets, particularly through applications for mobile banking and mobile finance (Duncombe and Boateng, 2009). By enabling rapid access to financial capital and transactions, ICTs have the potential not only to strengthen local livelihoods but also to improve the speed and efficiency with which local communities are able to cope with and adapt to climate change-related hazards and events.

ICTs can also speed up access to information. This is particularly important when an acute climate-related shock such as landslide or flood occurs. Mobile-based telecommunications networks allow rapid communication of information, thus improving the speed of disaster warning, response and recovery (Aziz et al., 2009; Samarajiva & Waidyanatha, 2009)

- **ICTs and Flexibility**

Within vulnerable livelihood systems, ICTs can help identify and undertake different actions to better withstand the effect of climate change-related events, and utilise the opportunities that may arise from change. Identification of diverse action possibilities arises from the sharing of knowledge – something that ICTs are particularly good at – by enhancing the social contacts that provide access to tacit knowledge; and by enhancing access to the explicit knowledge that is now held, for example, on web sites and e-learning systems worldwide. Access to information can also promote flexibility through identification of alternative possibilities, such as information about different income-generating opportunities including information on demand and prices at different markets.

The multi-functionality of ICTs themselves can also be argued to introduce greater flexibility into the livelihood systems of which they become a part and, perhaps, to encourage flexibility by embodying it as an inscribed value. That inherent quality of ICTs may enable greater flexibility of action where ICTs are part of the action processes within a livelihood system, as they increasingly are in relation to not just communication but also transactional processes such as finance, banking, education, and health. Where ICTs form part of a livelihood, the technology's flexibility can enable livelihood flexibility; for example, the ability to diversify relatively easily from one form of ICT activity (e.g. data entry) to another (e.g. digital photography) (e.g. Heeks and Arun, 2010).

- **ICTs and Self-Organisation**

ICTs can enable access to the set of resources that livelihood systems require to effectively self-organise in the event of climate change-related shocks or disturbances. As argued through examples related to the sub-properties of scale, redundancy, rapidity and flexibility, in addition to access to relevant data, ICTs can facilitate access to assets such as physical and economic capital (overt resources), as well as to other embedded social resources such as trust, motivation, knowledge and power (e.g. through social networks, local empowerment and inclusiveness, or the active engagement of local actors in participatory processes).

At the same time, ICTs can play a valuable role in the coordination of efforts between stakeholders, facilitating the different stages of cognition, communication and co-operation that, according to Fuchs (2004), play a role in self-organisation processes at a systemic level. More specifically, ICTs provide access to relevant data and information that is first processed at an individual level (cognition), then facilitate communication and interaction between a wide range of stakeholders, and ultimately enable co-operation, which can translate into adaptive actions being implemented with the participation of a wide range of stakeholders.

Exemplifying this multi-stage influence in self-organisation, in the Philippines SMS is being used for citizen engagement campaigns that seek to reduce air pollution while encouraging citizen participation (Dongtotsang and Sagun, 2006), suggesting the potential of these tools to foster environmental action and raise policy awareness. In cases such as this, ICTs can play a role from accessing relevant data and awareness on environmental issues at the individual level, to enabling communication and interaction using mobile telephony, to fostering co-operation with wider networks of stakeholders towards action, through social networking tools and the strengthening of participatory processes.

At the same time, studies in the field indicate that localisation and decentralisation play a key role in the success of self-organisation and adaptation strategies. One example would be the rural weather stations in Kenya, Zimbabwe and Uganda that help decentralise the analysis of climate information and design strategies at the local level (Kalas and Finlay, 2009). Contributing to communication and co-operation, ICTs can facilitate the implementation of participatory processes of natural resource management, as well as promote more inclusive processes of policy formulation and enforcement. They can foster better reporting mechanisms on the status of environmental initiatives through the engagement of individuals and civil-society organisations in monitoring. This includes enabling communities to monitor changes in local climatic conditions such as the number of frost days, the length of growing seasons or the changes in rainfall patterns, which can ultimately help strengthen local adaptive actions in sectors such as agriculture and forestry.

