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The Impact of Digital Technology on Environmental Sustainability and Resilience: An Evidence Review

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THE IMPACT OF DIGITAL TECHNOLOGY ON ENVIRONMENTAL SUSTAINABILITY AND RESILIENCE: AN EVIDENCE REVIEW

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Abbreviations

BLDS	British Library for Development Studies
BRACED	Building Resilience and Adaptation to Climate Extremes and Disasters
CCA	climate change adaptation
CCA&DRR	climate change adaptation and disaster risk reduction
CCAFS	Climate Change Agriculture and Food Security
CDKN	Climate Development and Knowledge Network
CIAT	International Center for Tropical Agriculture
CIFOR	Centre for International Forestry Research
CNR	conservation and natural resource management
DFFS	digital farmer field school
DFID	Department for International Development
DRR / M	disaster risk reduction / management
ESR	environmental sustainability and resilience
EWS	early warning systems
FAO	Food and Agriculture Organization
FFS	farmer field school
FSA	food security and agriculture
GCM	global climate model
GIS	geographic information systems
GPS	global positioning system
ICT4D	Information Communications Technology for Development
IDS	Institute of Development Studies
INDC	Intended Nationally Determined Contribution
IS	information systems
LAPA	local adaptation plan of action
M&E	monitoring and evaluation
NAPA	national adaptation plan of action
NFC	near field communication
NGO	non-governmental organisation
OECD DAC	Organisation for Economic Co-operation and Development Development Assistance Committee
PDA	personal digital assistant
pGIS	participatory GIS
RCCC	Red Cross/Red Crescent Climate Centre
REDD+	Reducing Emissions from Deforestation and Forest Degradation
RICM	rice-integrated crop management
SCP	seasonal climate prediction
SDGs	Sustainable Development Goals
UNDESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Environment Programme
UNICEF	United Nations Children's Emergency Fund
UNISDR	United Nations International Strategy for Disaster Reduction
WARED	Warning and Rapid Estimation of Earthquake Damage
ZSL	Zoological Society of London

1 Introduction

1.1 Topical relevance and objective

Striving for 'environmental sustainability and resilience' (ESR) is postulated as a crucial, universal and global challenge of the twenty-first century. Today, this challenge has to be addressed in a world that is dynamic in its societal, economic and political constituents, heightened by increased interconnectedness resulting from globalisation. From a developing country perspective these issues need to be reconciled alongside developmental priorities, producing ongoing controversies and contradictions. This is further compounded by the fundamental matter of climate change (Leach *et al.* 2010).

Undeniably the multitude of dimensions interlinked to achieving ESR are inherently complex and dynamic, inter-related across geographies of scale, space and place. Hence recent academic literature depicts the necessity of a systems-based approach in effectively conceptualising the field in the future (Fiksel 2006). It is proposed that to account for the competing challenges and complexity, radical rethinking and innovation of approaches are required. This standpoint contrasts strongly with conventional development approaches, which predominantly focus on 'palliative care' (Boyd *et al.* 2008). One area from which relevant innovation stems is the digital sector.

As this is now firmly what many term the 'digital age' or even 'digital revolution', there has recently been increasing application of digital technologies in developing country contexts (World Bank 2016a). To date, this innovation has incorporated a spectrum of developmental initiatives, inclusive of those categorised under ESR headings. Inevitably, evidence on the impact of these innovations in practice is key in justifying resources, continuous learning and enabling effective progress. The latest World Development Report, *Digital Dividends*, explores impact from a development perspective focused largely on increased prosperity and inclusivity through economic growth, social dynamics and public service delivery in developing countries (World Bank 2016a). Similarly, there are examples such as the UK Department for International Development's (DFID) recent review exploring the impact of digital technologies across their own development programmes (Ranger *et al.* 2015). However, there appears to be relatively limited work to date collating and addressing the existing evaluative evidence specifically from the ESR viewpoint. The evidence that does currently exist on these areas seems to be primarily documented at the individual intervention level.

The objective of this report was, therefore, to contribute to this evolving field by exploring and synthesising existing documented evidence. Commonalities and disjoints of successes and failures were drawn from across the findings, to produce a stronger evidence base on the impact of digital innovation in ESR. Impacts were considered alongside the academic theorisations of innovation with particular reference to complexity. This aims to identify emerging themes and gaps to ultimately deduce research-informed policy and to practice relevant lessons moving forward.

1.2 Digital innovation – process, product, business models

The importance of digital innovation and ICTs in development has gained increasing recognition over recent years (World Bank 2016a). The topic is addressed in the United Nations' newly formed Sustainable Development Goals (SDGs), as a target under Goal 9.

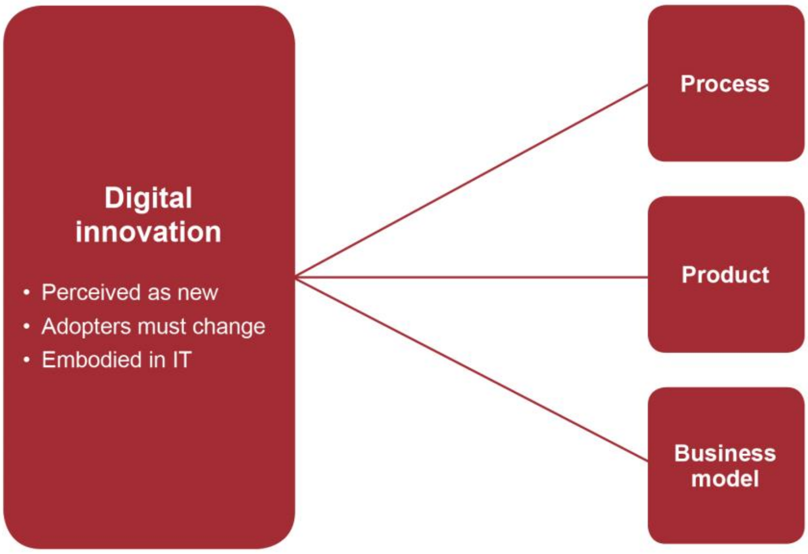
Figure 1.1 SDG Goal 9 and ICT-related target

Source: Adapted from United Nations (2016)

However, there is a critique that ICT is of sufficient importance to have been made a goal in and of itself, as opposed to being one of a total 169 targets. Other targets address digital innovation in more of an 'enabling role' (Unwin 2016). Aligned with this there is a presumption that effective use of digital innovation as a tool will be necessary to achieve many of the SDGs, of which several refer to ESR (Heeks 2015).

Hence, digital innovation has current and predicted impacts cutting across disciplines. This has several implications for research into its impact, one of which is the terminology used to define it in different disciplinary contexts. For the purpose of this report, digital innovation was interpreted in a broad manner so as to consider the range of innovative interventions and initiatives using digital technologies for ESR. Earlier academic discussion focused upon the distinction between process innovation as compared to product innovation (You *et al.* 2010; Utterback and Abernathy 1975). More recently, business innovation has gained recognition as a third innovation class (Teece 2010; Fichman *et al.* 2014). Today there is strong emphasis on the need to consider innovation across its different forms, alongside the resultant incremental to rapid impacts. To align with this, the review considered digital innovation as a 'product, process or business model that is perceived as new, requires some significant changes on the part of adopters and is embodied in or enabled by IT' (Fichman *et al.* 2014).

Figure 1.2 Forms of digital innovation



Source: Adapted from Fichman *et al.* (2014)

These statements are derived from a generic information systems prerogative. However, it was important to understand the roots of digital innovation to better comprehend its applications to ESR. This gave insight into underlying factors potentially shaping impact. It enabled consideration of whether the existing evidence on digital innovation for ESR reflected similar biases in focus as the 'parent' research. Exploring causation aims to inform further learning on impact for the ESR context.

Business model digital innovations as applied to ESR in the development context were of particular interest. In corporate settings users are also usually purchasers. However, in a typical development context, the funders of an intervention are often different individuals to the end users or beneficiaries. This leads to differential demands, with power typically lying with funders (Roche 1998). Yet these development scenario dynamics could change in interventions that leverage the surge in mobile phone ownership in developing countries; almost 70 per cent of those in the bottom fifth of the economic scale now own a mobile phone (World Bank 2016a). Personal ownership of the product puts more power into the hands of beneficiaries; this could potentially re-structure the typical donor–beneficiary relationship. Similarly, the number of internet users has more than tripled in the last ten years to approximately 3.2 billion people (World Bank 2016a), paving the way for new approaches to ESR. This also implies a new set of power dynamics shaping the 'business model', with the potential to influence impact of internet-based interventions. How these theorisations play out in practice with regard to ESR impacts was a key question in assessing existing evidence.

These advances equally raise important questions regarding access and inclusivity for the remaining 4 billion people not connected to the internet, or the almost 2 billion people without mobile phones (World Bank 2016a).

Differential access leads to what is termed the 'digital divide'. This concept first emerged in the mid-1990s as a technical problem, yet more recent debate has acknowledged its reflection of the wider issues in society (Light 2001). Most recently, the digital divide formed a major focus of the recent *World Development Report* 2016: *Digital Dividends* (World Bank 2016a). It is a theme that undeniably warrants careful consideration throughout this synthesis, with regard to the extent that the evidence on digital innovation in ESR addresses these issues.

Alongside the internet and mobile phones, a range of other digital innovations are used for ESR initiatives. Most are variants of ICT4D (Information and Communication Technologies for Development) solutions and hence apply existing digital tools for collecting, storing, analysing and sharing information to ESR (Pant and Heeks 2011). However, some ESR-specific digital technology has also been developed.

1.3 Defining environmental sustainability and resilience

ESR has thus far been referred to in its entirety and is open to interpretation, yet 'environmental sustainability' and 'resilience' represent two broad themes. Furthermore, interpretations of these areas are debated. Therefore, for clarity and accountability how these terms are interpreted in this review requires definition and justification (Geldof *et al.* 2011).

Environmental sustainability has been a contentious issue largely with regard to defining growth, limits, scale and substitutability, which can appear to conflict with developmental priorities (Goodland 1995). The concept has typically been based upon the natural capital concept and the output to input rule. This states that waste is maintained at assimilative capacities, harvest is within regenerative capacities of renewable resources and non-renewables are used at the rate at which renewable substitutes are developed (Goodland

and Daly 1996). The definition has since evolved to apply broader, systems-based thinking, situating environmental sustainability within the wider sustainability concept. One such example is the definition of sustainability in Leach *et al.*'s (2010) publication *Dynamic Sustainabilities: Technology, Environment and Social Justice*.

Sustainability

Sustainability is normatively defined as 'the capability of maintaining over indefinite periods of time specified qualities of human well-being, social equity and environmental integrity' (Leach *et al.* 2010: xiv).

Notably what constitutes 'specified qualities' of environmental integrity is still left open to the controversies of the aforementioned environmental sustainability definitions. However, the systems-based approach with regard to technology, environment and social justice subthemes is highly consistent with the framing of this review and so will form the interpretation henceforth.

Resilience, as per its application to the development context, forms the co-focus of this review. However, it is often deemed the latest development 'buzzword' and is conceptualised differently across development organisations (Weichselgartner and Kelman 2014). The United Nations International Strategy for Disaster Reduction (UNISDR) has formulated their definition based upon wide consideration of different international sources.

Resilience

The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.

(UNISDR 2009: 24)

This amalgamated definition has a specific objective to encourage common interpretation by the public, authorities and practitioners. It therefore makes it a fitting interpretation for this review, which aims to have practical and policy relevance. Furthermore, the definition references systems while also specifying community and societal levels. UNISDR (2009) expands on these concepts, by describing community resilience as the extent to which the system, community or society has the required resources to organise itself both before and during times of need. The definition therefore gives scope to consider the level at which the evidence on impacts of digital innovation on resilience is focused, with regard to prior discussion on the need for systems-based thinking. However, one aspect of resilience not explicitly captured by this definition, but potentially pertinent to this review's focus on innovation, is that resilience is 'dynamic' (Leach *et al.* 2010).

Having conceptualised resilience within the developmental context, it is important to return to the aforementioned controversies between environmental sustainability and development. This aims to ensure that the review maintains practical and topical relevance. In this regard conceptualisations of resilience that consider how the two themes can support each other were considered.

Recent work on resilience emphasises its transition from a descriptive concept to a normative agenda. Both challenges and opportunities are foreseen in ensuring that these aspects balance and support each other in the practical implementation of resilience initiatives. However, approaches to resilience have largely been based upon unchallenged assumptions of society, resulting in the use of technical-reductionist frameworks. This has meant that, in practice, resilience interventions often overlook societal complexities around knowledge, values and meaning (Weichselgartner and Kelman 2014). To the contrary, for resilience initiatives to be impactful they should be context-appropriate, socially robust and reliable. A 'critical resilience-thinking through locality and marginality' is advocated for, which highlights the need for integration of different types of knowledge across stakeholders to inform approaches. Crucially, this would better enable resilience initiatives to navigate the often overlooked dimensions of geographical differentiation, cultural heterogeneity and social plurality (Weichselgartner and Kelman 2014; Weichselgartner and Kasperson 2010). Furthermore, recognising that resilience traverses societal and environmental processes positions it to support, as opposed to detract from, sustainability. This also aligns with the earlier discussion, which situated environmental sustainability within a broader concept of sustainability that takes into account human wellbeing and social equity.

The use of these definitions to guide the review aims to ensure a strong overview of existing evidence on digital innovation's impact with regard to key topical aspects of ESR. Additionally, they encourage critical consideration of the manner in which evidence is currently framed. This is inclusive of the extent to which systems-based thinking is incorporated and what this may mean for future considerations.

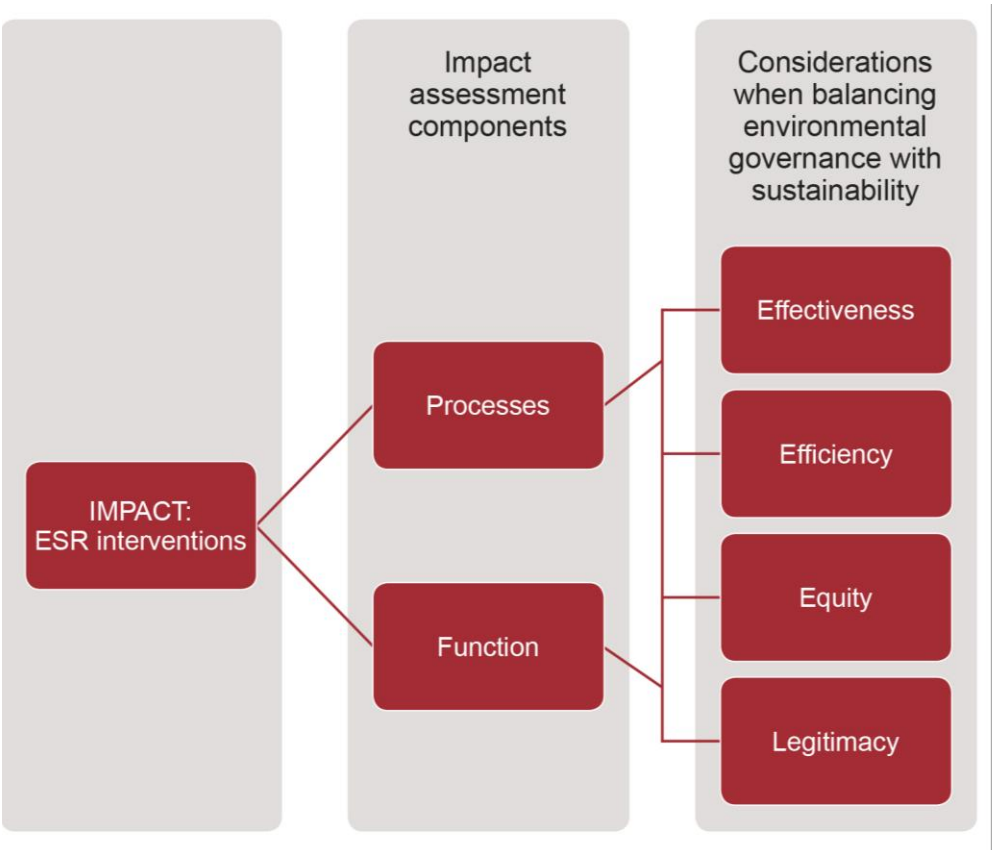
1.4 Contextualising impact

This report focuses on impact, yet with regard to ESR this is a further contested dimension, in part due to a lack of consensus on definitions, which in turn complicates agreement on evaluative procedures (Green 2013). While there are numerous options for evaluating levels of risk and vulnerability to specific stresses, capturing ESR with regard to multiple shocks and stresses is certainly more difficult (Nelson *et al.* 2007). Challenges arise as the ultimate impacts are typically interlinked to long-range future objectives and hence shifting baselines, making it difficult to reliably quantify them today (Bours *et al.* 2013).