Social networks can be fundamental in self-organisation, including community subsistence in times of scarcity and drastic climatic events, as well as for monitoring environmental changes, and identifying new mechanisms to reduce risk and uncertainty. They play an important role in peer-to-peer knowledge sharing and dissemination, which in remote villages could be key in the (self) organisation of effective early warning systems and coping strategies.

In turn, within decision-making processes that enable self-organised actions, ICTs can facilitate the assessment of options and the analysis of potential trade-offs that are involved in the adoption of particular courses of action (e.g. via climate change modelling, prediction and spatial planning applications). The availability of ICT infrastructure can also support the role of other system components for resilience and adaptation. ICT applications such as geographic information systems can reduce the uncertainty that characterises climate change scenarios, providing valuable input to inform decisions on issues such as land-use planning, environmental resource analysis, demographic analysis, and infrastructure planning, key in both rural and urban contexts that are vulnerable to the effects of climate change.

As Heeks and Leon (2009) identify in their exploration of information chains in remote areas, psycho-social factors are an important part of the ability of systems to independently self-organise. Where ICTs can provide such factors – an increase in hope, in motivation, or in perceive self-efficacy – they will increase system self-organisation; reducing dependency on external sources. There are already some signs that ICTs can do this (e.g. Pal et al., 2007). The information chain model also identifies a critical component in the analysis of ICTs' role within self-organisation as the capacity (knowledge) of the user to judge the accuracy, completeness and relevance of data in order to assess it and ultimately act on it. This knowledge is in turn linked to the potential of ICTs to foster learning, as explained next.

- **ICTs and Learning**

Experiences from the field suggest the role of ICT-enabled skills and access to knowledge in enhancing the capacities of local actors and empowering marginalised groups (Labelle et al., 2008). We may conceive this role in relation to the cycle of experiential learning that, according to Kolb (1984), involves four elements: concrete experience, reflective observation, abstract conceptualisation and active experimentation. ICTs can particularly facilitate reflection and thinking – the key constituents of systemic feedback – but will impact the whole cycle.

For example, Web 2.0 and new media applications can turn this into a collective learning process (GTZ, 2008). By sharing observations and reflections through ICT tools (e.g. blogs, wikis, environmental observations and monitoring), users foster new ways of assimilating or translating information (e.g. changes in their natural environment), which can be shared through wider networks, and then influence action (e.g. encourage testing or experimentation), enabling new experiences/practices to take place. This generation of new and broader learning cycles will in turn strengthen systemic resilience.

This potential is reflected in initiatives such as the DEAL project in India, which aims to create a digital knowledge base by involving various actors in the content creation process, while making this knowledge accessible to farmers and other agricultural practitioners (DEAL, 2010). Based on the use of Web 2.0 tools, it provides a way for the farmers to explain their problems and establish a dialogue with scientists and researchers through an audio blog. The blog captures tacit, experiential knowledge from the farmers through uploaded audio files, while ensuring collaborative practices for reflection, knowledge generation and reuse through action (GTZ, 2008). In this way, ICTs can expose the collective experience of rural farmers and existent traditional knowledge, which plays a critical role in the success of adaptation, while fostering new learning processes on issues that are key for the sustainability of local livelihoods amidst a changing climate.

e-Resilience

A systemic analysis of resilience allows us to broaden the understanding of adaptation beyond the vulnerability inherent to developing livelihoods, in order to understand that adaptive capacities are also built on resilience sub-properties that can be strengthened by ICTs, thus contributing to the achievement of development outcomes.

The analysis undertaken above of ICTs' potential contribution to resilience sub-properties is not easy at present. It was based on a retrospective re-analysis of ICT4D case studies; case studies that as yet rarely talk about climate change adaptation, let alone resilience. Nonetheless, the preceding material suggests we can analyse the contribution of ICTs to adaptive processes in two ways. First, through their dynamic links with resources (asset-base and enablers), with institutions (dis-abilities/constraints) and structures (at micro, meso and macro levels) to create capabilities (abilities or disabilities to act). Second, through their enhancement of resilience sub-properties.

While this document has adopted the latter approach, the summary framework shown in Figure 5 illustrates both possible routes to understanding ICTs' role. It also reflects the fact that ICTs are a component of livelihood determinants (i.e. part of the asset base of livelihood systems, while also inscribing institutional values and helping to structure processes), but that they should be specifically highlighted in order to emphasize the focus of this study.

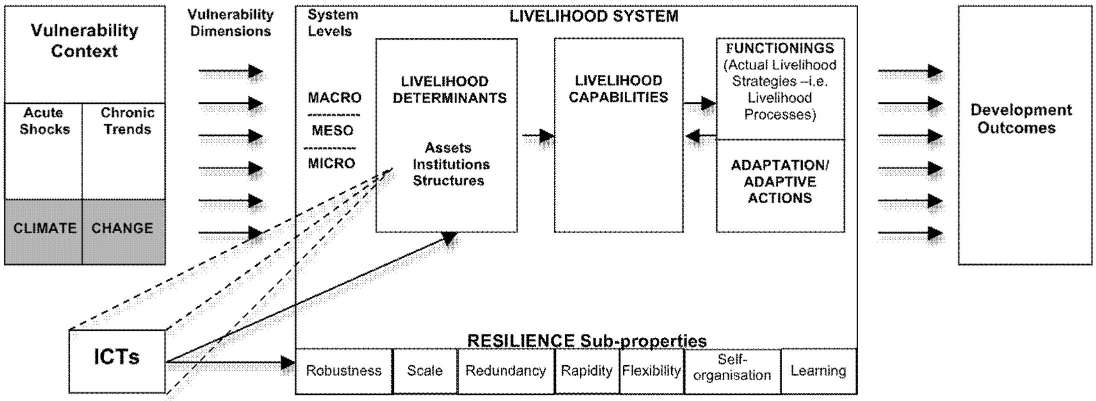

Figure 5: e-Resilience Framework

Conceiving ICTs' contribution to climate change adaptation in terms of their effect on resilience sub-properties, the concept of '*e-resilience*' emerges. e-Resilience can be defined as a property of livelihood systems by which ICTs interact with a set of resilience sub-properties, enabling the system to adapt to the effects of climate change. e-Resilience specifically and this model more generally aim to facilitate the identification, integration and analysis of ICTs' potential contribution to climate change adaptation, as part of the complex set of linkages and interactions that exist within the context of vulnerabilities faced by developing countries.

Having identified the main areas of potential in the use of ICTs vis-à-vis resilience, and in order to have a clearer understanding of their role within adaptive processes, the following section will address their role in adaptive actions and the achievement of development outcomes, which constitutes the last stage (right-hand side) of the e-Resilience Framework.

3.2. ICTs and Adaptive Actions

The systemic perspective reflected in this analysis suggests that ICTs can be conceived as contributing to adaptive processes not only through their influence on resilience sub-properties, but also through their dynamic linkages with other system components, namely assets, institutions, structures and capabilities, ultimately contributing towards adaptive functionings (unless not converted into functionings due to constraints).

In the previous sections, the focus was on ICTs and resilience (albeit incorporating discussion of technology's role vis-à-vis system components). However, whether discussing system properties or components, these are essentially precursors. What practitioners, at least, are more interested in is the downstream impact of ICTs on adaptation processes. We can assess this by considering the potential impact of ICTs in two different ways: first, with respect to livelihood systems at the macro/national level (which is key to adaptive actions); and second, their impact on the vulnerabilities identified at the beginning of this study (i.e. livelihoods and finance, socio-political conditions, health, habitat and migrations, food security and water supply), which constitute areas in which the likely impact of climate change is considered to be highest, and which play a critical role in the capacity of the system to achieve development outcomes.

ICTs' potential contribution to climate change adaptation either in these ways or if thought of in terms of e-resilience cannot, however, be taken for granted. The analysis will therefore conclude by discussing some of the challenges associated with the use of ICTs in adaptation processes in practice.