From the policy perspective, in some circumstances the future conditions will be presupposed, thus enabling value assessment of the actions identified for a particular outcome. This is, however, a reductionist approach, which moves focus away from long-term system viability. An alternative option would be to quantify components such as stability, self-organisation and learning. However, as was shown in research by Carpenter *et al.* (2001), measuring stability of social-ecological systems in terms of their ability to absorb disturbances, requires very precise definitions of both stability and disturbances. This high level of specificity then raises doubts about a potential wider applicability of this approach (Nelson *et al.* 2007).

Others suggest that measuring the impact of ESR initiatives should explore processes as opposed to results, and function as opposed to structure (Carlsson and Berkes 2005). This perspective aligns with the general principles of environmental governance, which are widely recognised (Lemos and Agrawal 2006). These principles balance the impacts of activities with broader sustainability, considering their effectiveness, efficiency, equity and legitimacy (Adger *et al.* 2003), also fitting with the report objectives. Consequently, as a result of the scope limitations of this report, process and function provide the main focus when discussing impact, although any evidence found demonstrating impact outside these realms was also acknowledged. Figure 1.3 summarises these concepts.

Figure 1.3 Measuring impact of ESR initiatives



Source: Author's own, compiled from Carlsson and Berkes (2005), Lemos and Agrawal (2006) and Adger *et al.* (2003)

Literature on digital innovation in development, unfortunately, does not offer much additional indication on clear ways to quantify impact. For example, Geldof *et al.* (2011) note that a major weakness of numerous ICT4D interventions has been the lack of rigorous monitoring and evaluation research. While some progress has been made, evaluations regarding ESR initiatives are still limited and hence it seems logical to turn to the generic literature on digital innovation, which can then be applied to the evidence found in the context of this report. This aligns well with the above proposed focus on the function and process of ESR initiatives, as generic digital innovation literature on impact is typically framed towards a process and function rhetoric. For example, Fichman *et al.* (2014) define impact as the fourth and final stage of a digital innovation progression, detailed in Figure 1.4.

Figure 1.4 Digital innovation progression

Stage	Explanation
Discovery	In this stage, new ideas are discovered for potential development into a process, product, or business model innovation. Key activities in this stage include invention, which means the creation of something new through a firm's own creative process, or selection, which means finding and evaluating an innovative technology in the external environment to potentially develop or adopt. Product and business model innovators tend to actively engage in both invention and selection (because innovations are often based on existing ideas that have yet to be developed), whereas organisational innovators tend more towards selection rather than invention, due to the rise of commercialised technology solutions such as software packages.
Development	In this stage, an idea for a core technology is developed into a usable innovation. For product and business model innovations, this involves developing and refining the core technology plus an activity we call packaging. Packaging means surrounding the core technology with complementary products and services that together form a solution that can be effectively used for a given purpose by a target adopter. For process innovations, activity in this stage involves a task we call configuring, which means deciding which technology features will be used, whether they will be used as is or with adaptations, how the technology will be integrated with other technologies the organisation already has in place, how related organisational elements (e.g., structures, processes) will be changed, and how the organisation will absorb and make use of the technology.
Diffusion	In this stage, an innovation diffuses or spreads across a population of potential users. From the perspective of product and business model innovators, the central activity in this stage is deployment, by which we mean marshalling the resources necessary to persuade and enable a population of firms or individuals to adopt and use the innovation. From the perspective of organisational innovators, deployment is also a relevant idea, except the relevant population is composed of people and units within the firm. When deployment goes well, the result is assimilation, which happens when individuals and other units absorb the innovation into their daily routines and the work life of the firm.
Impact	In this stage, the focus is on the effects (intended and unintended) that digital innovations, once diffused, have on individuals, organisations, markets and society. Within organisations, digital innovation can positively impact the cost side (via improved efficiency) and the revenue side (by enabling differentiated products and business models). Key activities in this stage include value appropriation and transformation. For product and business model innovators, appropriation involves such tasks as managing intellectual property and the ecosystem of complementary products and services so that profits are protected from suppliers, customers, and imitators. For organisational innovators, value appropriation involves continuously transforming the technology and organisation to take advantage of the new opportunities brought about by the innovation. Transformations can also happen at the market and societal levels.

Source: Fichman *et al.* (2014)

The key messages on the impact of digital innovation derived from the definition from Fichman *et al.* (2014) are summarised below:

Focus

- On the intended and unintended effects that digital innovations, once diffused, have on individuals, organisations, markets and society

Organisations

- Digital innovation can positively impact the cost side: via improved efficiency
- Digital innovation can positively impact the revenue side: by enabling differentiated products and business models
- Key activities: value appropriation and transformation

For product and business model innovators, appropriation involves

- Managing intellectual property
- Managing the ecosystem of complementary products and services
  - So that profits are protected from suppliers, customers and imitators

For organisational innovators, value appropriation involves

- Continuously transforming the technology and organisation to take advantage of the new opportunities brought about by the innovation

Market and societal levels

- Transformation of technology can also happen here

Source: Fichman *et al.* (2014)

Despite the evidently corporate nature of this definition, the ideas are applicable to exploring the impact of digital innovation for ESR initiatives through process and function, alongside the principles of governance. An awareness of these broader concepts is useful in collating and assessing the relevant literature, to quantify what types of evidence exist and to critically discuss its framing.

Returning to previous discussion, Fichman *et al.* (2014) emphasise that, to date, the literature has focused too much upon ‘process’ and too little upon the other two innovation forms, ‘product’ and ‘business model’. It might appear that the focus on ‘process and function’ for measuring impact contradicts Fichman *et al.*’s (2014) subsequent demand for a balanced research focus among the three innovation types and the corresponding interpretation of digital innovation selected for this report. However, this is not the case. The evidence will be collated with regard to digital innovation in its three forms and how it impacts the ‘process and function’ aspect of implementing initiatives for ESR. Of course this will be dictated by what evidence currently exists.

2 Methodology

2.1 Thematic areas and search methodology

Having stated objectives and motivations, and highlighted the theoretical background of the key areas, a search strategy for identifying relevant evidence was formulated. While this is an evidence synthesis and not a systematic review, it aimed to draw upon the key principles of rigour, consistency and transparency in collating, assessing and synthesising the evidence base as outlined in the systematic review protocol prepared by Geldof *et al.* (2011) for DFID. Furthermore, this protocol had a digital innovation focus reviewing the key lessons of ICT4D partnerships for poverty reduction.

2.1.1 Search terms and ESR themes

An initial scoping of the evidence base was used to determine key search terms.

Digital innovation terms: Including digital innovation; ICT; ICT4D; mobile phones; GIS; tablets; big data; digital tools; climate tools; and various other permutations.

Environmental sustainability and resilience terms: Due to the vast nature of these topics, themes were developed as to where digital technology is pertinent. The initial scoping study identified three key themes under ESR in which digital innovation was evident at some level:

- Conservation and natural resource management (CNR)
- Food security and agriculture (FSA)
- Climate change adaptation and disaster risk reduction (CCA&DRR)

Energy was also considered as a potential stand-alone theme, with particular regard to digitally supported initiatives enabling energy access for the poor. The impacts of digital technologies on non-renewable and renewable energy sources were explored, as well as the resulting environmental impacts. However, these areas cut across the above themes when linking energy to ESR. Access to energy and new energy sources contribute to resilience under CCA, and the environmental impacts of energy relate to conservation and natural resource management. Energy and digital innovation was therefore considered in this manner.

2.1.2 Search sources

The review was informed by targeted searches of key sources, as outlined below:

Electronic databases and library catalogues: SCOPUS, BLDS, Web of knowledge, Web of Science, Stockholm Environment Institute, Stockholm Resilience Institute, Resilience Alliance.

Search engines: Google Scholar.

Relevant academic journals: Top journals for each of the four themes and digital innovation were identified, with an aim to represent the multidisciplinary nature of the fields through incorporating societal, scientific, technical and cross-disciplinary journals. Where possible ranking tables were used such as the ‘ICT4D journal impact table’ and the ‘development studies journal ranking table’, as well as the Science Watch rankings of climate change journals to identify the most influential ones.

Websites of relevant organisations: IDS, ODI, DFID R4D, BRACED, KCL – CIRRR, CDKN, IIED, CCAFS, CGIAR, UNFCCC, IPCC, UNDP, UNEP, UNISDR, UNICEF, Oxfam, CARE, Plan International, Save the Children, Nesta, Rockefeller Foundation, International Center for Tropical Agriculture.

Participatory input: Further advice was sought from experts across the relevant areas, complemented with discussions with IDS academics, and participation in webinars.

2.1.3 Inclusion criteria

The following criteria was considered for inclusion of the sources.

Impact: Due to limitations in the extent of current evaluative research on digital technologies for development and ESR (Geldof *et al.* 2011; Eakin *et al.* 2015), any relevant and reliable documentation of key contextual interest that included an assessment on the impact of digital innovation was reviewed.

Language: Only evidence published in the English language was considered.

Low- and middle-income countries: Research focused on low- and middle income countries, as defined by the World Bank (2016b). Geographic coverage and origin of the retrieved material was noted.

Publication date: Studies published in the last 15 years were considered, prioritising the most recent.

Type of research, material and author: Qualitative, quantitative and mixed research were all considered, incorporating empirical studies, case studies, grey literature and accounts. Authors included academics from different disciplinary backgrounds, policymakers and practitioners.

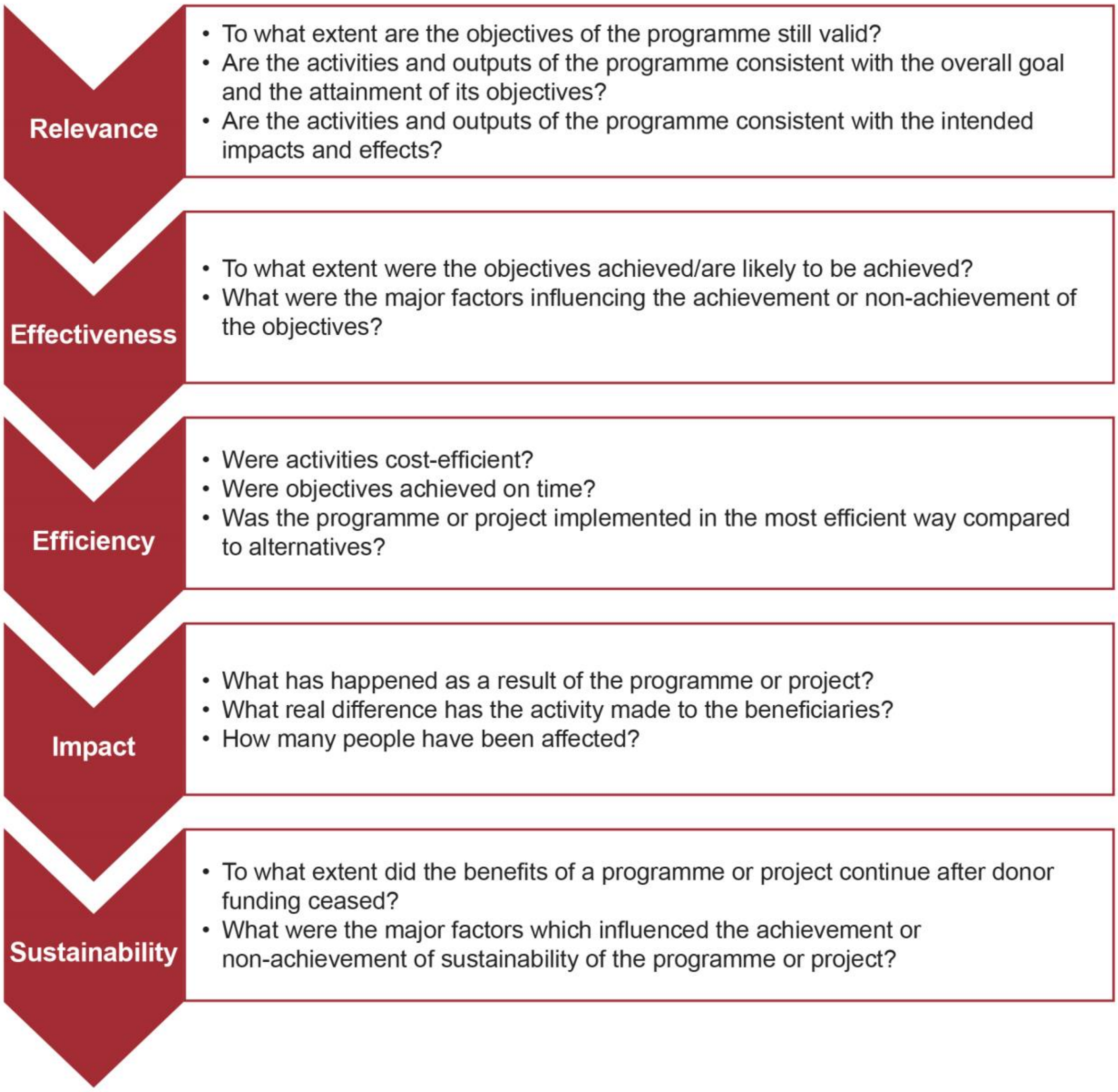
Relevance and quality: Quality was based upon rigour of study design, in terms of clarity of objectives and outcomes and ethical considerations, reliability of peer-reviewed sources, as well as validity such as biases in sampling or method. In reality, due to limited evidence and a focus on new innovation, quality and relevance were trade-offs and relevant documentation of interest that required further research was also accounted for.

2.2 Analysis of data

Collated data were analysed by personal reading and coding of relevant content regarding key concepts, impact and lessons learnt, by individual thematic area.

The OECD–DAC criteria for evaluating development assistance were used to guide the analysis of collated evidence on impact; summarised in Figure 2.1. They were selected due to their close alignment with the prior contextualisation of impact for ESR focused upon process and function, aligned with environmental governance principles and sustainability.

Figure 2.1 OECD–DAC criteria for evaluating development assistance – key questions



Source: OECD (2016)

The previous background discussion emphasised the importance of systems-based thinking and complexity in ESR interventions. Hence, the analysis aimed to reflect and acknowledge these concepts, in alignment with the OECD–DAC evaluation guidance. The structure utilised in Geldof *et al.*'s (2011) review protocol was considered, which focused upon ICT4D partnerships for poverty reduction. Its analysis reviewed whether successes or failures were explicitly or implicitly linked to the ICT4D partnership or to the ICT intervention itself. For this review, Geldof *et al*.'s (2011) criteria were expanded to be applicable to digital technology for ESR and to encourage broader, systems-based thinking. Whether successes or failures of digital innovation in ESR were explicitly or implicitly related to the digital technology itself or to external factors were considered. This was conceptualised as a matrix – illustrated in Figure 2.2.

Figure 2.2 Matrix to analyse success and failure factors of digital innovation for ESR

Source: Adapted from Geldof *et al.* (2011)

At both the thematic and the synthesis levels, the analysis aims to identify key gaps in the research and areas for future thinking. The final conclusions summarise a series of reflections on the intended and unintended outputs, outcomes and developmental impacts of digital innovation on ESR in developing country contexts. This aims to produce highly relevant evidence to inform policy and practice.

3 Initial findings

3.1 Pathways to impact

The literature was analysed with the previously discussed focus on impact as ‘process and function’ (Carlsson and Berkes 2005). This was combined with Fichman *et al.*’s (2014) definition of digital impact as the intended and unintended effects that digital innovations, once diffused, have on individuals, organisations and societies. This evidenced that the implementation approach was one especially relevant determinant in characterising the initiatives and shaping their impact. In this regard, across the three ESR themes that were identified for the review,[1] digital innovation was found to lead to impacts through four main distinct pathways or starting points:

i. Impacts on [ESR theme] through citizen-led usage of digital technology for [ESR theme]

In this pathway, citizens who have access to digital technology such as mobile phones and the internet, use the technology to initiate and lead their own actions for ESR objectives, without external intervention.

One example of this pathway is the emergence of citizen-initiated, devised and led digital volunteerism in the aftermath of disasters. This kind of action involves using a range of ICTs and social media for disaster response: from crisis-mapping enabling disaster victims to text their location and needs to a rescue organisation, to crowdsourcing local volunteers to help translate texts from local languages (Whittaker *et al.* 2015).

ii. Impacts on [ESR theme] through digitally supported participatory interventions for [ESR theme]

These kinds of digitally supported interventions use a participatory approach to directly promote ESR objectives and include local-level initiatives up to national level, or even systemic change. Digital innovation is used for any purpose within the participatory intervention – for example, ICT could be used specifically to enable participation, or be used by participants to attain ESR objectives, or used externally to achieve ESR objectives while citizens participate in decision-making and other process aspects.

One example of this pathway is provided by interventions for climate-smart agriculture which are initiated and led by organisations, but in which farmers participate in the monitoring process through recording data and feedback using handheld geographic positioning system (GPS) devices (Jarvis *et al.* 2015).

iii. Impacts through digitally supported non-participatory interventions for [ESR theme]

Refers to digitally supported interventions that aim to directly promote ESR objectives, but without using participatory approaches. The intervention could have impact on ESR objectives at the local level, up to the national level, or even a more general systemic change, without actively engaging citizen participation in the process.

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[1] The three ESR themes selected to be considered individually are: conservation and natural resource management (CNR); food security and agriculture (FSA); and climate change adaptation and disaster risk reduction (CCA&DRR).

One example is tracking illegal logging through use of markers and satellites, enforced by national and international-level policy (Brack and Hayman 2001; Hoare 2015).

iv. Indirect impacts of digital innovation on [ESR theme]

Digital innovation indirectly impacts ESR. This can be through digitally supported interventions that are developed for purposes other than ESR, whose impacts indirectly affect ESR. These include local-level initiatives up to national-level changes. Indirect impacts can also operate through more generic, systemic-level change resulting from digital innovation.

One example is that of ‘waste of electrical and electronic equipment’ (WEEE) or ‘e-waste’ – now a substantial globalised issue arising from digital innovation. WEEE can impact on the environment and human health, with regard to both its production and its disposal (Berkhout and Hertin 2004).

These starting points will structure the analysis of the ESR themes and prompt thought on differential perspectives, framings and narratives of impact. This analytical approach aims to acknowledge the innovative work done by the STEPS Centre and its ‘pathways approach’ to sustainability and justice, which accounts for different perspectives in interlinked, complex systems (Leach *et al.* 2007). Exploring digital innovation for ESR along particular possible pathways, together with the consideration of the social, ecological, technological and institutional elements that interact dynamically and that can evolve in different directions, adds depth and relevance to the analysis of impact.

4 Conservation and natural resource management (CNR)

4.1 Impacts through citizen-led usage of digital technology for CNR

Citizen-led usage of digital innovation contributing to conservation and natural resource management (CNR) appears to fall into two main categories: activism and entrepreneurialism.

Local environmental grass-roots activism is proposed as robust and globally pervasive despite the undulating nature of the general environmental movement (Mihaylov and Perkins 2015). Citizen action and mobilisation can contribute to highlighting the weaknesses in policy procedures and in standardised ways of doing things, with respect to ESR. In this regard citizens can drive specific perspectives and interests and effectively redefine theories and pathways to sustainability (Leach *et al.* 2010).

Nowadays there is strong recognition of the role of citizen-led action in environmental politics and hence there is also a large body of literature on this subject. Environmental movements at the grass-roots level in developing countries include, for example, the Green Belt Movement in Kenya, the Chipko movement in India and the Rubber Tappers movement in Brazil. They all pushed for sustainable usage of natural resources for local people's survival and started as informal associations formed and led by those affected. Typically, these informal movements gained momentum gradually, expanded and, in some respects, formalised their structure. These movements took place largely in the 1970s, hence prior to the advent of the digital age. In the current context, widespread access to digital technologies such as mobile phones, the internet and social media enable small-scale movements to reach international impact more easily than in the past (Falkner 2013). Technologies are making environmental activism more efficient. Furthermore, telecommunications are increasing their visibility, supporting activist agendas and forcing state accountability for social environmental justice (Russel 2010).

However, the impact of digital technology on citizen-led CNR activism is more complex than this. Technology can support the activist agenda, but it can also be used by those being challenged, who are typically powerful. When activist agendas reach national-level awareness, concerns have arisen about privatisation and control of media and telecommunications by those in power with vested interests. This shapes the stories that are reported at scale (Russel 2010). One accusation regards the Niger Delta in Nigeria, where oil extraction by Royal Dutch Shell has severely degraded the environment. Citizen-led peaceful protest in the 1990s led to support from Amnesty International. A public relations battle has followed between Shell and Amnesty that continues today. Vested interests in the oil industry have been linked to the manipulation of US mainstream media to misrepresent the story and to improve the image of the company (Russel 2010). The contradictory roles that digital technology can play in CNR activism causes ambivalence about its true impact. Technologically enhanced power dynamics are observed. How citizen activism plays out in this changing environment remains to be seen.

Entrepreneurial use of digital innovation by citizens in developing countries can stem from an unintended consequence of technology: the huge quantities of WEEE or 'e-waste' (Berkhout and Hertin 2004). Due to a lack of waste management laws, or waste treatment infrastructure, a buoyant, citizen-led, informal sector has sprung up to treat this waste. These entrepreneurs are motivated by a financial and livelihoods agenda, as opposed to green *per se*. Nevertheless, on the surface this contributes to promote the 3Rs ideology – reduce, re-use and recycle – and the move from a throwaway economy to a circular economy. In reality, the treatment of these toxic materials is often sub-standard, with negative impacts both on humans and the natural environment (Maffey *et al.* 2015). It pollutes waterways (Huang *et al.* 2014) and enters food chains (Robinson 2009), and heavy metals end up in the wider environment causing allergic reactions, brain damage and cancer (Puckett *et al.* 2002). This is a globalised issue, in part manifested due to global changes and failures of regulation; hence it will be revisited as an indirect consequence of digital innovation impacting CNR in Section 4.4.

4.2 Impacts through digitally supported participatory interventions for CNR

The literature widely recognises the importance of integrating indigenous knowledge, local knowledge systems and local environments into CNR. This is reflected by many CNR initiatives, which outwardly present participatory objectives that may have been donor-encouraged. In practice these approaches can range from fully meaningful participation by local stakeholders down to tokenistic participation, which risks extracting information under a guise of ‘participation’ (Agrawal and Gibson 1999; Cornwall and Brock 2005).

Digital technology is playing an increasing role within CNR initiatives. It holds considerable potential for increasing the understanding of, and facilitating interaction with, the natural world. It is much newer to this field than it is to domains such as health, education or human development. Due to the close parallels with lessons learnt in these sectors, they should be used to inform the evolving use of digital technology for CNR (Maffey *et al.* 2015).

Geographic information systems (GIS), however, is one technology that has initially stemmed from, and is now well established within, CNR. GIS were first utilised in a non-participatory manner, which has now evolved towards more participatory approaches. There are numerous proposed advantages to this. The United Nations Reducing Emissions from Deforestation and Forest Degradation (REDD+) initiative has used GIS from the outset to support forest surveillance. However, it has attracted numerous critiques because of its top-down approach and in some cases for disregarding local livelihoods that depend on access to and usage of natural resources (McGregor *et al.* 2014). There has been some movement towards participatory approaches to engage local people, as a way to bridge knowledge systems, reach compromises and avoid conflict of interests. Many of these initiatives incorporate digital innovations, like GPS, for example, linking GPS with mobile technology for multi-stakeholder forest management that also incorporates local knowledge, or linking GPS forest surveillance with a private rangers Facebook group, which can be alerted to any disturbances in real time and thus get engaged and investigate (Evans 2013). The main practical benefits identified are efficiency, versatility and cost-effectiveness. ICT supporting real-time data and alignment of science, information from satellites and the reality on the ground, is quoted as a major advantage. Results are produced and shared with a much quicker turnaround than paper-based methods (Pratihast *et al.* 2012; Evans 2013).

Yet the whole picture is more complex. As a relatively well-established approach, the advantages and disadvantages of ‘participatory GIS’ (pGIS) as a tool have been considered for some time. An effective summary adapted by Tripathi and Bhattarya (2004) from the original version by Jordan and Shrestha (2000) is included in Table 4.1.

Table 4.1 Advantages and disadvantages of participatory GIS

Advantages	Disadvantages
Viewed as a participatory process; it can empower the community by involving them in the decision-making process	If the participatory process is not well structured the community does not feel part of the decision-making process
It can be used to effectively combine quantitative and qualitative approaches to community development	There is a potential risk of the focus getting shifted mainly towards extractive data collection
Spatial data in the form of maps and other resource information can be used by the community in their decision-making process rather than having access to GIS	There is a likelihood of sensitive spatial information like cadastral maps being subject to unintended misuse if held centrally
Natural resource information can be easily put together, analysed and returned to the community for use	Excluding disadvantaged groups from the 'mapping' process can have a disempowering effect on them
Useful information can be returned to stakeholders for informed decision-making	Availability and knowledge of the technology itself encourages a centralised approach

Source: Adapted by Tripathi and Bhattarya (2004) from Jordan and Shrestha (2000)

The first advantage refers to 'empowerment' through discussion as an impact of pGIS. The ability of pGIS to 'engage' and 'empower' communities is mentioned in numerous studies, reports and articles globally (Rambaldi *et al.* 2006; Kolagani *et al.* 2012). Yet measuring and defining empowerment is complex and subjective. Critiques of the empowerment terminology deem it a buzzword and 'empty rhetoric' (Cornwall and Brock 2005). It is important to explore how empowerment is being conceptualised in the pGIS literature, particularly with regards to understanding power dynamics and agency of local stakeholders – aspects that are crucial to achieve genuine participation (Cornwall 2002). However, the discussion of 'power' in GIS and pGIS journals is not always prominent. Generic literature describes empowerment processes as incorporating a variety of actions, from individual self-assertion to collective resistance, protest and mobilisation that challenge basic power relations. Empowerment is not done 'to people', but rather means using participatory processes to engage people in self-reflection, inquiry and action, encouraging communities to question their world and develop a desire to act on their own terms (Veneklasen *et al.* 2004). Indeed, the remaining advantages and disadvantages in Table 4.1 suggest pGIS in CNR are typically a directed process, some kind of orchestrated participation, which appears to part ways with the empowerment-oriented versions.

Chambers (2006) raises some of the above concerns by highlighting questions such as 'Whose map? Who is empowered and who disempowered? Who wins and who loses?' These are concerns that resonate with Table 4.1 entries about the risk of 'extracting' information from participants, as well as with queries on the ownership rights of the information and where the data are stored. This is particularly pertinent if data are of a sensitive or personal nature. These ideas project onto current debates on data ownership: if not managed correctly, specialised technologies risk exacerbating power differentials for external gain (Arts *et al.* 2015; Maffey *et al.* 2013).

However, the literature also offers numerous examples that indicate that pGIS, used appropriately and conscientiously, can achieve many advantages listed in Table 4.1. It provides an opportunity to increase engagement with conservation actions (Sandbrook *et al.* 2014), improve information exchange (Banks and Burge 2004) and encourage utilisation of local and scientific knowledge in environmental decision-making (Reed 2008). Furthermore, Maffey *et al.* (2015) propose that digital innovation has the potential to be an equally valuable tool for CNR, as many propose it currently is for human development.

A crucial aspect is a tangible link between the online and the offline, typically through education or knowledge exchange. Within CNR, the recent evolution of pGIS to 'Mobile Interactive GIS' or 'MIGIS' suggests that, to some extent, initiatives are heading in this direction or are, at least, more attune to these issues in aiming to achieve grounded sustainable outputs and impacts.

MIGIS refers to a process of 'community-based planning' that uses a mobile interactive geographic information system incorporated into and wholly informed by Participatory Learning and Action (PLA). While very close to the theory behind pGIS, it is differentiated by its grounding in PLA, using GIS as a complementary tool and aiming to enable meaningful participation and detailed consideration of power dynamics. MIGIS initiatives attempt to combine key aspects of indigenous knowledge and scientific information in order to find a common ground for all stakeholders to optimise their understandings of both the environment and each other, and then plan collaboratively. Stakeholders could be, for example, farmers, government administrators and planners.

When implemented effectively, MIGIS technology adds a new dimension to the existing and relatively well understood PLA approach (Tripathi and Bhattarya 2004). McConchie and McKinnon (2002) suggest it brings advantages such as being a powerful knowledge storage tool that is simple to update, as well as producing credible and quantifiable data that are highly visual. It thereby offers a tool for effective and reliable baseline information collation, which should support and improve evaluation processes. Furthermore, GIS integrated into PLA can better assess and quantify the physical and socioeconomic constraints of a 'community'. The data can then aid in monitoring and, crucially, in testing scenarios, to help overcome potential challenges as they arise. Literature emphasises that the information outputs should be 'accessible to all'. However, this is often not the case even for well-established and designed participatory approaches, in which inclusivity is frequently an issue.

As captured in Table 4.1 and widely mentioned in the literature, inclusivity in an initiative is a key factor to consider, particularly for CNR upon which differentiated livelihoods typically depend (Agrawal and Gibson 1999; Tripathi and Bhattarya 2004). Notably, inclusivity is by no means an issue specific to initiatives utilising digital technologies; it is an essential aspect throughout most developmental approaches. Whether the issues manifest differently under digitally supported initiatives is key in determining impact. This has particular relevance with regard to so-called 'community-based' approaches to CNR. The term community is frequently idealised into an undifferentiated and unproblematic notion. To the contrary: local-level systems or 'communities' are highly complex, comprised of numerous different actors, with varying priorities and levels of power and influence across different spaces (Cannon 2008). This, for example, can result in differing levels of education, literacy and financial stability, which in turn shape how an individual may be able to engage with a technological initiative as well as how they perceive it. Highlighted by Agrawal and Gibson back in 1999, the issue seems to persist today (Cannon 2008).