3.2a. The Impact of ICTs on National-Level Adaptation

While livelihood systems may most readily be conceived at household or at community level, as discussed above, those systems are themselves held within a larger system which both contributes and draws assets, institutions and structures. That larger system must therefore be a subject of enquiry if we are to build a more complete picture of ICTs and climate change adaptation. We set the scope of that system as the global but – given the critical role of the nation-state and of national-level actors in setting and implementing relevant policies in the field of ICTs, climate change, agriculture, urban development, etc – we choose instead to focus at the level of the nation.

In order to conduct this analysis, three main areas of potential ICT impact at the national level have been identified, namely (i) policy on the ICT infrastructure and applications that are the foundation for e-resilience and e-adaptation, (ii) ICT-enabled formation of new structures (typically network-based) that can play a role in adaptation, and (iii) ICTs' role in the cycle of national-level data gathering, analysis, and decision-making that then leads into actions and policies which have an effect on climate change resilience and adaptability. Each of them will be addressed through illustrative examples of ICTs' potential.

- **Encouraging ICT Infrastructure and Climate Change-Related Use and Application of ICTs**

  The telecommunications sector can play a key role in climate change adaptation through the provision of technical and financial support, as well as the establishment of multi-sectoral alliances to implement ICT-related solutions in the field (Labelle et al., 2008). At the policy level, developing country institutions can support the provision of broader access and connectivity in rural areas, particularly in marginalized regions affected by climate change-related hazards or trends. Multi-sectoral alliances providing adequate infrastructure can be pivotal in the implementation of effective early-warning systems (ITU, 2007), as well as for the provision of incentives for ICT entrepreneurs to play an active role in the diversification of local livelihoods, thus reducing dependence on natural resources and vulnerability to the impact of climatic events.

  Faced by the daunting risks posed by climate change to agriculture and food security, developing country structures and institutions could play an important role through the provision of national ICT-based programmes that target small farmers and producers, aimed at strengthening local knowledge on crop diversification and production under variable conditions (e.g. agricultural models and techniques to reduce climate risks, on-farm product management and seed management). ICTs can also strengthen the internal capacity of nation-wide organisations to serve as effective facilitators of local adaptive actions (FAO, 2003).

- **ICT-Enabled National-Level Structures for Climate Change Adaptation**

  Despite the recognised value of self-organisation as a foundation for resilience, adaptive capacity is also increased by integrating communities into higher-level structures that can enable flows of catalytic assets and institutional values. ICTs can help this by, for example, fostering or strengthening social and socio-political networks. For example, the technology can help build multi-level, hybrid governance systems – based on flexible organisational topologies including social networks – to combine both external inputs and participatory contributions in order to address climate change uncertainty through more effective natural resource management (Folke et al., 2005). One example would be AMARC (World Association of Community Radio Broadcasters) in Latin America, which has used ICTs to share strategies developed by local communities to address the effects of climate change in food security (Kalas and Finlay, 2009).

  One can view the enabled flows largely at the meso-level: helping local communities to shape their local actions on the basis of knowledge developed with peers or from institutions of national expertise. But upward flows can be equally important, giving voice to the climate change-related experiences of individual communities, and ensuring these are heard and melded into the formation of appropriate national policies that will foster adaptation in the long term.

At the same time, ICTs can facilitate coordinated adaptational action by creating and supporting policy networks or policy communities between different national-level stakeholders, and around specific climate-related issues. The technology typically strengthens information exchange between the scientific community and policy makers, as well as with civil society organisations working on environmental issues in the field.

- **ICT-Enabled National-Level Climate Change Adaptation Data-Gathering, Analysis, Decision-Making and Action**

  ICTs can strengthen the capacity of national organisations working on climate change by enabling better-informed, and more participative decision-making processes. The use of ICT tools can help Ministries and pan-governmental agencies to coordinate actions and implement national-level campaigns, and facilitate the provision of locally appropriate mechanisms of prevention and response. ALERTA, for example, a disease surveillance application implemented in Perú, enables health professionals in rural areas to submit reports to health authorities via telephone or Web-based applications, as well as to receive information and assistance through voice mail, thus enabling the community to respond faster to short-term health-related emergencies, and also helping to track some of the longer-term changes in disease prevalence with which climate change is being associated (InfoDev, 2003).