Engagement and inclusion in an initiative are also likely to be gendered, and dependent on the specific cultural set-up and the socially determined roles for men and women. Cultural norms may dictate women's access to technology, with phones typically being owned by male family members (McGee and Carlitz 2013). Additionally, women's responsibilities for unpaid care often shape the time available for engagement and involvement with an initiative; this is an issue that has historically been overlooked in development agendas (Eyben 2012). This also appears evident in the CNR literature, which shows how some initiatives, particularly those linked to climate change adaptation, can actually increase women's unpaid care burden (Dankleman 2010). Engaging both genders is key in CNR, as gendered roles often mean men and women perceive their environment differently.

Additionally, men and women may have differentiated sets of indigenous knowledge informed by their gender-determined work experiences. Hence, to effectively utilise GIS or other technologies to support information collation and exchange for CNR, it is important to design processes that are inclusive and capture the full picture.

In practice many digitally enabled CNR initiatives overlook inclusivity, an issue which can significantly impact the project outcomes. One such example comes from an initiative focused on water resource management in Uganda. The M4W (mobile phones for improved access to safe water) had two main objectives: firstly, water-point mapping by community development officers, community health assistants and hand-pump mechanics, utilising Java-enabled handsets; secondly, citizen monitoring in which water-users report on functionality through text messages, using any mobile phone. The projected advantage of incorporating digital is the shortened response time, as compared to reporting to traditional water committees. It was deemed participatory in that stakeholders were invited to the planning meetings; however, it later transpired that none of the female 'water-users' were present.

In the project evaluation the mapping element of M4W was successful; however, the citizen monitoring aspect had low uptake, especially as compared to original expectations. Several reasons were projected including insufficient sensitisation of communities on the initiative. Hand-pump managers suggested reasons including dependency on NGOs to solve problems, complacency when other water sources are accessible, decreasing collective action and increasing individualism and apathy. The government's lack of support to water-user committees and their voluntary and non-enforceable make-up were further proposed as issues. However, on delving deeper into the cultural set-up it was revealed that women are the main water-pump users, yet many of them lack access to a mobile phone, which will sit with the male head of household if a family does own one. Even when women do have access to a mobile phone, they may lack the literary skills to utilise it in the way envisaged by the project. This therefore prevented reporting, had the women wished to. This has important lessons for culturally aware, context-specific approaches to incorporating digital into an initiative in order to achieve impact (Triple-S Uganda 2012; McGee and Carlitz 2013).

In the above, digital technology appears to be amplifying the status quo and the existing power differentials dictating who gets involved. This aligns with Toyama's (2015) law of amplification. However, there are cases in CNR where technology can encourage a shifting of power hierarchies, for example with regards to youth and elders. It is documented, from a generic perspective, that ICTs can engage and motivate young people to become active in developing and learning about their communities. This facilitates increased commitment and empowerment. Even when ICT-based initiatives do not have a youth focus, young people can often view such communication as being targeted primarily to their age group (UNDESA 2013). An anecdotal example of this is the multi-stakeholder forest management initiatives in Indonesia utilising pGIS. In this scenario young people grasp the technology quicker than their elders, resulting in them leading on the mapping or teaching others, thereby shifting the power dynamics in typically very hierarchical societies. This anecdote links back to the literature on pGIS and empowerment angles in a seemingly positive light. Yet, there is minimal documentation of youth involvement in forest management – both in general and in view of pGIS and other participatory technological approaches. MacNeil *et al.* (2013) highlight the almost complete lack of research on this topic, prior to their publication advocating for the importance of youth voice in forest management decision-making (MacNeil *et al.* 2013; Hubert 2014).

Engaging young people is proposed to be of key importance as they represent both the current and future environment (Kleine *et al.* 2014). This apparent lack of extensive evaluation in current literature flags an important area for future research.

4.3 Impacts through digitally supported non-participatory interventions for CNR

Large-scale conservation efforts at the systemic level do not necessarily consult with the local people who are dependent on the land and its resources. This results in largely non-participatory approaches to CNR. Technology, at this scale, can have a wide range of applications. It has effectively assisted in improving the efficiency of systems and streamlining methodologies. One example is tracking illegal logging through use of markers and satellites (Brack and Hayman 2001). The internet can then support these new approaches through online platforms for data storage and information exchange. In the case of logging, the 'Illegal Logging Forum', maintained by Chatham House to share data, approaches and knowledge has proven effective (Hoare 2015).

Global tracking and monitoring of a diverse range of wildlife has also improved substantially with the evolution of digital technology (Latham *et al.* 2015). The conservation and biodiversity literature documents numerous successful accounts that have benefited CNR objectives (Hebblewhite and Haydon 2010), largely with non-participatory approaches. For example, Msuha *et al.* (2012) used camera trapping to assess how anthropogenic land use changes affect species richness in northern Tanzania. Research outputs identified opportunities and threats, which aimed to shape management strategies for maintaining biodiversity. Today, there appears to be real optimism on the potential impacts of digital innovation for CNR. The Zoological Society of London (ZSL) promotes 'Conservation Technology' focusing on real-time monitoring, wildlife surveillance and public engagement. Technological advances are proposed as key to solving CNR challenges such as rapid global decline in biodiversity and the increasing numbers of species at risk of extinction. They permit more efficient and effective collection, processing and analysis of data across spatial and temporal scales. This improves identification of threats, development of mitigation plans and testing of impact (ZSL 2016).

Yet, literature observes that, while many biodiversity research programmes using technology have well designed ecological or conservation questions to answer, others are conducted solely because the technology is available to do so (Hebblewhite and Haydon 2010). It is in this regard that Latham *et al.* (2015) deemed it necessary to propose a set of six questions that should be answered to justify deploying GPS on wildlife. This leads on to a substantial critique that technology for CNR tends to act in its own right, searching for an application (Maffey *et al.* 2015).

Advocates of this critique propose it results in more extractive approaches. Digital solutions for CNR are more typically introduced *into* a societal group as opposed to an initiative that comes from *within* (Maffey *et al.* 2015). This has been with reference to GIS and information-gathering particularly which, as discussed under 4.2, originally came to the foreground from the top-down development paradigm (Tripathi and Bhattarya 2004; Jordan and Shrestha 2000). In terms of impact, action based upon one-way information flows are unlikely to effectively account for local people's culture, practices and norms. Typically, CNR from the community perspective is centred upon food or income source choices (Mbile *et al.* 2003). Yet, CNR technologies have been used by those in power to secure their own positions (Unwin 2012). When local voices are not heard, or listened to, externally dictated, non-participatory CNR actions may cause beneficiaries to suffer, without any appropriate alternatives or compromises being established. Local stakeholders may attempt to jeopardise CNR interventions that detract from their livelihoods. Hence, some types of non-participatory CNR interventions can risk being ineffectual and unsustainable. They can also risk enhancing existing social inequalities by, for example, expanding the digital divide (Thompson 2004).

4.4 Indirect impacts of digital innovation on CNR

The ‘digital revolution’ has led to a huge surge in demand for raw materials required to manufacture digital devices. This has indirectly created serious issues for CNR. Since environmental regulations on the mining of these raw materials may be weak, or not well enforced, this can lead to unsustainable extraction methods and environmental degradation (Maffey *et al.* 2015). Furthermore, mining can also involve human rights abuses, with particular reference to cobalt mining, a key component in lithium-ion batteries for smart phones. A recent Amnesty International and AfreWatch report found that major phone companies were sourcing cobalt from organisations that used child labour in the Democratic Republic of Congo (Amnesty International 2016). There is additional major controversy in that digital technologies manufactured to support specific developmental interventions and CNR may in fact be diverting the issues elsewhere, or even creating new problems. Greater consideration needs to be given to the environmental and societal costs of using digital tools as opposed to analogue options (Sui and Rejeski 2002; Maffey *et al.* 2015).

Another substantial globalised issue resulting from digital innovation is that of ‘waste of electrical and electronic equipment’ (WEEE) or ‘e-waste’. WEEE can impact the environment and human health, with regard to both production and disposal (Berkhout and Hertin 2004). This topic has been previously discussed from the citizen perspective, but it is the result of digitally led globalised systemic change. The United Nations University (UNU) concluded that in 2014 around 42Mt (million metric tons) of e-waste were generated globally, of which 6Mt were estimated to be ICT-related. This figure keeps growing every year and is expected to accelerate (Balde *et al.* 2015). The problem is exacerbated by the market-driven concept of ‘planned obsolescence’, meaning that devices are purposefully designed and manufactured for shorter operational life spans than they could have. Consequently, they need replacing after a pre-determined period, encouraging continuous sales. Combined with a global demand and desire for the most up-to-date gadgets, the subsequent disposal of previous products leads to significant quantities of e-waste (Maffey *et al.* 2015). While consumption and use of electrical and electronic goods is rapidly increasing in developing countries, it has been predominant in developed countries. Despite the establishment of the Basel Convention in 2011 aiming to address concerns of transboundary movement of e-waste as toxic materials, it is estimated that 50 to 80 per cent of e-waste is exported to developing countries (Huang *et al.* 2014). As discussed previously, this waste is largely treated sub-standardly by the informal sector, leading to health and environmental degradation (Maffey *et al.* 2015).

Environmentally sound treatment of e-waste will require regulation, establishment or improvement of recycling infrastructure and implementation of workers’ health and safety standards. Indeed, UNEP suggests that these factors could enable the emergence of numerous ‘green jobs’, something that would contribute simultaneously to reducing poverty and to ‘greening’ the economy (Balde *et al.* 2015).

There is a need for a global effort to address the issue of WEEE by means of significant changes in the practices of involved industries (Nnorom and Osibanjo 2008). This flags a second major contradictory area with regards to CNR interventions which use digital technology. It is crucial that there is acute awareness of the wider impact that the disposal of these technologies may have. Development of technology for CNR objectives must account for localised considerations to ensure that addressing CNR in one area does not negatively impact efforts elsewhere (Maffey *et al.* 2015).

5 Food security and agriculture (FSA)

5.1 Impacts through citizen-led usage of digital technology for FSA

To effectively review the evidence on citizen-led action for food security and agriculture (FSA) using digital technology requires understanding how FSA is conceptualised theoretically. FSA is typically defined by two prominent narratives: food security as an issue of food supply and hence agricultural production, and food security as an issue of food access (Maxwell and Smith 1992). Amartya Sen first documented the food access narrative in 1981 (Sen 1981). Famine was demonstrated as not just a consequence of nature, but also as an avoidable economic and political catastrophe. Starvation is often preceded by drought and flood, but decline in food production is rarely the cause. Often, even if thousands die, the country has sufficient food to feed its population or money to import it. There has been, however, much debate on food security within academia and, importantly, also in practice, among policymakers and institutions in positions of power too. A focus on food production is still prominent, particularly with regards to future food needs with a growing population and climate change (Estrada-Flores *et al.* 2010). Globalisation is a further influential factor of food security and poverty (Pinstrup-Anderson 2004).

Currently, however, the food access narrative has greater prominence in the academic literature (Thompson and Scoones 2009). According to this view, sufficient food is produced to feed the world's population; the issue is of distribution – an 'abundance versus availability' paradox, as food access is ultimately controlled by policies, institutions and processes (Gonzalez 2002; Pinstrup-Anderson 2009). Major actors governing food systems include government, NGOs and international organisations. Institutional motivations, decision-making processes, social norms and customs, gender, caste, class, language and 'the rules of the game' act to shape the narrative (IFAD 2012). These elements interact on the international and national scales and impact access to food and livelihood outcomes at the local level. This applies to both the livelihoods and development context and the humanitarian context of FSA.

Citizen-led action on FSA as an issue of food access, therefore arguably becomes a matter of citizen voice to challenge established policies, institutions and processes (Thompson and Scoones 2009). Power dynamics are evidently at the forefront and digital innovation appears poised to play a role. Documented evidence of citizen-led challenge against the status quo appears most prominent in extreme situations. Certainly motivation to act is highly complex and nuanced, but it could be assumed that the urgency of emergency situations can overwrite perceived risks of questioning the establishment. One example is the food riots from 2007–12 that took place in India, Bangladesh, Kenya and Mozambique. They were triggered by food price spikes and acted to challenge underlying issues of injustice, inequality and political repression. While technology does not feature explicitly in the events themselves, it impacted the aftermath in assisting citizens to share their perspectives through digital story-telling (Bush 2009; Hossain *et al.* 2014). Another thought-provoking example is the anecdote of a refugee in the Dagahaley camp in Kenya. At the camp's internet café, he searched online for the telephone numbers of two United Nations officials in London and Nairobi. He texted them to explain the lack of food and demanded assistance. More food was subsequently delivered, although at the time the organisations cited different reasons (*The Economist* 2007). Albeit an individual example, it illustrates how technology can supersede conventional hierarchical communication structures and create a more fluid motion of voices, blurring power dynamics (Ramalingam 2013). At the day-to-day livelihoods level, accounts of citizen-led action challenging institutional FSA processes are minimal.

Yet, there is a growing literature on the role of technology in citizenship and citizen voice, as well as in e-governance and service provision (Schuppan 2009). How these evolving areas interact could be pertinent to the future trajectory of FSA. Yet, while highly applicable to the food access narrative, exploring the impact of digital innovation on citizen capacity to influence institutional mind-sets is beyond the scope of this report.

Evidence of citizen-led usage of digital technology for FSA under the food supply narrative, however, is much greater. The proliferation of mobile phones is a key systemic change that has had an impact on food production. Typically, young men travel to market to sell the household's production. It is this same demographic that most commonly own a mobile phone. This has enabled young farmers to remotely access market information and prices. Travel has therefore been reduced and sales and timings can be better planned. This has affected the dynamics of value chains. The process has typically been shrouded in information asymmetries. It is therefore proposed that digitalisation will bring transparency and in this regard is a public good (Annan *et al.* 2016).

Rural citizens' access to mobile phones has inspired new types of services within FSA. Social enterprises and for-profit organisations are using this medium to offer agricultural advice. This is led and shaped by citizen requirements. 'Farmer helplines' have emerged in some countries, for both arable farming and livestock husbandry. Mobile is uniquely positioned to quickly deliver the critical agricultural information that rural smallholder farmers want. Farmers can, for example, text a specific question or request weather forecasts. This can enable them to make better informed agricultural decisions, such as on the timing of planting or harvesting. This then boosts productivity and profit (GSMA 2015).

However, these initiatives raise many questions. Firstly, from the macro-level practical perspective, the distribution of this impact may be limited by the infrastructure of the country. For example, in weather, forecasting meteorological centres are key; these are sparse in many African countries, particularly in the most marginalised and vulnerable areas (Hansen *et al.* 2011). Furthermore, farmers' access to mobile phones and mobile phone reception can present issues. At the micro level, who has access to the phone is also an important consideration, as in most cases when there is only one phone in a family it is male-owned. Sending them information can reinforce gender roles and power differentials (McGee and Carlitz 2013). The literacy level required to read text messages presents another major issue in some areas. Additional barriers can also arise, as experienced by 'Esoko', a for-profit organisation supplying weather forecast data, farming advice and market prices to smallholder farmers in Ghana. Challenges include poor network coverage preventing farmers from receiving texts, compounded by mobile providers' automatic deletion of messages after 24 hours. The low level of electrification in rural areas is a further issue in ensuring phones are charged when forecast messages are due (Ewbank 2012b).

The contrasting rural and urban dimensions of food production, access and security integrated with the urban-centric distribution of digital innovation are a further dynamic that could shape impact. However, analysis of this in the literature as an interlinked, systemic notion, is limited.

5.2 Impacts through digitally supported participatory interventions for FSA

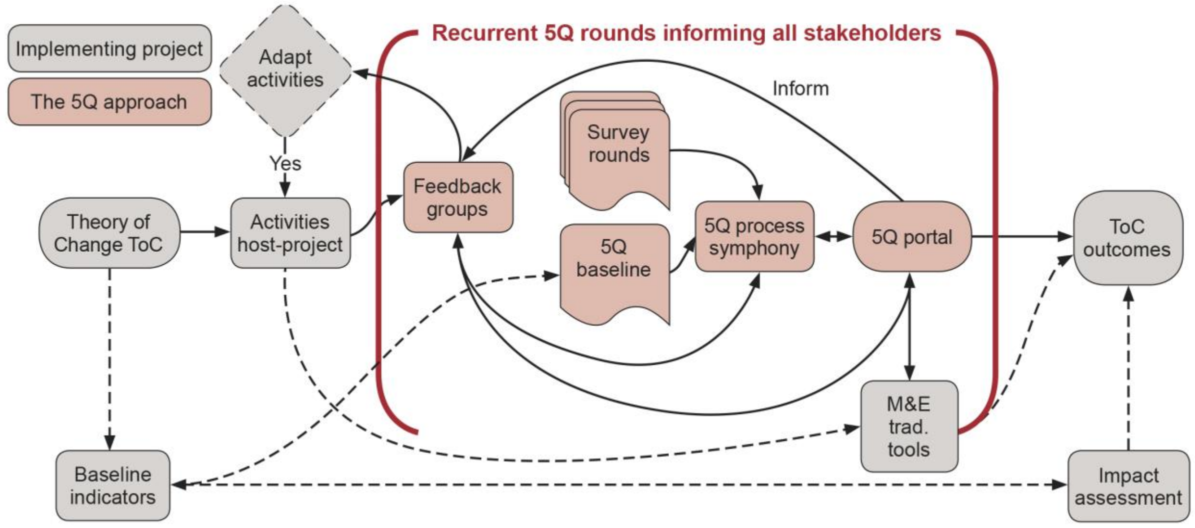
There have been some interventions that made use both of digital tools and participatory approaches, broadly under the narrative of food access where politics, policy and institutions are central. They aim to delve into the power dynamics and increase the voices of citizens, inclusive of those who are marginalised. Objectives are therefore typically wider than solely FSA. Hence, most interventions explicitly framed by FSA fall under the food supply and agricultural production narrative, including many that utilise digital innovation. Of these initiatives, those that take a participatory approach often focus upon information and knowledge-sharing (Ballantyne *et al.* 2010). A major issue that is increasingly recognised in this sector and also within the wider development sector, is that information and knowledge are often held in silos, by different stakeholders. Linked to this is the concept of the 'information gap', in which information that is locally relevant to agricultural practices is produced by specialists but it is not presented in a format that farmers understand and trust (Hansen *et al.* 2011). An example would be climate seasonal forecasts. An underlying barrier is the lack of dialogue between scientists and users (Lemos and Rood 2010). To varying extents and impact, participatory approaches aim to address this issue through facilitating voice and communication. Yet initiatives targeted at improving agricultural production tend to be directed from scientific and technical information-sharing prerogatives, as opposed to approaches to provide citizen voice under the food access narrative (Ewbank 2012a).

Exploring this subject with regards to agricultural production, it is proposed that mobile phones will contribute to make all aspects more participatory (Annan *et al.* 2016). In practice, though, examples appear more in the scoping or monitoring stages, and focus on information exchange. To date, many agricultural initiatives have found it difficult to produce impact, due to a lack of cost-effective feedback systems to collect both beneficiaries' and implementers' feedback (Jarvis *et al.* 2015). However, with the advance of real-time data collection, a range of digitalised feedback options is now emerging. Digital technology increasingly allows monitoring to be better integrated into the intervention stage, providing continuous streams of feedback. Digital technologies are seen to promote exchange, with advantages over analogue methods in terms of efficiency in data capture (Annan *et al.* 2016).

A report from the International Center for Tropical Agriculture (CIAT), *Less Is More: The 5Q Approach* (Jarvis *et al.* 2015), provides an interesting example. The 5Q approach capitalises on real-time monitoring enabled by ICTs, so as to capture the learning as it is happening and when information is most readily available. This is done through a five-question, '5Q' methodology. Using low-cost ICTs, sets of five questions are sent at regular intervals to the major stakeholders to get continuous feedback for adapting and improving the initiative. Piloted in Tanzania on a climate-smart agriculture project, it is now being rolled out across East Africa. Phase one, recently completed, demonstrated that 870 farmers could be contacted to produce actionable feedback in 15 minutes for TZS25 cents each, making the total text messaging cost just under US$10. Researchers deemed 5Q to be a 'cheap, efficient and highly-effective M&E tool able to better project performance and increase potential for positive impacts' (Jarvis *et al.* 2015).

Figure 5.1 compares 5Q to a traditional monitoring and evaluation (M&E) system and demonstrates the extensive additional feedback achieved through digital innovation tailored to recipients' needs. It also shows how digital technology can support an adaptive project approach, with challenges recognised and amended. For example, voice-recorded messages were used with illiterate farmers, combined with face-to-face communication. Questions were asked at appropriate times of the day, based upon farming schedules and initiated with an advance text message. Gender was also considered, as respondents were also asked demographic questions – like sex and age – in acknowledgement that a family would typically share one mobile phone.

Figure 5.1 The 5Q methodology embedded into a traditional monitoring process



Note: Dashed lines represent traditional pathways of impact assessment.

Source: Jarvis *et al.* (2015)

Evidently at the level of process and function of an initiative, ICT appears to be advantageous to the approach. Moving forward, researchers acknowledge the importance of ensuring the feedback loops really do go full circle, so farmers as well as other stakeholders benefit from the information. However, currently this is often an area where ICT-facilitated information exchange initiatives fail to achieve impact (Jarvis *et al.* 2015).

Radio and television programmes and internet-accessible advisory services are examples of partially participatory uses of ICT for information-sharing that can impact at scale. One interesting initiative in Kenya is the popular Kenyan farming television programme *Shamba Shape Up*, which offers farming advice to smallholder farmers. It is funded by a range of organisations, including Africa Enterprise Challenge Fund and CCAFS – Climate Change Agriculture and Food Security (USAID 2013). *Shamba Shape Up* has reached more than 3 million individuals and a separate study showed that 36 per cent of viewers stated it had changed their farming practices (USAID 2013). The televised information is also captured on a webpage, Facebook and Twitter, yet access is largely influenced by wealth, an issue also reflected by other studies on barriers to accessing information (Philips 2003). A further critique of these formats is the necessity to generalise information (USAID 2013), a common issue of ICT tools for information dissemination. Information is often reduced to misleadingly deterministic formats, which can hide uncertainties such as presenting rainfall level as part of a seasonal forecast only and not making maximal use of seasonal climate prediction (SCP) data (Ewbank 2012a).

Digital innovation for FSA can also be designed to overcome emergent circumstantial constraints. The digitalisation of 'farmer field schools' to support agricultural practice in Sierra Leone during the Ebola outbreak is one such innovative example (Witteveen *et al.* 2016). Farmer field schools (FFS) are a widespread, participatory initiative in which groups of farmers meet to study a particular topic, from conservation agriculture to animal husbandry. The focus is on learning by doing and farmers become experts in their own farms. Farmers and facilitators debate observations and experiences, and exchange new information with neighbouring communities (SUSTAINET 2010). Impact is complex to measure due to methodological obstacles, the range of immediate and developmental impacts and varying opinions across stakeholders. However, their benefits have been acknowledged widely by a broad range of stakeholders, including farming communities, local and national governments, NGOs and donors (Van den Berg 2004).

In response to the Ebola outbreak, gatherings of more than five people were prohibited. This prompted the design of a prototype digital farmer field school (DFFS), which offers a tablet-based alternative to traditional face-to-face certification training for cocoa farmers in Sierra Leone. It was concluded that DFFS offers new opportunities for exchange and creation of knowledge. Specific advantages are that it increases the autonomous role of both female and male farmers in the initiative and that training is very adaptable to their requirements. There is potential for some aspects of the DFFS to be used as stand-alone tools, for example the films and regular communication between the farmers and the back office using the tablet. The recommendation is for further development and testing of an affordable, intuitive design that uses available resources innovatively (Witteveen *et al.* 2016).

5.3 Impacts through digitally supported non-participatory interventions for FSA

There are non-participatory digitally supported interventions for FSA under both the food access and food supply narratives of food security.

Fair trade is a large-scale non-participatory initiative tackling food access through just regulation of the processes, policies and institutions governing agricultural value chains. Digital technology has supported the advancement of fair trade initiatives and the tracking of the production process. Additionally, the promotion of accountable, transparent and long-term trading partnerships gives small producers consistency of income. This permits planning ahead and investment in new approaches, including digital technology that should ultimately increase income and support business development. Negative impacts are also debated across the literature, regarding inclusivity and divisions, for example the effects on the poorest farmers or those not part of the fair trade system (Nicholls and Opal 2004).

Mobile money, now prominent in numerous developing countries, is proposed as a future application of digital technology to improve food access. Mobile money or e-vouchers are advocated for to enhance efficiency and accountability of government subsidies for fertilisers, through enabling farmers to buy them directly. This is in contrast to the current situation where money is typically sent to a middle organisation; while moving from donor to farmer money often goes missing (*The Economist* 2016). E-vouchers and cash transfers are already in use for FSA in emergency contexts. Driven by a needs-based approach, emergency response has evolved to be largely focused upon crises in the rural context. Yet, in recent years the frequency and intensity of large-scale urban disasters have increased. The need to improve the speed, appropriateness and efficiency of response has been emphasised. Hence, digitalised voucher systems have been developed that regulate food access better than traditional methods, in difficult and challenging situations. A study on their use in Haiti, Pakistan, the Occupied Palestinian Territories and Côte d'Ivoire, demonstrated positive outcomes and recommended further investigation (Cross and Johnston 2011).

Non-participatory initiatives under the food supply narrative include specialist technology designed specifically for FSA purposes. A key example is precision agriculture, developed largely without end-user input. It incorporates recently commercialised technologies of GPS, yield-monitoring and variable rate agrichemical application. These are combined with adaptation of existing GIS and remote-sensing technologies or rapid invasive soil property measurement technologies (Plant 2001). These geo-statistical tools increase specificity of agricultural practice and move it away from the large-scale standardised approaches. Standardised approaches, which were introduced due to mechanisation and scientific knowledge, have increased yields overall but leave parts of fields underperforming. Precision agriculture collects site-specific data on a field so farmers can cultivate each area accordingly and maximise the productivity of a piece of land. Yet the precision concept is not new. It returns to approaches to farming used before large-scale uniform processes took over (Stafford 2000). However, digital technology enables collation of large-scale spatial and temporal quantitative data to support low-input, high-efficiency sustainable agriculture (Corwin and Lesch 2005).

While precision agriculture has so far been predominantly adopted in developed countries, it is relevant to this context as it is typically framed as an answer to global future food security. Some have dubbed it a 'revolution' (Lowenberg DeBoer 2015), although the number of short-lived 'revolutions' prominent within the development context make this a term to be cautious of. The outputs of precision agriculture have been extensively documented; however, these studies are limited to the geographical contexts in which activity is taking place, and hence largely focus upon the developed world (Tran and Nguyen 2006).

Evaluation is largely from the scientific perspective, for example focusing on specific aspects of capability to delineate geo-referenced areas in a field. Precision agriculture has accounted for numerous factors that determine crop yield such as edaphic, anthropogenic, biological and meteorological factors, as compared to prior options in agricultural practice (Corwin and Lesch 2005). It has assisted a growing number of farmers to use farm inputs such as fertilisers, insecticides, fungicides, herbicides and irrigation water more effectively. This has resulted in productivity, efficiency – particularly through more productive use of working hours – and ultimately profits. The environmental implications of agriculture are also improved through these technologies, in terms of reduced carbon footprint and lessened input wastage (Brown *et al.* 2015). The extent of these benefits, however, is shaped by aspects such as farm size, cropping cycle and variation in soil properties impacting upon yields. There are also questions around the economics of using highly technological tools in agriculture. However, as cost-benefits are currently under investigation, there are few studies of empirically based estimates from the economic perspective relevant to developing country context (Knight *et al.* 2009; Tran and Nguyen 2006). The current distribution of access to this technology flags up the digital divide conundrum.

Small farm sizes, limited resources and traditional agricultural practices typical of developing countries indicate that precision agriculture cannot be applied to these contexts in the same manner as in developed country contexts. It is proposed that a move to mechanised agriculture is required first. This aims to increase land and labour efficiency in order to be better positioned to implement high-level precision farming systems.

Interestingly, while digital technology often offers routes to side-step infrastructure, in the case of agriculture the 'traditional' development trajectory is advocated for, in order to create the environment for technology to impact. However, the potential for further solutions and innovation should not be overlooked; in African countries, for example, agricultural innovation is flourishing in alignment with increasing stability and improved governance (*The Economist* 2016). This emphasises the importance of the institutional environment to enable the proliferation and impact of innovations.

Interestingly, aspects of the digitally enabled precision agriculture concept have inspired replication in a non-digital manner in developing countries. One example is its application to rice farming and the resultant 'rice integrated crop management (RICM) systems' as explored by the Food and Agriculture Organization (FAO) (Tran and Nguyen 2006). Impacts of integrated crop management systems are evident and have enabled farmers to close the yield gap between fields and research stations, which remains vast in numerous countries.

Digital technology is, however, used to support agronomy in developing country contexts. One such example is the 'Decision Support System for Agro-technology', a specialised computational software that collects data on environmental variables, such as soil type and temperature. Short- and longer-term predictions of growing conditions and resultant crop yields can be generated to help guide farming decisions. However, this approach has received criticism with regard to impacts and who ultimately benefits. One conclusion voiced at the recent ‘contested agronomies’ conference hosted by the Institute of Development Studies stated that the rural poor feature heavily in research proposals but are surprisingly absent in impact evaluations. It is proposed that the modernist approach to agricultural research, based upon intensification, does not work for the poor. According to (Nelen *et al.* 2016), initiatives need to start at the level of the farmer, to ascertain what is needed for their livelihoods and to support a nutritious diet for themselves and their families. Currently, digital technology appears to improve data sets, but its impact and practical application by those most vulnerable is in question. Those in power determine the focus of innovation and in this regard technology reinforces the current dynamics. This raises questions on whether digital innovation has pushed FSA further towards the productivity narrative.

5.4 Indirect impacts of digital innovation on FSA

The huge quantities of e-waste or ‘waste of electrical and electronic equipment’ (WEEE) produced as a result of the digital revolution was previously discussed with regard to impacts on CNR. The poor management of waste disposal in many developing countries also impacts FSA. Agricultural practices and food supply are affected by pollution of waterways (Huang *et al.* 2014) and heavy metals entering food chains (Robinson 2009) and the wider environment (Puckett *et al.* 2002).

Digital technologies such as affordable mobile phones and access to the internet in developing countries are new outlets for consumerism, with demand rapidly increasing (Maffey *et al.* 2015). Changes in spending dynamics could indirectly impact FSA at the local and household levels. For example, poor people with minimal income may choose to spend less money on ensuring good nutrition and food security, instead choosing societal luxuries, including digital technologies (Banerjee and Duflo 2011). Increased access to technology, conditioned by the digital divide, can certainly impact local cultures and societal dimensions (Nassanga *et al.* 2013). It would be interesting to explore how cultural changes resulting from digital innovation could indirectly affect FSA, an area not widely covered by current literature.