  ICT applications (e.g. geographic information systems) form an increasingly-embedded role in gathering data about urban environments, and in assisting urban planning and development decisions by government agencies. This includes data of specific relevance to climate change vulnerabilities such as patterns of current and likely future water supply (eoPortal, 2010). By drawing information from a variety of stakeholders, from communities to meteorological departments, ICTs help these agencies not merely understand the present situation but model future – including climate-affected – scenarios, leading to decision-making on measures to improve climate resilience such as sea walls, reservoirs, or large-scale irrigation systems.

  Similarly, and based on the use of applications that allow advanced mapping and visualisation, piloting and modelling, as well as participatory approaches that reflect local needs, ICTs could support the design of new policies and regulations on human settlements, as well as rules on building standards implementation, contributing to reduce existing vulnerabilities in this area. The role of these tools can also support advocacy from organisations (e.g. to secure rights of access to water supplies for small-scale farmers and ensure water availability), among other adaptive actions.

  Alongside policies that aim to have a direct effect on climate change vulnerabilities, adaptation will also require action on more contextual, institutional shapers such as access to markets or fiscal policy. Solid information systems are a key pre-condition for policies such as effective tax administration or incentive structures designed to encourage environmental practices. This suggests the existence of linkages between e-government strategies and the effective promotion of environmental and adaptive practices at the national level.

3.2b. The Impact of 'e-Adaptation' on Climate Change Vulnerability Dimensions

Having identified key areas of potential ICT adaptive impact at the national level, a systemic analysis of their role also requires exploration of their contribution in delivery of adaptive actions that directly address (i.e. reduce) climate change vulnerability dimensions in developing countries.

- **Livelihoods and Finance**

  Emerging experiences from the field suggest the potential of ICTs to support local livelihoods (i.e. productive processes and local livelihood activities) in regions vulnerable to climate change. One way they do this is by providing information on the climate-related aspects of livelihoods. An example would be providing local farmers with information on new varieties of crops, crop diseases, and more effective production processes, fostering productivity and facilitating adaptation processes of local livelihoods (Scott et al., 2004). In Uganda, for instance, a country that is highly susceptible to climatic variations and shocks (Magrath, 2008), iPods and podcasts are being used in marginalized communities to access creatively-packaged content relevant to their livelihoods. Most content to date is generic agricultural improvement information, but it can readily incorporate climate-relevant content such as changing seed/crop choices, and changes in agricultural practices (ALIN, 2010).

  The way in which ICTs can help bring finance into communities affected by climate change has been noted above. As yet, few studies, have looked specifically at the financing of climate change adaptations, and the way in which ICTs can help. Similarly, ICTs can help build more-resilient livelihoods: for instance, providing more accurate price and demand information that enables sales with higher profits or to a wider range of markets (Jensen, 2007); or by creating ICT-based micro-enterprises that may provide additional and/or more robust income streams (e.g. Heeks and Arun, 2010). Again, though, there is little evidence yet viewing this from a climate change-specific perspective.

- **Socio-Political Conditions**

  The broader socio-political conditions within which local community adaptation sits has been discussed already in the previous section. There we saw that ICTs can help enable new structures within the socio-political environment which can foster inclusiveness and participation in the design and implementation of adaptation processes, thus reducing the potential for the emergence of social tensions or instability. In the Caribbean, a study of women organic farmers found these tools strengthened networking, cooperation and advocacy among the farmers, improving their resilience in the face of climate change-related changes (Tandon, 2009).