6 Climate change adaptation and disaster risk reduction (CCA&DRR)

6.1 Impacts through citizen-led usage of digital technology for CCA&DRR

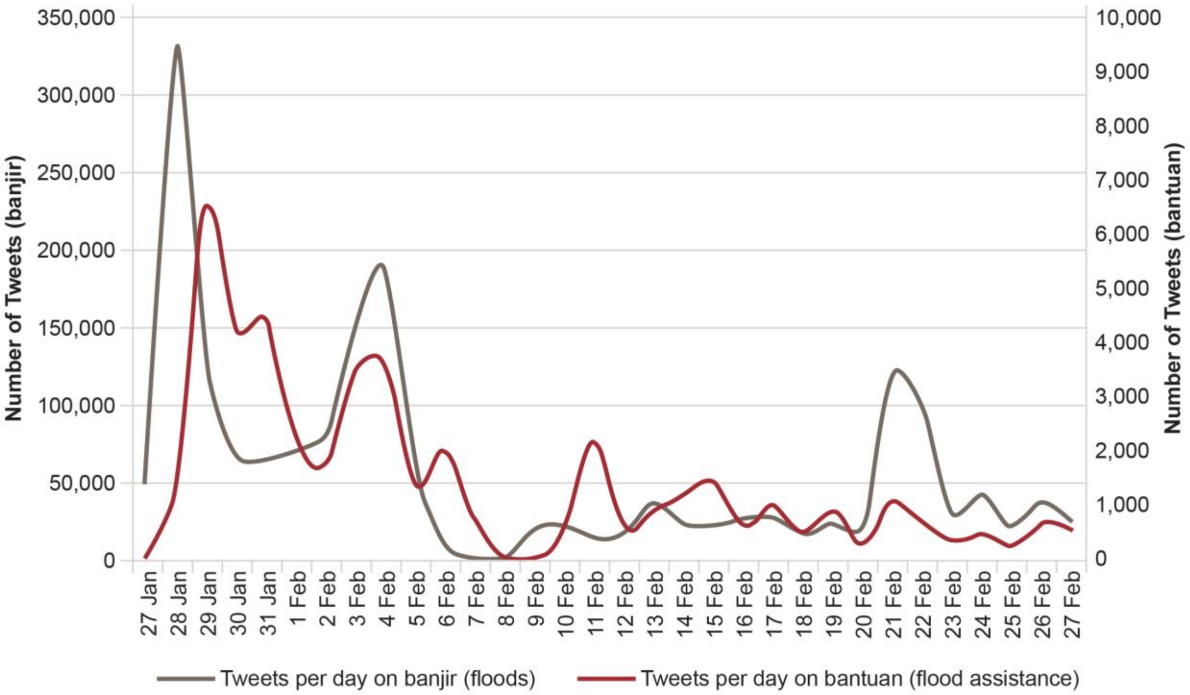
CCA&DRR interventions can be broadly classified as planned adaptation or autonomous adaptation. Planned adaptation results from deliberate policy decisions, informed by the changing conditions and an understanding that to maintain, reach or return to a desired state requires action (Nelson *et al.* 2008). Autonomous adaptation – also called spontaneous adaptation – refers to responses to climate and its impacts without an explicit plan or conscious focus on addressing climate change (IPCC 2014).

Autonomous CCA at the local stakeholder level is, in a sense, an inherently intuitive process. Whether accessible digital technologies are utilised to support this in a similarly intuitive manner should be considered. Earlier literature appears to have made little reference to this potential scenario (Malik *et al.* 2010). Yet the recent literature is starting to touch on evidence regarding potential effects of digital innovation in this area. For example, the expansion of mobile phone ownership across the developing world has changed communication structures (World Bank 2016a). This could facilitate discussion of experiences or exchange of information prompting autonomous adaptation. It is suggested that responses to unexpected shocks as they happen, termed 'autonomous emergent adaptation', would be improved by communities becoming better at self-organising themselves as a system. Digital innovation, in the form of transformational ICTs, could support this progression through permitting development of collective capabilities in a community-led manner (Pant and Heeks 2011).

Yet the limited evidence shows that, in practice, local informational capacities have not especially developed, nor has community self-organisation proliferated alongside access to digital technologies – at least not to a sufficient level to respond to the worsening effects of climate change. To the contrary, mobile phones can lead to the opposite effect by atomising information to individuals and lessening the need for community-based services and infrastructures. Hence, how to take action to promote the potential positives as opposed to negatives is discussed in the literature with regard to autonomous and intuitive usage, some suggesting a need for more participatory design (Pant and Heeks 2011).

For DRR, in the aftermath of a disaster, planned, spontaneous and emergent responses come together. Informal volunteer groups typically perform citizen-led action. Digital innovation shapes and impacts responses with intuitive application of digital technology. Digital volunteerism has emerged, led and devised by volunteers, and includes a range of innovative and effective usages of ICTs and social media; from crisis-mapping enabling disaster victims to text their location and needs to a rescue organisation, to crowd-sourcing local volunteers to help translate texts from local languages (Whittaker *et al.* 2015). Current evidence suggests social media is highly beneficial to citizens during times of crisis (MacLean 2015). Figure 6.1 illustrates how the use of Twitter significantly peaks during disasters, with an example showing the number of flood-related tweets during the 2014 Jakarta floods.

Figure 6.1 Tweets on flooding in Indonesia during the January 2014 Jakarta floods



Source: Wagemaker (2015)

However, geographic location and access to technology are determining factors in the feasibility and impact of digital volunteerism. The potential impact is also limited by the formal structures, in particular by institutional set-up and culture. Another consideration is that on the ground these informal groups and agendas can be seen as unhelpful by those involved in the overall organised formal response and their efforts devalued. However, ICTs have started to play a role in coordinating groups for a more organised overall response. With the rise in frequency and intensity of disasters linked to climate change, it is inevitable that informal volunteering will increase. Hence effective, efficient and reliable tools supporting coordination will become increasingly important (Whittaker *et al.* 2015). In some countries, citizen-led, digital volunteerism has been formalised. Standardised hashtags on Twitter are used to disseminate information and respond to urgent needs. The government of the Philippines was an initial propagator of this approach, first using it effectively during Typhoon Bopha in 2012. Additionally, passive use of Twitter data is now emerging. Flood Tags' platform allows filtering and extracting of actionable data from thousands of messages tweeted by citizens in times of crises (Wagemaker 2015).

The importance of mobile phones to facilitate citizen-led action on CCA&DRR has been recognised and promoted at the institutional level, albeit also driven by corporate incentives. Documented and perceived future impact of mobile phones in CCA&DRR efforts has triggered efforts to improve mobile networks. The crucial role of mobile networks before, during and after disasters in enabling both access to information and the coordination of assistance between government, NGOs and the international humanitarian community, has led to the establishment of the 'Humanitarian Connectivity Charter' (GSMA 2015). It has been the result of two years of industry consultation and is led by mobile network operators of the GSM Association (GSMA), an organisation representing the interests of mobile operators globally, uniting almost 800 operators. The charter establishes a set of principles taken up by major actors in the mobile industry to support better access to communication and information for people impacted by a crisis, with the objective to decrease human casualties and support the humanitarian response (GSMA 2015). How it works in practice remains to be seen, as well as its geographical reach. Institutional set-up and cultural context can be predicted to play a significant role in its upscale.

6.2 Impacts through digitally supported participatory interventions

It is now acknowledged that CCA&DRR approaches for poor communities are much more likely to be effective if grounded in local knowledge and coping strategies. Communities are considered to have the right to participate in decisions that affect them (Reid *et al.* 2009). Community-based insights are additionally considered a crucial element of planning, in order to develop effective decision-support tools that increase understanding of and response to challenges and opportunities (Nay *et al.* 2014).

Discussion and evidence on the importance of stakeholder participation in practices and programmes is frequent in the development literature. The CCA&DRR literature reflects this view too, classifying the approach as community-based adaptation (Reid *et al.* 2009). More recently, child-centred climate change adaptation as a participatory initiative has been promoted (UNICEF 2014). While this report will not extensively review the debate on classifying ‘participation’ it should be noted that there is a large body of literature around this (Jordan 2003; Peet and Hartwick 1999). Hence when exploring how digital innovation has contributed to participatory approaches to CCA&DRR, ‘meaningful participation’, particularly regarding representation of knowledge, voice and ownership, will be kept in mind (Cornish and Dunn 2009).

Documentation of CCA&DRR interventions that use digital technologies and apply participatory approaches shows how stakeholders typically participate in a directed way, through the use of ICT as an intervention. Participatory approaches are used across the different stages of adaptation programmes: scoping, implementation and M&E. The extent to which the impact of CCA&DRR participatory digital interventions has been evaluated is variable. Comprehensive impact evaluations, however, appear limited (Eakin *et al.* 2015). As the sector is relatively new, well-established long-term CCA&DRR initiatives using analogue methods are rare. Hence rigorously evaluating the specific advantages of digitalised approaches over traditional methodologies is not very applicable. The continuous evolution of approaches to CCA&DRR adds to this challenge. Therefore, studies tend to just provide a general insight into the impact or discuss the future potential of the initiative.

Digital innovation used in the scoping of CCA&DRR interventions provides a mechanism for knowledge-sharing and co-production, alongside stakeholder engagement (Canevari-Luzardo *et al.* 2016). These are arguably crucial aspects to ensure an effective and sustainable design of CCA&DRR interventions. Two main trajectories were identified: using digital technology in a participatory manner to gather data for an intervention, and using analogue participatory approaches to gather data to inform a digital implementation stage or a specific technology.

Mapping of local areas to assess hazards and vulnerability is a key area where technology has been prominent in project scoping. This has been supported by GIS which, as discussed in Section 4.2, have recently evolved towards a participatory application, becoming participatory GIS or pGIS. Flood mapping to enable adaptation plans for increasingly frequent flooding is one example where technology has facilitated integration of local and external knowledge. pGIS enables local stakeholders to identify and document key areas at risk of flooding, which are then digitally integrated into geo-spatial data and existing knowledge of local hazards. This produces a more comprehensively informed and representative picture of the flood risk. Digital technology is enabling more efficient and thorough information capture. However, supporting analogue methodologies involving discussions and initial engagement of stakeholders appear to be a key element of its effective implementation (Balram and Dragićević 2006).

pGIS can also be applied more generally, asking communities to map any hazards they deem relevant. This puts greater emphasis on their conceptualisations of the local environment and increases the participatory element. One example is a recent study on the potential of pGIS for CCA conducted in Grenada. It gathered local spatial knowledge on hazards and vulnerability, while supporting the creation of risk and vulnerability reduction procedures. The innovative model integrated community vulnerability mapping with household geo-referenced data. It was shown effective in improving both understanding and management of vulnerability to climate change in small Caribbean communities. The study concluded by proposing that the approach was replicable to other countries across the world (Canevari-Luzardo *et al.* 2016).

Numerous case studies identify pGIS as playing a community engagement and empowerment role in CCA&DRR interventions. Yet, as recognised with regards to CNR in Section 4.2, it is important to critically assess how engagement and empowerment are conceptualised (Veneklasen *et al.* 2004). This is particularly relevant with regards to CCA&DRR interventions, as they refer to highly complex topics. Initiatives typically aim to influence people's behaviours and hence may challenge cultural norms. Culture, religion or simple fatalism enable people to live in disaster-prone areas and make sense of their lives. For example, communities experiencing variable weather patterns may have developed their own set of explanations grounded in culture or beliefs. A scientific forecast may therefore challenge those explanations. Furthermore, unequal power relations, integral to culture, can be a contributor to people's vulnerability to climate change, as often it is those who have minimal influence who have to cope with dangerous environments (IFRC 2014). Consequently, 'empowerment' should not be claimed lightly as an impact in the CCA&DRR context.

pGIS is typically only 'partially' participatory in that an external facilitator will often undertake the technical GIS elements of the mapping process (Canevari-Luzardo *et al.* 2016). pGIS data are ultimately evaluated and located in external systems, which questions the extent of stakeholder engagement and empowerment. Ownership of data comes into contention too. This returns the discussion to Chambers' (2006) pertinent questions: 'Whose map? Who is empowered and who disempowered? Who wins and who loses?' The questions prompt critical thought on who is ultimately benefiting from a project intervention, a fundamental consideration relevant across development initiatives. For CCA&DRR, partial participatory digital innovation that uses scientific technologies requiring specialist input and external analysis could exacerbate ownership issues. Impact for vulnerable communities is hence likely to be highly dependent on the behaviour and attitude of facilitators and on who controls the process (Chambers 2006).

Building on this, Wong and Chia (2004) highlight a key lesson: technology should not try to replace existing forums for community dialogue, special data collection or information-sharing. It can be speculated that this was concluded from cases where digital tools may have reduced 'empowerment' as compared to analogue community mapping exercises. The latter take place entirely at village level and evaluations have shown the approach to be effective at navigating power dynamics (Di Gessa *et al.* 2008).

There is a critique that technology use is predominantly grounded and framed by the specific scientific literature and journals. Yet to be effective in complex interdisciplinary CCA&DRR contexts, it also needs to draw upon interdisciplinary sources. It should be well integrated into larger systems of relevant stakeholders, as opposed to one organisation working alone.

This should better ensure effective use to achieve objectives such as information-gathering, information-sharing and engagement in an ethical manner (Balram and Dragićević 2006).

M-health is another area where digital is contributing to CCA&DRR, with climate change projected to increase the spread of infectious diseases. Arguably, the major example of real-time monitoring sits within top-down approaches, with few interventions initiated by end users or communities (Ramalingam 2016). Yet there are examples of participatory approaches at the scoping stage to inform digital technology design for health interventions. Participatory design enables comprehensive consideration of culture, values and beliefs when incorporating digital innovation into initiatives. A recent innovative example is the work with mothers in Udaipur, Rajasthan, India to design a culturally appropriate necklace for babies that contains a computer chip holding their vaccination records for up to two years. It also sends reminders for medical check-ups. The necklace aligns with the traditional amulet worn by children in this area to ward off disease. Mobile health, wearable technology and cloud computing have been integrated to produce a platform that aims to bridge the vaccination gap. Digital is being used to overcome challenges of field immunisation camps, increase mothers' understanding of vaccination importance and improve current data collection methods that are cumbersome and lack patient specificity. This initiative is still in its formative stages, so long-term impact is yet to be seen, but currently a randomised controlled trial is being undertaken to gain initial insight. However, the necklace was designed for one specific cultural area and hence attempts to replicate its use in different contexts will need to re-consider the design, again in a participatory manner (Khushi Baby 2015).

Overall, implementation of CCA&DRR interventions tend to be non-participatory and top-down. However, there are new initiatives focused upon advocacy and social change that take a participatory approach to digital innovation in the implementation stages – for example, community radio. While radio as a tool is well recognised for other development agendas, it is relatively novel in the CCA&DRR sector. It is used as a medium for broadcasters to explore, integrate and promote local perspectives on climate change, as opposed to more typical transmissions of external information. Radio overcomes access issues that many other ICTs present. In Africa, radio is the ICT with the widest geographical reach, despite exponential growth in access to other technologies (Myers 2008; Harvey 2011). However, the vast complexity of climate change, which operates across spatial, temporal and jurisdictional scales, has to be acknowledged. The topic extends further than singular institutional or actor knowledge, therefore requiring an understanding of the overall systemic picture in order to effectively facilitate knowledge-sharing on climate change at the community level (Ensor and Harvey 2015). Yet, while technologies such as radio permit the large-scale reach, with this come risks of reductionist information. It is proposed that community radio can have greatest impact when combined with other modes of communication (Abreu Lopes 2014). This includes new ICTs for interventions developed in a participatory manner and alongside organised listening groups. Supported by these other elements, the technology can be accredited with offering a strong platform for community voice in places where language, transportation and poverty are significant challenges to expression (Gauthier 2005; Harvey 2011). In this regard radio is shown to be effective for both learning and behaviour change, which are key to effective CCA&DRR (AFFRI 2008).

The 'Climate Airwaves' radio programme in Ghana, an initiative striving for climate justice, is a good example. It is focused upon engaging and strengthening networks, while increasing capacity for collective action amid complex challenges. The process had numerous stages, supported by discussion initiatives. Human and financial resources were required to educate local broadcasters on climate change. They were also trained to self-evaluate ongoing impact through audio-journals. Studies have shown that this approach successfully engages people in local discussions of the political, environmental and social aspects of climate change. Increased understanding has been demonstrated through workshops. This locally led, participatory approach to accessible technology provides an additional substantial value because of its potential to embed itself within the community structure (Harvey 2011).

Community radio uses digital technology in a participatory manner. Other approaches use analogue participatory methods to communicate outputs from digital technology. Again, examples sit within advocacy, social change and awareness-raising. The Red Cross/Red Crescent Climate Centre (RCCC), for example, aims to make the scientific information on CCA&DRR understandable at the local level through the use of purposeful games and a combination of online and offline resources. By means of experiential learning and a highly immersive and participatory angle, it aims to trigger responses to the externally produced technological and scientific data (Mendler de Suarez *et al.* 2012). This methodology has been shown to be effective anecdotally, but as an innovative approach, more comprehensive impact evaluations are still in progress (Suarez *et al.* 2014).

M&E of CCA&DRR interventions is complex and currently limited, for reasons discussed above. Frameworks are being developed, but not yet utilised to any extent. Participatory M&E (pM&E) is a relatively new concept to the development and environmental sectors. Hence, it is significant that a number of the documented M&E approaches include participatory elements supported by digital technologies. Mobile phones as a medium for reporting on CCA&DRR initiatives in the agricultural and health sectors are evidenced. Using mobile phones to enable farmers to feed back on a climate-smart agriculture intervention is one such example (Jarvis *et al.* 2015), detailed in Section 5.2. Participatory video for CCA&DRR is also promoted, enabling local stakeholders to produce compelling reports. The process involves local communities, offers a creative means of expression and encourages accountability, while also being compatible with other types of M&E systems. Sufficient time and budget for effective training are considerations in cost-effectiveness of pM&E using digital technologies (Prabhakar 2011; Lemaire and Muñiz 2011). In-depth evaluations with regards to inclusivity of pM&E in this context are limited. Yet, overall digital innovation appears poised to support the emerging pM&E concept for CCA&DRR, an area for ongoing research.

6.3 Impacts through digitally supported non-participatory interventions for CCA&DRR

As CCA and DRR are newly evolving fields, digital technologies are often incorporated into new approaches. Looking at process and function of interventions, technology materialises as a range of 'tools'. Despite the participatory rhetoric for CCA&DRR, these tools are most commonly implemented in a non-participatory manner. This has resulted in local stakeholders becoming 'beneficiaries' of externally conceived interventions (Pant and Heeks 2011).

Climate tools include both analogue and digital innovations including documents such as a handbook or checklist, websites and computer programs. The use of tools is not new to development. However, existing tools have recently been adapted for CCA&DRR purposes and new dedicated CCA&DRR tools have also been developed, many of which are digital. Climate risk screening tools have become increasingly mandatory for multilateral and bilateral organisations, while still optional for NGOs (Hamill and Tanner 2011). The digital tools designed for CCA&DRR are normally complex and frequently require specialist knowledge to be operated or benefited from. This infers a tendency towards non-participatory initiatives and why there can be a lack of participation or 'meaningful participation' in CCA&DRR approaches. Climate tools for adaptation can be divided in the groups summarised in Table 6.1.

Table 6.1 Types of tools for CCA&DRR

Type of tool	Explanation
Process guidance tools	Include tools for communication, screening, assessment and implementation and M&E. Guide users through one or several steps of processes.
Data information tools	Include climate information primers – tools for acquiring primary climate information, like temperature or rainfall data – and projections such as global climate models (GCMs). Generate or present information for use in other steps. This group also includes secondary impact models and maps, as well as vulnerability information such as poverty, livelihoods and socioeconomic data.
Knowledge-sharing tools	Typically consist of web-based platforms offering access to relevant news, to scientific, policy and project documents, to personal observations and experiences, to professional networks and also to the previous two groups of tools. Allow users to share knowledge and experiences that will inform and refine adaptation. These tools support across the adaptation process: from awareness and engagement, to screening, risk assessment and analysis, to options evaluation, implementation and finally to M&E.

Source: Hamill and Tanner (2011)

Digital technology is an integral aspect of many CCA&DRR data information tools. A major contribution of digital innovation to the sector is the continuously improving predictions of climatic change and weather patterns through computer-aided integration of data. This helps to ascertain expected impacts in the short and longer term. However, the impact of this technology has limitations in terms of geographical reach. For example, in some of the most vulnerable areas to climate change the density of meteorological stations is often low, thereby reducing capability and accuracy of climate models. The importance of information on micro-climates is also required but not always readily available. For the digital tools to have a real impact, there needs to be greater emphasis on climate change predictions at the regional level and at the medium-term scale (Hamill and Tanner 2011; Ewbank 2012a).

Even when scientific weather and climate prediction data are effectively generated, making this impactful to the end stakeholders has presented challenges (Hansen *et al.* 2011). The often quantitative, complex and specialist nature of the information has typically been presented in an academic, scientific manner. Development practitioners, wanting to use the data to climate-proof their programmes, may not have high awareness of cause and effect relationships in climate change. Hence integrating the data into development initiatives can be challenging (Christian Aid 2015). Furthermore, it is difficult to raise the awareness of development organisations about the relevance of climate change, when much of the climate change data require specialist knowledge to be understood. At the institutional level immediate development, such as health and education, may be prioritised over action on climate change as it can seem a distant reality. This is compounded by uncertainties around long-term climate change projections, caused in part by limitations of current technology. As a result, the use of climate impact assessment information in policy decision-making tends to be minimal. Hence, more work on translating the scientific information into an applicable and policy-relevant format is required in order to achieve impact (Washington *et al.* 2006). The Red Cross Red/Crescent Climate Centre (RCCC) is spearheading innovative participatory approaches to tackle this issue (Mendler de Suarez *et al.* 2012), as discussed under Section 6.2, but there is much work to do.

'Early warning systems' (EWS) are another major example of data information tools supported by a range of digital technologies. Participatory approaches and analogue EWS exists – inclusive of child-centred initiatives (Save the Children 2011). Yet, digitalised EWS have typically been developed and used in a non-participatory manner. Sentinel Asia, a space-based disaster management support system in the Asia-Pacific region is one example. Various regional space agencies and disaster management organisations collaborate, using remote sensing and GIS technologies to support disaster management (Kaku and Held 2013). Other interventions apply specialist internet-based software to automatically receive seismic information, which can be used to map disasters and organise rescue groups, such as the 'Warning and Rapid Estimation of Earthquake Damage' (WARED) system used in Iran, receiving data every 30 seconds. Its main objectives are decreasing casualties, integrating aid efforts and transmitting required information to municipal management and private voluntary groups. It has effectively impacted the DRR process through early warning systems, being able to function with minimal data. It reached operational capability comparatively quickly – six months – and was able to localise data with reference to the chaotic and complex conditions found in unprepared cities. Furthermore, this internet-facilitated approach is deemed cheaper, as it does not need installation of expensive equipment (Kangi 2015).

Digital technology is also fundamental to many knowledge-sharing tools: web-based platforms are frequently used to collate information from across different sources. They are normally compiled, developed and maintained in a largely non-participatory manner, but partial participation of stakeholders may also occur. The platforms have potential to have a profound impact on CCA&DRR, due to the interdisciplinary nature of the topics, informed by many sources. Collaboration is essential for effective, well-informed processes and web-based platforms can be an efficient means of collating data in one place. Yet this application raises questions on both content and access. Content in terms of whose data are being prioritised on the platforms, both from a geographical perspective and the types of stakeholders – whether climate scientists, technology specialists, different types of development organisations, institutions, local stakeholders, local communities, etc. Issues of open data also arise: if local stakeholders' perspectives are recorded, personal data and ethics become a factor to consider. Access is the second major issue and it is noted that these web-based information channels are not accessible by all. Those with no internet access are typically the poorest sector of populations, and hence often the most vulnerable to climate change impacts (Adger *et al.* 2003).

Digitally supported process guidance tools for the scoping and implementation of non-participatory interventions overlap with prior discussion in terms of data and knowledge-sharing. Tools for M&E of CCA&DRR is a new, evolving area. Currently there is little evidence on the impacts of digital innovation for non-participatory approaches to M&E for CCA&DRR. Proposed approaches and new ideas are documented in the literature. SEA Change and UKCIP (Bours *et al.* 2013) have synthesised the tools, frameworks and approaches to M&E of CCA&DRR into a report. It is targeted as a process guide for practitioners, however the implementation stage is still largely embryonic.

Future research on the impact of digital innovation should explore how nation states have proposed to use technologies under their national action plans for adaptation (NAPAs), and whether and how current ICT architectures are used to improve national, regional and local adaptive capacity. The strategic temporal and spatial priorities to develop and/or replicate digital technology should also be reviewed (Pant and Heeks 2011).

6.4 Indirect impacts of digital innovation on CCA&DRR

Digital innovation can indirectly impact CCA&DRR efforts in a positive manner, especially by supporting autonomous emergence of climate change adaptations, which materialise as the need arises. ICT initiatives created for purposes outside CCA&DRR – developed without an awareness of, or not directly targeting climate change impacts – can also have emergent use in disaster situations. Agricultural, food and health information systems, supported by mobile phones and personal digital assistants (PDAs), have been applied to emergent CCA strategies in Chile, Nepal, Uganda and Mozambique. The networks are utilised for real-time information and knowledge exchange during extreme events to facilitate problem-solving and decision-making. Economic and social development interventions, based upon ICT-exchange networks, may also have indirect impacts on CCA&DRR. Emergent use is a possibility, although evidence is limited. Alternatively, they may be poised to support adaptive capacity development (Pant and Heeks 2011).

Other indirect impacts of digital innovation on CCA&DRR relate to the ‘connectivity equalling productivity’ debate. Cross-panel data studies show that connectivity can result in economic growth and increase trade. Recently, Meijers (2014) proposed that internet usage first opens up trade which then results in economic growth in developing country contexts. Economic growth is likely to affect CCA&DRR, but whether impacts are positive or negative is uncertain (Bowen *et al.* 2012). There is general agreement that growth and development are integral to reducing vulnerability to climate change. Resilience to climate change shocks and stress depend on factors that are strongly correlated with economic growth, like education, health and sanitation infrastructure, strong institutions and well-established financial sectors (Noy 2009). The implication, therefore, is that economic growth should increase resilience, yet in reality the impacts of economic growth are much more complex. Similarly, the impacts of increased trade are complex and context-specific. International trade can reduce reliance on climate-dependent domestic markets, but this can have numerous other implications on local capacities, including CCA&DRR capacities (Noy 2009). Overall, the type of economic growth is proposed as a key determinant of outcomes (Bowan *et al.* 2012). However, while there is literature on the impacts of digital innovation on economic growth, and literature on the impacts of economic growth on resilience, research that cuts across both areas is lacking. Questions of climate change vulnerabilities, inclusivity and digital divide should also be raised. While inferences can be made, this presents an important area for dedicated future exploration.

7 Evidence applied to evaluation criteria

As introduced in Section 2.2 to explain our analysis strategy, the collated evidence on digital innovation in environmental sustainability and resilience (ESR) has been synthesised and evaluated using the OECD-DAC criteria for evaluating development assistance, as a way to gain an overview insight into the impacts. These criteria are described in Figure 2.1, and are: relevance, effectiveness, efficiency, impact and sustainability.

Pathways to impact in the use of ICT for ESR have remained differentiated as they were deemed especially relevant in determining effectiveness of the interventions. The review sub-themes of conservation and natural resource management (CNR), food security and agriculture (FSA) and climate change adaptation and disaster risk reduction (CCA&DRR) were synthesised in relation to each other, so as to consider ESR holistically as a system. As proposed in Section 1.4, for the evaluation of impact the focus was on process as opposed to results, and function as opposed to structure, taking additionally into account environmental governance principles (Carlsson and Berkes 2005; Lemos and Agrawal 2006; Adger *et al.* 2003).

7.1 Relevance

Digital innovation was introduced in Section 1.2 as taking three forms: product innovation, process innovation, and business model innovation (Fichman *et al.* 2014). Evidence indicated that the 'pathway to impact', the approach used for the intervention – citizen-led versus top-down, and participatory versus non-participatory – broadly correlates with specific forms of digital innovation. This consistency infers applicability and broad relevance. Yet, context-specific aspects of the technology's relevance to a programme were variable.

Citizen-led interventions appear to use digital technology with a clear, relevant purpose. As the objectives, incentives and rewards are achieved, ulterior motives for using technology are reduced. However, technology can only be relevant to citizen-led action on ESR when citizens have access to it. The 4 billion people who are not connected to the internet or the almost 2 billion people without mobile phones are, therefore, largely excluded from digitalised citizen-led action (World Bank 2016a).

Digitally supported citizen-led action on ESR often had business – or quasi-business – driven incentives, from a livelihoods perspective. Hence, business model digital innovation was prominent, alongside some process innovation. For example, citizen-led use of mobile phones to access agricultural market prices (GSMA 2015), telecommunications supporting environmental activism, often entwined with a livelihoods agenda (Falkner 2013), and citizen-led recycling and re-using of electronic waste, typically initiated for financial gain (Maffey *et al.* 2015). However, citizen-led digital volunteerism – using mobile phones and social media to support disaster response – stems from an altruistic motivation (Whittaker *et al.* 2015).

Notably, external organisations have recognised citizen-led activity on ESR and capitalised upon innovations, often pushing it further towards a business model. For example, social enterprises have formalised citizen-led mobile phone usage for accessing market prices remotely by developing farmer helplines, which offer market insights, alongside information and advice on agricultural practice, via text message (Ewbank 2012b). Additionally, the recognition of citizen-led disaster response using mobile phones furthered the case for mobile network operators to establish the 'Humanitarian Connectivity Charter', which aims to improve mobile phone networks and coordinate responses (GSMA 2015), although it can be assumed alongside corporate incentives. Citizen-led recycling of e-waste, for profit, represents business model innovation directly relevant to ESR under the 'reduce, re-use and recycle' ideology, albeit instigated by an unintended output of the digital age. Currently an informal enterprise, there are proposals to formalise the business model and create numerous green jobs, as a way to green the economy and reduce poverty (Balde *et al.* 2015). Recognition and external interest in pursuing digitally supported citizen-led initiatives impacting ESR strengthens the case for digital technology's relevance.