- **Health**

  The ALERTA example given previously showed how ICTs can help monitor alterations in patterns of disease that are predicted to arise as a result of climate change. ICTs can also drive new health information back into communities, using technologies that are accessible in the field (e.g. mobile phones, community radio) to provide climate literacy on key health topics, to improve the local response to shifts in vector-borne (e.g. malaria and dengue) and water-borne diseases, heat, declining food security and decreased availability of potable water (IISD, 2005); as well as to internalise other health-related adjustments that may become necessary within local communities (Kalas and Finlay, 2009).

- **Habitat and Migration**

  ICT applications can help alleviate the pressures posed by migration and redistributions of people triggered by sea-level rise, drought, desertification or extensive flooding, among other potential impacts of climate change. As noted already, applications such as remote sensing and GIS can facilitate urban planning, thus improving the habitat conditions of displaced populations that are forced to settle in deprived and/or over-populated areas. At the same time, ICTs can enable communication between family members separated or disrupted due to climate events, thus ameliorating the psychological stress these types of migrations can cause among vulnerable populations (Dempsey, 2010).

- **Food Security**

  Crop yields affected by drought or flooding, or by an overall decrease in agricultural productivity due to climate variability can create food shortages, triggering malnutrition and related problems within vulnerable populations. Within such contexts, ICTs can play an important role in support of agricultural extension services, broadening the reach of such programmes particularly in rural, marginalised area of developing regions. In many ways, this overlaps with the agricultural livelihoods role described earlier. For tribal farmers of North-East India, for instance, where inadequate dissemination of farm information and technologies have led to low productivity and food insecurity, ICTs (including radio and television) are being used to disseminate information on pest and disease management information, among others (Saravanan, 2008; e-Arik, 2010). However, ICTs will have a food security role beyond just production; providing information for the planning and operation of food storage, distribution, and consumption.

- **Water Supply**

  ICTs can help improve water resource management techniques, monitoring of water resources and awareness raising at the community level. In Peru, the Centre for Social Studies (CEPES, 2010) has implemented a project based on a small network of telecentres in the Huaral Valley, a remote region where droughts and water scarcity have hindered agricultural production and local livelihoods. With the support of ICTs, an agrarian information system has been put in place that includes software to improve the distribution of water (APC, 2007). As with other vulnerabilities, though, most cases to date relate to the vulnerability generally rather than identifying ICTs' role in specifically assisting water supply management issues that are arising as a result of climate change.

As just noted, the examples reported here are almost all drawn from the ICT4D literature rather than the 'ICT4CCA' (climate change adaptation) literature; not least because the latter hardly exists. Likewise, although we have drawn out the vulnerability-specific aspects of each case, in practice, ICT projects often overlap several vulnerabilities. A single rural information system, for example, might well cover livelihoods, food security, health and water.

On the one hand, this reinforces the need for a rapid expansion of climate change-specific analysis of ICT projects. On the other, though, it indicates the value of taking a holistic perspective towards ICTs and climate change adaptation: one that goes beyond short-term solutions for individual climate change shocks and symptoms; and which addresses the underlying causes of vulnerability and exposure to longer-term trends and uncertainties. That, of course, is exactly what the e-Resilience Framework seeks to do.

One common aspect that could be drawn from the vulnerability areas identified – and also reflected in the e-Resilience Framework – is the potential of ICTs to help bridge and converge the priorities of actors at the micro, meso and macro levels, as well as to broaden access to assets, capabilities, and supporting organisations and institutions towards the enactment of adaptive functionings. ICTs could also contribute towards the implementation of more inclusive, participatory processes that reflect the needs and power relations that exist within local contexts.

Solutions that are disconnected from the priorities and characteristics of the local social fabric will not have the long-lasting effects that are necessary for future adaptation and the achievement of development outcomes. Within development contexts, the potential of ICTs could complement integrated approaches that include not only monitoring and early warning, but also broader measures to reduce vulnerability in areas such as livelihoods diversification, socio-political conditions, food security, water supply, habitat and migrations, among others. Put another way, ICTs alone do not represent the solution to climate change adaptation; they must be an integrated part of a holistic approach.