Conversely, regarding relevance at the intervention level, technology has been critiqued for working in its own right, searching for an application (Maffey *et al.* 2015). Examples include GPS tracking of wildlife without clear ecological objectives, or partially participatory technologies that require external expert input which detracts from the participatory approach. However, for both these cases the literature also acknowledges many effectively implemented examples of digitally supported interventions, with clear objectives and outcomes (Hebblewhite and Haydon 2010; Tripathi and Bhattarya 2004). There are numerous documented benefits of digitally supported approaches over analogue methods, demonstrating relevance to the target group, recipient or donor. For example, many agricultural initiatives find it difficult to produce impact, due to a lack of cost-effective systems to collect both beneficiaries' and implementers' feedback. Digitalised feedback options, offering real-time data collection, now offer new opportunities (Jarvis *et al.* 2015). Evidence also suggests relevance and appropriateness, in that different forms of digital innovation are typically used for participatory versus non-participatory interventions.

Participatory interventions tended to use digital innovation in its process form, supporting aspects of the intervention, such as pGIS for participatory hazard mapping and knowledge exchange processes (Banks and Burge 2004), mobile phones for M&E feedback (Jarvis *et al.* 2015), GPS linked to social media for real-time forest surveillance (Evans 2013) and community-based radio for knowledge-sharing (Harvey 2011). Product-focused digital technology was more frequently used in non-participatory interventions – for example, computer-aided integration of data to produce weather and climate predictions (Hamill and Tanner 2011), GPS-enabled wildlife tracking devices (Latham *et al.* 2015) and internet-facilitated early warning systems (Kangi 2015). Precision agriculture cuts across product and business model forms of digital innovation (Tran and Nguyen 2006).

Digital innovation across its three forms also has substantial indirect relevance to ESR, most specifically with regards to the poor management of e-waste. The informal processing techniques lead to environmental degradation and negatively impact human health (Maffey *et al.* 2015). E-waste is a significant globalised issue of the digital age. It results from process, product and business model technologies and the scenario is worsened due to business model relics, like planned obsolescence, consumerism and poor production and waste management.

There are also documented examples of indirect impacts of digital innovation having more positive relevance to ESR, for example, digital innovation developed for other purposes being later applied to emergent CCA&DRR response in disaster situations (Pant and Heeks 2011). Future relevance of indirect impacts are also postulated, primarily the potential for business model digital innovation resulting from internet connectivity, to stimulate economic growth (Meijers 2014).

7.2 Effectiveness

Effectiveness is a measure of the extent to which digital innovation attains or is likely to attain its purpose in a digitally supported initiative. It considers the major factors influencing the achievement or non-achievement of objectives (OECD 2016).

As discussed, the pathway for implementation was deemed an especially relevant aspect in determining effectiveness, hence the structuring of the review. The pathways focus infers that the interactions of the drivers, motivations and incentives of the intervention with the external environment are influential for impact. It questions the extent to which a digitally supported intervention is successful due to the technology itself, or due to external factors, and emphasises systems-based thinking in ESR, as illustrated in Figure 2.2.

Citizen-led use of digital innovation for ESR purposes appears relatively effective, perhaps due to initiatives typically evolving organically and technology being used to support as needed. External environment plays a role, particularly in determining trajectories and outcomes of citizen-led environmental activism. Digitally supported activism can overcome some of the constraints that politics, policy and institutions exert over traditional forms of activism. Yet, those they oppose can also use technology to promote their own persuasions and positions (Falkner 2013; Russel 2010). It could be proposed that technology simply acts as an augmenter, supporting intensified activism and opposition agendas, a phenomena coined by Toyama (2015) as 'the law of amplification'. However, telecommunications arguably enable citizens to exert pressure at scale, increase visibility and force state accountability in a manner that was not possible prior to digitalisation. Conversely, where citizen-led action on ESR aligns with the external environment, a number of these initiatives have been formalised by organisations and social enterprises, as discussed in Section 7.1. The further development of an initiative suggests a certain degree of effectiveness of the initial idea. In the evidence collated, the formalisation of initiatives maintained the ESR objectives. However, whether this would always be the case is questionable.

The effectiveness of digital innovation in participatory interventions appears strongly influenced by the external environment. There is limited documentation of failures. Yet, the existing evaluative evidence emphasises that culturally aware, context-specific approaches to using digital technology are key in successfully achieving impacts. This includes an awareness of power dynamics, which for example could refer to understanding who typically owns a mobile phone in terms of gender and age, or who controls internet access within a family (McGee and Carlitz 2013). When external environments are appropriately considered in programme design, digital can act to support its ESR objectives. It can also offer new opportunities for involvement, input and voice by more marginalised groups, in a culturally sensitive manner (Gauthier 2005; Harvey 2011). These dimensions are often overlooked in the technological literature, although more recent evidence is beginning to account for these aspects. For example, a culturally sensitive, highly context-specific approach was used for the prototype digital farmer field school in Sierra Leone. This resulted in autonomous input, feedback and knowledge-sharing using internet-enabled tablets, from both female and male farmers marginalised due to the Ebola crisis (Witteveen *et al.* 2016).

The technology itself also plays a role in effectiveness. Specialised technology, requiring input or data processing by technical experts, risks detracting from participation and can result in extractive processes (Tripathi and Bhattarya 2004). Technology for ESR is also critiqued for being overly grounded by the specific scientific literature, overlooking the interdisciplinary nature of the topic. Hence, effective technological interventions are well integrated into larger systems of relevant, cross-disciplinary stakeholders. They incorporate analogue methodologies for discussion and engagement and do not attempt to replace existing forms of community dialogue, special data collection or information-sharing (Balram and Dragićević 2006). The effectiveness of digital innovation used in a participative manner is highly dependent on the behaviour and attitude of facilitators, and on who controls the process (Chambers 2006).

Product-focused innovation, used within non-participatory digitally supported interventions, has been effective in improving specific aspects of ESR. It has improved climate and weather predictions, early warning systems for disasters and digitalised farm machinery.

Effectiveness in terms of reliability and accuracy are limited by the technology itself. Yet, external factors also determine effectiveness. The political and financial context are factors. Limited capacity to invest in meteorological stations in many countries, particularly in Africa, decrease the reliability and specificity of predictions (Hansen *et al.* 2011). Hence, risk and reliability of predictions produced need to be well communicated so stakeholders and policymakers can make informed decisions. Scientific forecasts need to be translated into formats that are understood by non-specialists in order to be effective. This is often not the case and can even lead to mistrust (Washington *et al.* 2006; Ewbank 2012a).

Effectiveness of digital innovation for ESR, however, is compromised when balanced against the indirect impacts of its production and disposal. While both aspects provide economic benefits and income to poor people, the work is typically informal, poorly regulated and exploitative. Mining of the raw materials and the management of e-waste degrade the environment and impact human health (Maffey *et al.* 2015). It is a globalised issue and requires collaborative action if digital innovation is to become truly effective for ESR.

7.3 Efficiency

Efficiency measures the qualitative and quantitative outputs in relation to the inputs. Cost-effectiveness, timeliness and efficiency as compared to alternative options can be considered (OECD 2016).

Increased efficiency is frequently postulated as a key advantage of technology to citizen-led action on ESR, as technologies make environmental activism more efficient. Mobile phones, internet and social media enable small-scale movements to reach international impact at significantly smaller sizes than previously (Falkner 2013). Farmers accessing market prices remotely via mobile phone instead of going to market, reduce their travel time, allowing them to be more efficient in their work (Annan *et al.* 2016). However, evidence on citizen-led volunteerism infers that it can either increase efficiency of disaster response, or be seen to hinder the formalised systems through misalignment of approaches dependent on the context. Yet, here, ICT is also postulated as the solution to facilitate collaboration and coordination of response efforts (Whittaker *et al.* 2015).

Evidence documents digital innovation as increasing efficiency in participatory ESR interventions. For example, ICTs increase efficiency, versatility and cost-effectiveness of environmental management, through producing real-time data and integrating these with the scientific information from satellites and the reality on the ground. Outputs are produced and shared much more quickly than paper-based methods (Pratihast *et al.* 2012; Evans 2013). However, the generic literature on participation recognises that inputs can be time-intensive. Digitalised participatory interventions can exacerbate this when additional training is required on how to use the technology (Prabhakar 2011; Lemaire and Muñiz 2011). Comprehensive evaluations of outputs are scarce, yet participation is proposed as key in addressing ESR, suggesting the greater inputs have strong potential to be justified by greater outputs (Calheiros *et al.* 2000).

Product innovation used in non-participatory ESR initiatives often has efficiency as a primary objective in its design and framing. For example, precision agriculture enables low-input, high-efficiency sustainable agriculture (Corwin and Lesch 2005). Efficiency is also frequently documented as a reason to digitalise large-scale non-participatory initiatives, for example, efficiency through digitalised streamlining of processes, such as tracking illegal logging through GPS and collating information in a centrally managed webpage (Hoare 2015). Cost-effectiveness is also key. Internet-facilitated early warning systems are deemed cheaper than alternatives that typically require the installation of costly equipment (Kangi 2015).

In emergent CCA&DRR, existing digital innovation systems produced for other purposes can be applied to disaster response. This can be presumed to be more efficient than developing new systems during urgent, emergency situations (Pant and Heeks 2011).

7.4 Impact

According to Fichman *et al.* (2014), the impact of digital innovation is framed by objectives of cost-effectiveness, efficiency and revenue (Fichman *et al.* 2014), aspects that have been discussed in Section 7.3. As indicated in Section 1.4, the focus of this review for the evaluation of impact lies in the analysis of the effect of technology on process and function, as opposed to results and structure. Evidence includes elements of appropriation and transformation, also referenced by Fichman *et al.* (2014) regarding digital innovation impact.

Digital innovation is changing communication structures (World Bank 2016a). In citizen-led initiatives, positive impacts include increased citizen voice, forcing state accountability for ESR decisions (Russel 2010), and increased agricultural productivity and profit due to remote access of market price information (GSMA 2015). From the citizen-led perspective it was proposed that transformational ICTs could support development of collective capabilities in a community-led manner, important for CCA&DRR. Yet, mobile phones have been seen to lead to the opposite effect too, atomising information to individuals and reducing the need for community-based services and infrastructure. Participatory interventions are proposed as a way to promote the potential positive impacts of digitally enabled information exchange (Pant and Heeks 2011).

Documentation of effective information exchange, knowledge-sharing and co-production through participatory interventions are evidenced (Canevari-Luzardo *et al.* 2016). There are numerous subjective accounts, with some more structured evaluations. An interactive agricultural advice television programme, *Shamba Shake Up*, has reached more than 3 million individuals and a separate study showed that 36 per cent of viewers stated it had changed their farming practices (USAID 2013). Yet ICT-facilitated information exchange initiatives can be critiqued for failing to really achieve impact, as feedback rarely goes full circle (Jarvis *et al.* 2015).

Digital innovation within participatory interventions are also often credited with empowerment and engagement of stakeholders for ESR objectives, particularly pGIS (Rambaldi *et al.* 2006; Kolagani *et al.* 2012). Positive influences on power dynamics are documented, for example with regard to supporting youth engagement in community action in contexts where their participation in decision-making is typically disregarded (UNDESA 2013). Youth, as a target group, has important relevance for ESR. Yet, the participation literature flags that 'empowerment' and 'engagement' should be used cautiously, only with considered justification and contextualisation (Cornwall and Brock 2005). Digitally supported interventions can amplify existing power dynamics, too. For example, if men typically own the mobile phone through which an intervention interacts with a community, women and young people are likely to miss out. From an ESR perspective this negatively affects the information generated and subsequent actions with regard to gendered roles and knowledge. The digital divide deserves greater consideration in this context, although it is rarely at the forefront of ESR literature.

Impacts of non-participatory digital innovation documented at the process level include real-time monitoring, information exchange at scale, data-storage and accountability. Technological advancement has also improved the general quality and availability of ESR-relevant data. Illegal logging has been reduced, as a result of GPS tracking (Brack and Hayman 2001; Hoare 2015) and data supporting bio-diversity initiatives have been produced through new technologies that monitor a wider range of wildlife (Hebblewhite and Haydon 2010). Climate and weather predictions have also been enhanced. However, uncertainties still persist and limited geographic reach and specificity reduce potential impact (Hamill and Tanner 2011; Ewbank 2012a). Impact can also be obstructed due to overly scientific, complex presentation of information, which reduces its potential application by local stakeholders (Christian Aid 2015).

Indirect systemic impacts of digital innovation centre upon the poorly managed e-waste disposal. This causes polluted waterways (Huang *et al.* 2014), entry to food chains (Robinson 2009) and heavy metals ending up in the wider environment causing allergic reactions, brain damage and cancer (Puckett *et al.* 2002). The positive indirect impacts are improved emergent responses to CCA&DRR, representing transformation at the societal level, although these areas are not well documented (Pant and Heeks 2011).

7.5 Sustainability

Sustainability refers to the degree in which the positive impacts of an activity are likely to continue after the withdrawal of funding (OECD 2016). As digital innovation for ESR is largely an emerging field, with initiatives being relatively new, evidence of longer-term sustainability is limited. Some ESR interventions make reference to this in a generalised manner. One example is ‘Climate Airwaves’, the community-based radio initiative on climate justice in Ghana. The multi-stage process in which broadcasters are educated on specialist content and information is exchanged on the approach, is postulated as being hugely influential in its potential to embed itself within the community structure. In this way it can be sustainable over the long term, as opposed to development initiatives with exit strategies (Harvey 2011). However, a few years after the project finished, the radio programme no longer seems to exist. This illustrates how elusive sustainability is, even for programmes specifically designed to achieve it.

Sustainability is also an important consideration regarding the empowerment and engagement that digitally supported interventions often claim as their objective, and whether it is sustained in the longer term. Currently there is very limited documentation of this.

8 Conclusions

The impact of the application of digital innovation for ESR is multi-dimensional, and spans across the three innovation forms defined by Fichman *et al.* (2014): process, product and business model. There are significant positive and negative impacts from targeted interventions, as well as indirect and unintended negative impacts that result from the generalised technological development that characterises our age.

Existing evidence is focused more towards how digital technology supports the intervention process as opposed to the results. Increased efficiency features highly as a major advantage of digitalised approaches to ESR. Opportunities for improved information exchange and knowledge-sharing and co-production are also discussed frequently with regards to numerous areas across ESR. Empowerment and engagement aspects of digital approaches are often highlighted, although the real extent of these impacts is likely to be more complex than much of the ESR literature suggests.

The effectiveness of digital innovation for ESR is a result of both the technology itself and the external factors surrounding its application. Hence, successful interventions were shown to consider both aspects. The importance of integrating specialist technology with existing systems for information-sharing was emphasised. The need for culturally sensitive and context-specific approaches to integrating technology into an intervention was also highlighted. Yet, in existing interventions, explicit consideration of context-specific power dynamics and the digital divide was often missing in ESR literature.

Currently, it is the indirect and unintended consequences that are most visibly impacting ESR. The production and disposal of electronics is a substantial issue for the environment and human health. With increasing demand from both developing and developed countries for digital technologies, the problem looks set to increase. This is a globalised issue that requires urgent consideration and action if ESR, from a systemic perspective, is to truly benefit from digital innovation.

Overall, ESR is a highly complex field, where innovation is crucial. Digital innovation looks poised to play a key role in the development of the field. However, there is a need for much greater focus on comprehensive evaluations to ascertain the systemic impacts of technology on ESR. While the complexity of the topic makes the evaluation of results difficult, this does not justify the current lack of research. Ascertaining the longer-term sustainability of interventions requires greater focus. Complexity and systems-based thinking is imperative with regard to direct and indirect, intended and unintended outputs. Further research should aim to ensure that intervention approaches are context-specific, culturally sensitive, well informed across disciplines and sustainable, and that they combine the technological innovations with the existing effective analogue approaches. This way, there is exciting potential for real impact.

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