3.2c. Challenges of Using ICTs to Support Climate Change Adaptation

The analysis conducted thus far indicates the existence of positive, valuable linkages between ICTs and the resilience of systems vulnerable to climate change. However, developing countries are characterised by the interplay of a complex set of stressors and inequalities including socio-political contexts where power relations and potential divisions are based on factors such as gender and ethnicity, and where the implementation of innovative ICT approaches must be assessed carefully (Duncombe, 2006). Thus, analysis of ICTs' role must also acknowledge their potential to impact negatively on livelihood systems, possibly reducing their resilience and adaptive capacity to climate-related hazards, trends and variability.

Perhaps most obviously, ICTs can act as a resource sink, drawing away valuable assets from within any system, such as a community. ICTs cost money and will typically divert expenditure from other uses (e.g. Diga, 2007). Less tangibly, ICTs might divert time and motivation, thus undermining adaptive capacities and actions. Even where they do deliver new assets, those assets are not necessarily usable. For example, ICTs may provide unreliable information or information that does not correspond to the local realities or that is made available in a language that is inaccessible for the local actors. This can not only undermine the potential of these tools within adaptive processes, but also contribute more generally to an increase in uncertainty or even encourage mistaken and maladaptive actions.

Adaptation as a response to a particular climate-related disturbance can undermine systemic resilience by making the community more vulnerable to other shocks, or by constraining generic sub-properties such as flexibility (Nelson et al., 2007). If used within adaptive actions that do not integrate or acknowledge these factors, ICTs could contribute to overall maladaptation; for example, by focusing attention and resources on one initiative – say a disaster early warning information system – and thus drawing those assets away from application to other initiatives.

At the same time, it is necessary to recognise that livelihood systems in developing contexts involve complex power relations and inequities which determine access (e.g. to assets and opportunities), and can turn the potential benefits of ICT interventions into situations where the power of more privileged groups is strengthened (e.g. those with greatest access to decision making), widening the gap with those that are most at risk. According to Pettengell (2010), "addressing existing conditions that cause vulnerability to climate change or limit adaptive capacity is a vital component of adaptation" (ibid, p. 29), those conditions including distributions of power.

For example, actions that do not acknowledge the specific vulnerabilities and role of women within adaptive processes face the risk of deepening existing gaps; say, in regards to ownership of land, rights to assets, or access to assets such as financial credit (ibid). ICTs might also facilitate the adaptation of individuals, but not necessarily that of broader groups. Applications that strengthen the livelihood options of a family or group do not necessarily have the same effect at community level, in some cases deepening the gap between the 'haves' and the 'have nots' within particular communities. If ICTs are used without considering the gender and other imbalances and power relationships within a given community, the use of these tools can reinforce existing inequalities, giving voice to the interests of certain groups that may not be the most vulnerable. Therefore, ICT solutions must acknowledge the role and contribution of power and inequality to adaptation processes, targeting them if effective and inclusive adaptation is to be achieved. These examples suggest that, within contexts characterised by poverty and inequality, the reduction of climate-related risks is not sufficient to indicate success. The analysis of ICTs' potential requires careful consideration of the underlying factors of vulnerability within developing environments, as well as the existing institutions and structures that characterise a given livelihood system.

4. Conclusions

Despite the fact that much remains to be explored in terms of the role and potential of ICTs within the climate change field, the analysis conducted here sheds light on key conceptual foundations that help better understand the complex linkages that exist within vulnerable livelihood systems, and that ultimately determine the role of digital technologies in achieving development outcomes amidst an uncertain climatic future.

The framework developed integrates the key concepts that mediate ICTs' role in climate change: vulnerability, adaptation and resilience, and development outcomes. Based on the foundations provided by the sustainable livelihoods approach, new institutionalism and the capabilities approach, the model constitutes a conceptual tool for the understanding of climate change resilience in vulnerable systems. It provides a basis to analyse how the dynamic interactions between components (e.g. asset-based, institutional and structural determinants of capabilities) and processes (adaptive functionings) that play a role in the achievement of adaptation and development, can be understood at macro, meso and micro levels.

The analysis conducted suggests that, in the event of climate change-related shocks or trends within a particular context, the capacity of the system (at the household, community or national level) to respond through adaptation can be understood either as a set of components or as a set of (sub-)properties, which interact to create the adaptive capacity of the system. Resilience, thus, emerges as an important property to consider in the analysis of livelihood systems that are subject to climate-related changes and uncertainty; a property that interacts with assets and other components to shape the trajectory of functioning and adaptation after any acute or chronic disturbance (Norris et al., 2008).

The systemic analysis of resilience allowed us to broaden the understanding of adaptation beyond the vulnerability inherent to developing livelihoods, in order to understand that adaptive capacities are also built on resilience sub-properties that can be strengthened by ICTs, thus contributing to the achievement of development outcomes.

Within these contexts, the concept of *e-resilience* is defined as a property of livelihood systems by which ICTs interact with a set of resilience sub-properties, enabling the system to adapt to the effects of climate change. Thus, e-resilience is suggested as an emerging area of study to understand how innovative ICT tools and approaches can strengthen the response of vulnerable systems to the challenges and uncertainty posed by climate change.

The value of this approach resides in its contribution to better understand the complex set of relations between livelihood system components, properties and processes, which in turn are characterised by the presence of multiple development stressors. It is expected that the model can serve as a tool to explore the potential and challenges of ICTs' role within processes of adaptation, while facilitating the identification of strategies that could contribute to the enhancement of adaptive capacities, and ultimately to the achievement of development outcomes in the face of long-term climatic uncertainty.

The analysis recognised that information has both an analytical and functional role within the livelihoods framework, and should be considered as part of a dynamic process of change rather than as a static resource (Duncombe, 2006). These attributes are particularly relevant considering the dynamism and unpredictability that characterise the climate change field. It also recognised that ICTs must be seen not simply as a tool for processing and communicating information, but also increasingly as a means to undertake digital transactions, and as a means of production for new ICT-based enterprise.

The study suggested the relevance of considering both short-term (e.g. hazards) and long-term (e.g. trends and variability) climate change impacts, as well as differentiating between short-term coping/rebound actions, and longer-term processes of adaptation that may involve system transformation. Related to this recognition, the development of the e-resilience framework indicates that the study of ICTs' potential in the climate change field requires the acknowledgment that dynamic ICT processes can be formal or informal, can fulfil both short-term (coping/rebound) and long term (adaptation/transformation) needs, and be actionable at different levels (micro/ meso/ macro), in addition to fostering interaction between structures and institutions, capabilities and functionings (ibid.). ICTs can, therefore, make a contribution to adaptation, something that can be considered directly under the heading of 'e-adaptation'.

Within this context, innovation and flexibility have proved to be key characteristics in building local resilience to changing conditions in the short, medium and long term (IISD, 2005). Innovation, thus, emerges as the ability of the system to do new things with existent determinants, and is therefore, closely related to flexibility as a resilience sub-property.

Carpenter et al. (2001) argue that the best way to cope with surprise is resilience. The development of the e-resilience framework suggests that ICTs have the potential to contribute towards adaptive capacities, helping vulnerable systems to change and adapt in the face of climate change disturbances and uncertainty. This perspective of resilience provides a valuable context for the analysis of systems' responses to climate change in developing countries, as well as for the identification of the potential and challenges associated with the use of ICTs within adaptive processes.

The analysis also suggests the possibility that, because of their emphasis on information models or development goals, projects in the field of ICT4D have been poor in addressing and building resilience. It is hoped that this study will stimulate greater research and discussion of the possibilities and potential of ICTs in climate change adaptation, particularly with respect to the challenges posed by climate change in developing regions.

Ultimately, the challenge for developing countries resides not only in their capacity to withstand and recover from climatic events, but mostly in their capacity to adjust, change and transform amidst slow changing trends and unpredictable variability; while facing a future where the only certainty is uncertainty itself, and within which, development outcomes will be determined, to a large extent, by their ability to foster 'development epiphanies' and innovate with the support of tools such as ICTs.

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